**EFFECT OF DIAPHRAGMATIC BREATHING EXERCISES ON SPEECH AND SWALLOW FUNCTIONS IN INDIAN ELDERLY**

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**Register Number: P01II24S123016**

A Dissertation Submitted in Part Fulfillment for the Degree of Master of Science

(Speech -Language Pathology)

University of Mysore

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**JUNE, 2026**

## CERTIFICATE

This is to certify that this dissertation entitled **"Effect of Diaphragmatic Breathing Exercises on Speech and Swallow Functions in Indian Elderly"** is a bonafide work submitted as part of fulfilment of the degree of Master of Science (Speech Language Pathology) of the student with Registration Number P01II24S123016. This has been carried out under the guidance of a faculty of this institute and has not been submitted earlier to any other university for the award of any other Diploma or Degree.

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## CERTIFICATE

This is to certify that this dissertation entitled **"Effect of Diaphragmatic Breathing Exercises on Speech and Swallow Functions in Indian Elderly"** has been carried out under my supervision and guidance. It is also being certified that this dissertation has not been submitted to any other University for the award of any other Diploma or Degree.

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## DECLARATION

This is to certify that this dissertation entitled **"Effect of Diaphragmatic Breathing Exercises on Speech and Swallow Functions in Indian Elderly"** is the result of my own study under the guidance of **Ms. Sindhusha Chandran**, Assistant Professor of Speech Sciences, Centre for Swallowing Disorders, All India Institute of Speech & Hearing, Mysuru and has not been submitted earlier to any other University for another Diploma or Degree award.

Mysuru **Registration number: P01II24S123016**

June, 2026

## ACKNOWLEDGMENT


*First and foremost, Alhamdulillah - for placing the right people, opportunities, and even difficult moments exactly where they needed to be.*

*I sincerely thank Dr. M. Pushpavathi, Director of AIISH, for providing me with the opportunity and academic platform to undertake this work. I would like to express my deepest gratitude to my guide, Sindhusha Ma'am, whose guidance shaped not only this dissertation but also my learning experience throughout the process. Your patience, encouragement and thoughtful feedback made challenges feel lighter.*

*To my greatest source of strength - Ippa and Imma, words feel insufficient. Your endless duas, unconditional love, patience, and unwavering belief in me became the foundation on which this journey stood. To my siblings - Femi & Zalu, thank you for bringing laughter, warmth, and countless small moments of happiness. Jamshie, thank you for navigating the highs and lows right alongside me. Your presence has been my clarity when things blurred and constant pillar of support.*

*A special mention to Babu Kaku and Haqeeba, for being long-standing sources of support. To Rasimma, Rahimma, Mami, Manukaku, Immamma, Ippappa, Rinu, Innu, Myaaji, Rashi, Ridha and Naja, thank you for your care and thoughtful gestures, whether small or significant, have meant more than words can express. To the little entertainers, Oupu and Zalu, thank you for bringing joy and light moments whenever they were needed most! To Nabeelaka, Ramya Chechi, Kunjaku, and Vinutha, thank you for the Bangalore days! To the 'Chatholi fam', thank you for the warmth and affection that always made me feel supported. Thanks to Jinesh uncle for the emergency help!*

*To Sahra, Sammy, and Neelima - thank you for being there through both difficult seasons and joyful moments. To Jums - thank you for your thoughtful check-ins and quiet encouragement.*

*To the ‘GROUP ’members - thank you for being such an important part of my bachelor’s years and for creating moments of joy, laughter, and memories that continue to stay with me. To Shradha, Kriba & Akshaya- Thanks for the positive vibes and quiet warmth. To my dissertation partners - Nihala & Parvathy, thank you for the timely support and making this journey one marked by shared effort and lasting memories. I also extend my gratitude to all my seniors, juniors, batchmates (ECHO & Celestials), and every individual who crossed paths with me and made this journey memorable and meaningful. Thank you, Kapila, for filling the past six years with coziness, laughter, and unforgettable moments!*

*I extend my deepest appreciation to the participants of this study for their time, cooperation, and willingness to contribute, which were vital to its completion. A special thanks to Femi, whose timely help in finding participants became a turning point in moving this study forward.*

*Special thanks to Jesnu Sir, Getcy Mam, and Srividya Mam for their kindness and assistance. A special note of gratitude to Swalih Sir, whose mentorship since my bachelor’s years has left a lasting impact. Thanks to Vasanthalakshmi Ma’am and Sahana mam for the statistical guidance, and for teaching us statistics like no other.  My heartfelt gratitude extends to Sandeep Sir, Priya Ma’am, Sridevi Ma’am, Jayashree Ma’am, Hema Ma’am, Swapna Ma’am, Irfana Ma’am, Animesh Sir, RRS Sir, Yeshodha Ma’am, Gopi Sankar Sir, Prathima Ma’am, Prashanth Sir, Manjula Ma’am, Sharath Sir, and all the clinical staff and teaching faculty for laying the academic and clinical foundation that I will carry forward throughout my professional journey.*

*Finally, to myself - for showing up through every setback and every long day, for continuing even when progress felt uncertain, and for learning, adapting, persevering, and growing through every stage of this journey.*

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# CHAPTER I

# INTRODUCTION

Ageing is a universal, natural, progressive, and irreversible biological process characterised by a gradual accumulation of physiological changes and a diminishing capacity to respond to environmental insults, culminating in predisposition to chronic illness and functional decline across organ systems (da Costa et al., 2016). Among the most clinically significant consequences of advancing age are the changes affecting the systems that underlie two of the most fundamental human activities, that is communication and swallowing. The respiratory, phonatory, articulatory, and deglutitive subsystems, all integral to speech production and swallowing, undergo well-documented age-related deterioration that can substantially compromise an individual's ability to communicate effectively and consume food and fluids safely (Kendall, 2007).

Globally, the elderly population is growing at a faster rate. According to the World Population Prospects (United Nations, 2019), by 2050, one in six people in the world will be over the age of 65, compared to one in eleven in 2019, with the number of persons aged 80 years and above projected to triple from 143 million in 2019 to 426 million by 2050. In India, this demographic shift is particularly rapid. The National Statistical Office (2021) estimated India's elderly population at 138 million in 2021 and projected it to reach 194 million by 2031, with elderly individuals expected to constitute approximately 20.8% of the total population by 2050 (Madiwalappagol, 2025). The term "elderly" lacks universal definitional consensus; however, the World Health Organization and India's National Elderly Policy consistently define 'elderly' as older persons as individuals aged 60 years and above, a threshold that identifies the population segment where age-related declines in respiratory muscle strength, chest wall compliance, vocal fold elasticity, and deglutitive reflex timing reach both statistical significance and clinical relevance. Accordingly, the present study operationally defined elderly as community-dwelling adults aged 60 years and above.

The respiratory system undergoes significant structural and functional changes with advancing age, marked by loss of elastic recoil, increased chest wall rigidity, and enlargement of distal air spaces, collectively described as “senile emphysema”, which reduces the total alveolar surface available for gaseous exchange (Sharma & Goodwin, 2006). Critically, the strength of the diaphragm declines by more than 20% as a direct consequence of age-related muscle atrophy, leading to reduced maximum inspiratory pressure, diminished vital capacity, and compromised subglottic pressure generation necessary for both speech and forceful coughing (Lee et al., 2016). Sarcopenia, the progressive age-related loss of skeletal muscle mass and strength, affects the respiratory musculature. Its prevalence ranges from approximately 6-30% among individuals aged over 60 years and exceeds 50% in those aged over 80 years (Baumgartner et al., 1998; Iannuzzi-Sucich et al., 2002). These changes manifest as significant reductions in forced vital capacity (FVC), forced expiratory volume in one second ($FEV_1$), and Peak Expiratory Flow Rate (PEFR). Indian spirometric studies have corroborated these findings, which have additionally reported lower normative values in Indian populations compared with Western reference values, reflecting both ageing effects and population-specific physiological variation (Agarwal et al., 2020; Annapurana, 2009; Jepegnanam et al., 1996).

The respiratory system occupies a foundational role in speech production. Sarcopenia of the diaphragm and intercostal muscles reduces vital capacity and expiratory force, compromising breath support for sustained phonation and connected speech, and weakening the expiratory muscles that are crucial for voice intensity, endurance, and intelligibility (Kim & Sapienza, 2005; Langmore et al., 1998). Alongside respiratory changes, the ageing larynx, referred to clinically as presbylarynx, undergoes significant structural degeneration, including atrophy of laryngeal musculature, thinning of the lamina propria's elastin fibres, and incomplete glottal closure, resulting in a voice characterised by vocal fatigue, breathlessness, decreased projection, and alterations in fundamental frequency (F0), a constellation of changes collectively termed presbyphonia (Allen & Miles, 2019; Kendall, 2007). These phonatory changes manifest acoustically as alterations in F0, increased jitter and shimmer, and reduced maximum phonation time (MPT) (Goy et al., 2013; Spazzapan et al., 2024). Beton et al. (2022) reported that voice changes occur throughout life in up to 52.4% of elderly individuals, with a prevalence of voice disorders four times higher than in the general adult population.

At the articulatory level, age-related neuromuscular slowing produces measurable declines in the stability and speed of speech motor control. Older adults demonstrate reduced speaking rates, higher spatiotemporal variability in articulatory movements, longer deceleration phases, and reduced stability of tongue movement, particularly after the age of 60 years, even in cognitively healthy individuals. These changes reflect a gradual decline in speech motor planning and execution (Hu et al., 2023; Tremblay et al., 2018; Wohlert & Smith, 1998). These changes are quantified clinically through diadochokinetic (DDK) rates and speech rate measures, both of which indicate significant age-related decline (Benjamin, 1982; Pierce et al., 2013). In the Indian context, normative data confirm articulatory decline in Kannada and Telugu-speaking individuals, with DDK rates decreasing across successive decades (John et al., 2014; Patil & Manjula, 2014).

Presbyphagia, defined as age-related changes in swallowing physiology occurring in otherwise healthy elderly individuals, represents an equally significant clinical concern. Physiological changes in swallowing function include delayed swallow reflex initiation, reduced pharyngeal constrictor strength, decreased hyolaryngeal excursion, impaired bolus clearance, and disruption of the normal expiration-swallow-expiration respiratory-swallowing coordination pattern that underpins airway protection (Wang et al., 2015; Martin-Harris et al., 2008). Impairment of respiratory musculature further directly compromises swallowing by reducing expiratory force and contributing to oropharyngeal dysphagia (Laciuga et al., 2014). A systematic review and meta-analysis by Cai et al. (2024) estimated the global pooled prevalence of presbyphagia at 30.8% among community-dwelling elderly adults. In India, Dodderi et al. (2024) documented a prevalence of swallowing difficulty of 36.6% among community-dwelling elderly adults in Karnataka, while Chilwan et al. (2025) reported swallowing fatigue in 41.5% of community-dwelling Indian elderly. These figures highlight that age-related swallowing decline is prevalent, under-identified, and carries significant implications for risk of aspiration pneumonia, nutrition, and quality of life.

The cumulative impact of age-related decline across the respiratory, phonatory, articulatory, and swallowing domains underscores a critical need for targeted, accessible, and evidence-based preventive interventions that address the shared underlying mechanisms of these interconnected deficits, rather than targeting each domain in isolation. Among the range of rehabilitation strategies explored for elderly populations, exercise-based approaches have demonstrated consistent promise. Oropharyngeal exercises, vocal function exercises, and respiratory muscle training have each been shown to partially address age-related functional decline within their respective target domains. However, given that the respiratory system constitutes the foundational physiological substrate for phonation, articulation, and swallowing safety alike, interventions targeting respiratory musculature may have the potential to produce concurrent benefits across all four functional domains. Respiration acts as the power source for voice production, the determinant of breath group duration in connected speech, and the regulator of expiratory force critical for airway protection during deglutition. Diaphragmatic breathing exercise (DBE) represents one such intervention that specifically targets the respiratory musculature to simultaneously produce clinically meaningful gains.

DBE involves the systematic retraining of the diaphragm that promotes maximal diaphragmatic descent during inhalation and active abdominal muscle contraction during exhalation. By enhancing alveolar ventilation, strengthening the respiratory musculature, and restoring the mechanical efficiency of the breathing cycle, DBE directly addresses the underlying respiratory deficits that compromise both speech production and swallowing in elderly individuals. The clinical rationale for DBE as a multidomain intervention for elderly individuals is grounded in the interrelationship between respiratory, phonatory and swallowing functions. Structured diaphragmatic retraining improves lung volumes, respiratory muscle strength, phonatory stability, and cough effectiveness, which contribute to improvements in speech intelligibility, voice stability, and airway protection during swallowing (Kim & Sapienza, 2005; Hamasaki, 2020). This mechanistic chain places DBE in a valuable position among respiratory approaches as an intervention that targets a single physiological substrate, the respiratory musculature, while producing clinically meaningful outcomes simultaneously across the interconnected domains of communication and swallowing safety.

Hamasaki (2020) documented that DBE consistently improves lung volumes, diaphragmatic excursion, PEFR and respiratory muscle strength. Abdullahi et al. (2024) confirmed significant improvements in FVC and $FEV_1$ following DBE in stroke patients. Chukwu et al. (2025) demonstrated significant improvement in FVC, $FEV_1$, $FEV_1$/FVC, and MPT in healthy vocalists following DBE. Prathanee et al. (2025) documented improvements of up to 55% in MPT and 84% in PEFR in community-dwelling elderly following respiratory muscle training (DBE) combined with quadriceps exercises. Systematic reviews by Dai et al. (2024) and Su et al. (2025) established that respiratory training significantly improves swallowing function and reduces aspiration risk in elderly populations. In the Indian context, Shirodkar and Deo (2024) reported significant improvements in PEFR following DBE in individuals with COPD.

Despite this growing evidence base, no published study has simultaneously examined the effects of a structured DBE programme on respiratory, phonatory, articulatory, and swallowing outcomes within the same cohort of healthy community-dwelling elderly individuals. Furthermore, there are reduced evidence from the Indian elderly population. Clinical practice among Indian speech-language pathologists (SLPs) also shows considerable variability in the assessment and management of elderly speech and swallowing disorders, largely due to the restricted access to instrumental assessments and the absence of standardised national guidelines (Rangarathnam & Desai, 2020). The present study was therefore designed to address these interconnected gaps.

**Need for the study**

The confluence of India's rapidly expanding elderly demographic, the high prevalence of age-related decline in speech and swallowing function, the absence of Indian-specific preventive intervention, and the systemic gaps in geriatric speech-language pathology service delivery collectively establish a compelling and urgent need for the present study. The India Ageing Report 2023 (UNFPA, 2023) identified the urgent need for enhanced community-based geriatric care and rehabilitation services in India, noting that current support systems are inadequate to address the functional and rehabilitative needs of the rapidly growing elderly population. Approximately, 75% of Indian elderly suffer from one or more chronic illnesses (LASI, 2021) many of which directly or indirectly compromise respiratory, phonatory, and swallowing function. Despite this substantial burden, speech and swallowing disorders remain profoundly underrecognised and undertreated in community settings across India.

Firstly, no published study has simultaneously examined all four functional domains, namely, respiratory, phonatory, articulatory, and swallowing in a single cohort of healthy community-dwelling elderly following DBE. Understanding whether DBE- induced respiratory improvements generalise across these interconnected domains is essential for establishing the full clinical scope of this intervention and its potential as a unified preventive approach in geriatric speech-language pathology.

Secondly, the burden of presbyphonia and presbyphagia in India is both substantial and insufficiently quantified. Mathew and Shilpa (2019) identified presbylarynx as a predominant aetiology of geriatric dysphonia in rural India. Dodderi et al. (2024) reported a 36.6% prevalence of swallowing difficulty among community-dwelling elderly in Karnataka, Agnes et al. (2024) identified oropharyngeal dysphagia symptoms in 9.9% of elderly in Kerala, and Chilwan et al. (2025) found that 41.5% of community-dwelling elderly experienced swallowing fatigue in Mangalore, Karnataka. These figures confirm that speech and swallowing decline is not a rare clinical event but a pervasive health concern requiring targeted, community-accessible preventive intervention.

Thirdly, the existing literature on DBE and functional outcomes in elderly populations reveals a clear and progressive gap when mapped geographically. Studies examining the combined effects of DBE on both respiratory and functional speech-swallowing outcomes have been conducted primarily in Thailand (Prathanee et al., 2025) and Japan (Maki et al., 2018). In India, published evidence is limited to the single-domain effect of DBE on respiratory function in clinical populations such as COPD patients (Shirodkar & Deo, 2024) and stroke patients (Shetty et al., 2020), with no study examining its speech and swallowing effects in any Indian population. Critically, evidence on the combined effect of DBE on speech and swallowing simultaneously in healthy community-dwelling Indian elderly, the population at greater risk of subclinical functional decline and with the least access to specialist rehabilitation, is absent. The present study directly addresses this specific gap.

Fourthly, Indian elderly differ from Western populations in language-specific speech motor patterns across various parameters such as, different language backgrounds, cultural dietary practices, baseline spirometric and acoustic norms, body composition. These factors directly influence both baseline functional levels and the nature of intervention effects. Population-specific evidence is essential for clinically relevant practice guidelines. Normative data for spirometry (Annapurana, 2009), DDK rates (John et al., 2014; Patil & Manjula, 2014), and swallowing screening (Mohandas, 2023) have been established for Indian adults, providing the reference framework necessary for interpreting outcomes in the Indian context. Population-specific intervention evidence is essential for deriving clinically relevant, culturally appropriate, and linguistically sensitive practice guidelines applicable to Indian elderly.

Fifthly, clinical practice among SLPs in India is characterised by considerable variability in the assessment and management of elderly speech and swallowing disorders, largely attributable to restricted access to instrumental assessments and the absence of standardised national guidelines for geriatric populations (Rangarathnam & Desai, 2020). This variability underscores the urgent need for population-specific, evidence-based intervention data to inform standardised, accessible, and culturally appropriate clinical decision-making. DBE represents such an intervention that is non-invasive, low-cost, deliverable in community settings, and adaptable to hybrid online-in-person formats, as demonstrated in the present study. This holds exceptional clinical and health policy relevance for India’s ageing population.

Sixthly, the present study was motivated by a preventive imperative. Although the participants were healthy, community-dwelling elderly adults without overt dysphonia or dysphagia, subclinical changes in respiratory, phonatory, and articulatory performance were observed, consistent with age-related physiological change. Addressing these subclinical declines before the emergence of clinical disability is both more effective and more cost-efficient than treating established disease. Abadi et al. (2022) demonstrated that DBE significantly improved quality of life in healthy elderly women, and Nazir et al. (2026) confirmed significant improvements in physical function, fatigue, and quality of life in community-dwelling elderly following DBE. These findings confirm that benefits extend beyond pulmonary function to encompass health-related quality of life. If demonstrated to be effective in the Indian elderly context, DBE could be integrated into community-based healthy ageing programmes led by SLPs, providing a scalable, evidence-based approach to preserving communication and swallowing function across India's rapidly expanding elderly population.

**Aim of the study**

The aim of the study is to examine the effects of diaphragmatic breathing exercises on speech and swallow functions in individuals aged 60 or older.

**Objectives of the study**

1: To compare respiratory measures pre-, post-, and four weeks after the intervention in Indian elderly.

2: To compare phonatory measures pre-, post-, and four weeks after the intervention in Indian elderly.

3. To compare the articulatory measures pre-, post-, and four weeks after intervention in Indian elderly.

4. To compare the swallow measures pre-, post-, and four weeks after intervention in Indian elderly.

# CHAPTER II

## REVIEW OF LITERATURE

Ageing is a natural biological phenomenon which involves a progressive loss of structural and functional integrity of organ systems over time. Changes that take place in the respiratory, phonatory, articulatory and swallowing subsystems support speech and swallowing and they are among the most clinically significant consequences of ageing. These are referred to as prebyphonia and presbyphagia, respectively, which represent a continuum of ageing. These significantly impact on the communication efficiency, safety and quality of life in the ageing population (Kendall, 2007; Dodderi et al., 2024). The National Statistical Office (2021) has estimated that India's population aged 60 years and above of age was 138 million in 2021 and is likely to grow to 194 million by 2031, making it one of the fastest ageing populations globally. Thus, understanding the nature of these age-related changes and to identify easy, accessible interventions is a prime focus in geriatric speech-language pathology.

The respiratory system plays a critical role in both speech production and swallowing. It is the primary source for phonation and the key regulator of airway protection during deglutition. Aging-related sarcopenia of the respiratory muscles, especially the diaphragm, impairs lung capacities, expiratory force and cough strength which has downstream effects on phonatory stability, articulatory accuracy and swallowing safety (Kim & Sapienza, 2005).

Diaphragmatic breathing exercises (DBE) involve systematic retraining of the diaphragm, the primary inspiratory muscle, through controlled abdominal breathing that promotes maximal diaphragmatic descent on inhalation and active abdominal contraction on exhalation, thereby enhancing alveolar ventilation, strengthening the respiratory musculature, and addressing the respiratory deficits that underlie both speech and swallowing decline in elderly individuals. While there is increasing evidence of the efficacy of DBE among various clinical populations (e.g. stroke, COPD, Parkinson's disease), there is limited evidence of the impact of DBE on speech and swallow outcomes in healthy elderly adults (Hamasaki, 2020; Prathanee et al., 2025). There is very little published literature on the Indian elderly. In a recent study by Rajaselvi & Sharma (2025), evaluated the impact of diaphragmatic breathing exercises on blood pressure and stress levels in elderly hypertensive patients in South India, revealing positive effects of DBE among Indian elderly. However, there is very little evidence about its impact on speech and swallowing performance in Indian elderly living in the community, which needs to be examined.

**2.1 Ageing and its impact on the respiratory system**

Age-related respiratory declines are characterized by structural and functional changes that impact speech and swallowing. Sarcopenia of respiratory muscles, including the diaphragm and intercostal muscles has been described as a key factor in this decline. Sarcopenia is defined as the progressive loss of skeletal muscle mass, strength, and functional capacity. The prevalence of sarcopenia was reported to range from 6-30% in individuals over 60 years and to exceed 50% in those above 80 years (Baumgartner et al., 1998; Melton et al., 2000; Tankó et al., 2002; Iannuzzi-Sucich et al., 2002). This muscle wasting results in weaker respiratory muscles, loss of lung elasticity and chest wall stiffness, which in turn result in decreased vital capacity and peak expiratory force (Kim & Sapienza, 2005). Spirometric studies have reported decline in forced vital capacity (FVC), forced expiratory volume in one second ($FEV_1$) and peak expiratory flow rate (PEFR) with age, accompanied by a nearly 50% rise in residual lung volume, while the total lung capacity remains unchanged (Kim & Sapienza, 2005; Janssens et al., 1999).

These changes are further compounded by age-related postural changes, such as thoracic kyphosis, restricting rib cage expansion and preventing descent of the diaphragm during inspiration (Leão et al., 2023; Rapoport et al., 2018). Structurally, stiffening of costal cartilages increases the stiffness of the rib cage and kyphotic posture of the spine decreases chest wall compliance and can prevent complete inspiration (Janssens et al., 1999). Pulmonary changes include reduced lung elasticity as a result of changes in elastin and collagen, leading to increased residual lung volume and decreased vital capacity, with gas exchange and ventilation efficiency impaired. Jeon et al. (2015) also showed that FVC and $FEV_1$ show strong associations with appendicular skeletal muscle mass, confirming the relationship between respiratory function and systemic muscle wasting in ageing. Indian studies confirmed these global findings, but also revealed regional differences. A study by Mankar et al. (2021) conducted in Davangere, Karnataka, demonstrated significant age-related reductions in FVC, $FEV_1$, $FEV_1$/FVC, SVC and PEFR, highly correlated with both lung structural changes and respiratory muscle weakness, further confirming the findings of Indian normative studies. Shetty et al. (2020), compared DBE with two forms of incentive spirometry (flow-oriented incentive spirometry and volume-oriented incentive spirometry) in subacute stroke patients and found that DBE group demonstrated significant improvements in FVC (+21.27%), confirming that DBE produces substantial respiratory gains in Indian clinical cohort. In the South Indian population, Annapurana (2009) observed age-related reduction in the FVC, $FEV_1$, and PEFR, and they were lower than Western standards. These findings indicate that respiratory changes in the elderly in India may be more functional and occur earlier than previously assumed.

Langmore et al. (1998) emphasised that weakness of expiratory muscles has a significant and direct impact on speech intelligibility, vocal intensity, and endurance, demonstrating the clinical implications of respiratory decline on speech function. These age-related respiratory changes such as reduced lung volumes and expiratory airflow, which ultimately affect the power source for speech, warrant a more in-depth review of the effects of ageing on speech production in its phonatory and articulatory components.

## 2.2 Effects of ageing on speech production

### *2.2.1 Age-related respiratory changes*

Age-related respiratory decline has shown a cascading effect on speech production. Respiratory decline due to ageing has a downstream impact on speech. The reduction in subglottic pressure and maximum phonation time (MPT) affect the pneumo-phono-articulatory integration, which is crucial for smooth and accurate speech production (Duffy, 2013). Impaired respiratory support and reduced laryngeal efficiency led to lower vocal loudness, prosodic changes and shorter breath groups in elderly adults' connected speech (Leão et al., 2023).

### *2.2.2 Age-related phonatory changes*

At the phonatory level, ageing is characterized by structural degeneration of vocal folds and intrinsic laryngeal musculature. This leads to fundamental frequency (F0) instability, jitter and shimmer (Ramig, 1983; Goy et al., 2013). These acoustic changes are clinically reflected in presbyphonia, an age-related voice disorder that is characterised by vocal roughness, breathiness, elevated pitch in men or lowered pitch in women and reduced vocal stamina (Kendall, 2007; Kost & Sataloff, 2018). Goy et al. (2013) developed normative voice data for young and elderly adults, and demonstrated a statistically significant jitter and shimmer increase with age in both men and women.

Spazzapan et al. (2024) assessed acoustic measures, including jitter, shimmer and standard deviation of F0 across the lifespan of 526 vocally healthy Brazilian Portuguese speakers. The findings revealed that jitter and shimmer were stable in adulthood, whereas shimmer was sensitive to voice changes in the elderly male population. This suggests the potential clinical value of these perturbation measures as indicators of voice change with age. In a review, Benton et al. (2022) reported that voice changes were present in up to 52.4% of the elderly. Their voice was characterized by increased jitter, shimmer, and noise-to-harmonic ratio (NHR), and decreased MPT and maximum intensity levels in both genders compared to typical younger adults. The study found that the prevalence of voice disorders in those over 65 years was four times higher than in the general population, which highlights the clinical significance of presbyphonia as a public health concern.

Structurally, age-related atrophy of the thyroarytenoid muscle, along with the loss of elastic fibers and thickness in the vocal fold mucosa results in poorer glottal closure, producing a weak and breathy voice (Sato et al., 1997; Kendall, 2007). Phonatory instability (tremor, voice breaks, breathiness, and hoarseness) is more prevalent in elderly voices, with acoustic measurements of perturbation (a measure of irregularity) reflecting a loss of amplitude and F0 stability with age (Gorham-Rowan & Laures-Gore, 2006). Similar to this, the harmonics-to-noise ratio (HNR), which reflects aperiodic noise in the voice, is also reduced in elderly as compared to younger adults, associated with incomplete glottal closure and less periodic vocal fold vibration (Ferrand, 2002). Moreover, research on MPT is mixed. Some studies reported MPT values significantly declining with age (Beton et al., 2022; Ptacek et al., 1966; Kreul, 1972), while other studies reported that MPT values did not significantly diminish in some elderly adults (Goy et al., 2013; Lortie et al., 2015; Maslan et al., 2011), implying that some compensation may occur to counter phonatory decline. Adequate expiratory airflow is very critical for the production of pressure consonants, and its reduction in the elderly directly affects articulatory clarity and speech intelligibility (Tong & Sataloff, 2022).

### *2.2.3 Age-related articulatory changes*

In elderly individuals at the articulatory level, ageing leads to neuromuscular slowing and reduced precision of lip, tongue and jaw movements. This results in significantly slower diadochokinetic (DDK) rates and reduced speech intelligibility (Benjamin, 1982). Pierce et al. (2013) reported normative AMR rates of 5-7 syllables/s and SMR rates of 5-8 syllables/s in healthy adults. Statistically significant reduction was seen in elderly age groups compared to younger adults. Kent et al. (2022), in a comprehensive scoping review of DDK across 360 studies over the lifespan documented consistent age-related declines in both AMR and SMR rates across diverse populations including children, young adults, elderly adults, and clinical populations, and across multiple languages such as American English, British English, Canadian English, Mandarin, Taiwanese, Korean, Japanese, Thai, Hebrew, Dutch, Arabic, Persian, Portuguese, Kannada, Tamil, Malayalam, Indonesian languages, and Brazilian Portuguese. Tafiadis et al. (2022) examined DDK rates in healthy young and elderly Greek-speaking adults and found age-related slowing of articulatory movements.

In the Indian studies, John et al. (2014) established normative data for the Motor speech Profile (MSP) in native Kannada-speaking adults across three age groups (20-40, 41-50, 51-60 years). In addition to increased jitter and shimmer, which reflect decreased phonatory stability with age, their findings showed a significant age-related decline in DDK rate, with the 51-60 year group having the lowest values (males: 2.72 syllables/s, females: 3.25 syllables/s). Similarly, Patil and Manjula (2014) developed a normative database for the MSP across four age groups (20-30, 30-40, 40-50, and 50-

60 years) in Telugu-speaking adults, which also reported a consistent declining trend in average DDK rate from 5.38 syllables/s in the 40-50 year group to 5.28 syllables/s in 50-60 year group.

A preliminary study by Sun et al. (2024) on elderly Shanghainese speakers established the link between speech and swallowing in ageing. They reported significant age-related declines in MPT and DDK (AMR and SMR) rates in elderly compared to younger adults. And proposed that these speech acoustic parameters could serve as predictors of presbyphagia due to their shared underlying neuromuscular basis. The articulatory and phonatory changes of elderly speakers share the same physiological foundation with swallowing dysfunction, implying that the ageing process affects speech and swallowing via common pathways. Therefore, serves as an association that lends itself to a specific review of swallowing changes in the elderly.

## 2.3 Effects of ageing on swallowing

### *2.3.1 Presbyphagia: prevalence and characteristics*

Presbyphagia is defined as the age-related changes in swallowing function in healthy elderly adults. Dodderi et al. (2024) reported a prevalence of self-reported swallowing difficulties in approximately 36.6% of community-dwelling elderly adults in Karnataka, along with significantly impaired swallowing- related quality of life highlighting the considerable burden of dysphagia in the Indian elderly. A systematic review and meta-analysis by Cai et al. (2024) estimated the overall prevalence of presbyphagia in elderly adults devoid of disease-related dysphagia across 19 studies. The combined prevalence was 30.8% (95% CI: 24.8-36.7%), however after taking into account publication bias, it was 17.3% (95% CI: 11.0-23.6%). This large-scale meta-analysis provided the most robust global estimate of presbyphagia prevalence to date. This confirms its high occurrence in community-dwelling elderly populations and establishing a strong evidence base for preventive and rehabilitative intervention.

Ambiado-Lillo and Borjas (2024) conducted a systematic review examining the proposed definitions of presbyphagia in the specialized literature. And identified three main definitional approaches: presbyphagia as an alteration in swallowing in healthy elderly adults, as a disorder compensated by physiological reserve and as a synonym for oropharyngeal dysphagia. The authors stated that presbyphagia should be understood as the etiological basis of oropharyngeal dysphagia, with significant implications for early diagnosis and preventive clinical management in the ageing population.

Age-related changes in swallowing includes all phases of deglutition. They are seen as prolonged oral transit time, reduced tongue base retraction, delayed pharyngeal reflex, and decreased hyolaryngeal excursion, compromising the efficiency and safety of swallowing in the elderly (Robbins et al., 1992). Wang et al. (2015) also documented that elderly adults exhibited delayed onset latency of the swallowing reflex, longer swallowing apnea duration, and reduced prevalence of the expiration-swallow-expiration pattern compared to younger adults, which results in increased aspiration risk.

### *2.3.2 Respiratory-swallowing coordination*

The coordination between respiration and swallowing is critical for safe deglutition and airway protection. An aged individual's risk of aspiration is greatly increased when breathing and swallowing are not adequately coordinated (Hiss & Treole, 2001). In healthy adults, the predominant pattern is the exhale-swallow-exhale pattern. This provides optimal subglottic pressure and expiratory airflow for post-swallow airway clearance (Martin-Harris et al., 2008; Valenzano et al., 2020). Elderly individuals demonstrated an increased incidence of inspiration immediately before and after swallowing. This pattern is associated with elevated aspiration risk. The other key factor is the lung volume at which swallowing is initiated. The deterioration of the coordinated breathing-swallowing pattern is linked to the weakened respiratory musculature, reduced pharyngeal sensorimotor function, and decreased laryngeal closure efficiency in the elderly.

The other key factor is the lung volume at which swallowing is initiated. In young adults, swallowing usually takes place at mid-to-high lung volumes that offer the greatest subglottic pressure for airway protection. However, elderly adults due to declining respiratory function, often begin swallowing at lower lung volumes impairing the effectiveness of airway closure and at risk for aspiration. Martin et al. (2005) also reported that decreased respiratory and vocal function in the elderly is linked to delayed initiation of swallowing and failure of the larynx to close during swallowing. Given these interrelated impairments, researchers and clinicians have proposed targeted rehabilitative strategies that target the expiratory muscles, rather than compensatory swallowing strategies (Sapienza, 2008).

### *2.3.3 Respiratory interventions*

A systematic review and meta-analysis by Dai et al. (2024) examined the effect of respiratory training on swallowing function across populations with swallowing disorders. The review included studies employing inspiratory muscle training (IMT) and expiratory muscle strength training (EMST). This review confirmed that respiratory training, including both inspiratory and expiratory muscle training significantly improved swallowing safety and efficiency by strengthening the shared neuromuscular mechanisms underlying both respiration and deglutition. The authors found that respiratory training appeared to be an effective non-pharmacological treatment for dysphagia. Thus, providing physiological justification for the use of breathing-based interventions such as diaphragmatic breathing in swallowing rehabilitation. Further, Su et al. (2025) conducted a systematic review and meta-analysis specifically evaluating the efficacy of respiratory training in elderly patients with dysphagia. They found that respiratory training substantially improved both respiratory and swallowing function in those aged 65 years and above and also significantly reduced the risk of aspiration compared to conventional care alone. This review provided the most current and age-specific evidence supporting the clinical use of respiratory training for elderly populations.

The strength of the cough is a critical indicator of airway protection ability as measured by PEFR and the Semiquantitative Cough Strength Score (SCSS). According to Hammond et al. (2008), PEFR is one of the most reliable predictors of aspiration in stroke patients. While a PEFR below 160 L/min was considered insufficient for effective airway clearance (Smina et al., 2003), a SCSS score of 3 or lower was linked to aspiration pneumonia (Khamiees et al., 2001; Smina et al.,2003). Thus, age-related reductions in expiratory muscle strength and peak cough flow (PCF) compromised airway protection during swallowing in the elderly.

Evidence specifically in elderly populations confirm the effectiveness of respiratory training in improving cough strength. Kaneko et al. (2022) conducted a RCT in 53 ambulatory elderly adults without airflow limitations and demonstrated that cough training produced significant increases in cough peak flow at four weeks, with the cough training group maintaining significantly higher cough peak flow than the inspiratory muscle training group. He et al. (2021), in a systematic review and meta-analysis, confirmed that respiratory muscle training significantly improved PEFR by a pooled 2.16 L/s (95% CI: 1.16–3.17, $p < 0.0001$) across populations, establishing that respiratory training consistently improves the expiratory force underlying airway protection during swallowing.

Oguchi et al. (2000) found that healthy elderly adults performed fewer swallows during the Repetitive Saliva Swallow Test (RSST) than young adults (average 5.9 vs. 7.4 swallows/30 seconds). This confirms that decreased swallow frequency in elderly individuals is a clinically meaningful functional marker of presbyphagia risk. Ben-Hayoun et al. (2024), in a normative study of healthy adults (20-90 years), established mean RSST values of $7.01 \pm 2.86$ swallows per 30 seconds, with males achieving significantly higher scores than females (7.60 vs 6.47; $p = 0.001$) and RSST demonstrating an inverse correlation with age ($r = -0.463$), confirming RSST as a clinically sensitive age-related marker of swallowing decline. Hsu et al. (2025), in a systematic review and meta-analysis of 11 RCTs of oropharyngeal exercise interventions in elderly adults, confirmed that exercise interventions produced significantly greater RSST improvements compared to controls, establishing that targeted exercise reliably improves repetitive swallowing frequency in elderly populations.

In the Indian context, Mohandas (2023) developed and validated a 25-item Swallow Abilities Screening Questionnaire for the Indian Elderly (SASQ-IE). It evaluates participation restrictions, activity limitations, and phase-specific swallowing difficulties. This questionnaire provides a population-specific and culturally sensitive method of detecting swallowing difficulties among Indian elderly in the community. Given the high prevalence of presbyphagia and the key role of respiratory muscles in swallowing safety, strategies that focus on improving respiratory function are likely to have a profound effect on swallowing performance, and the most non-invasive and easily administered approach is that of DBE.

## 2.4 Impact of age-related changes on quality of life

Functional consequences of presbyphonia and presbyphagia go beyond physiological impairment and have an impact on the quality of life of the elderly in psychological, physical and social areas. In terms of communication, reduced speech intelligibility, vocal intensity and vocal fatigue may result in communication breakdowns, leading to reduced confidence, frustration, and subsequent reductions in social participation and social isolation, which may result in decreased participation in daily activities.

From a swallowing perspective, eating and drinking difficulties can lead to dietary changes, reduced nutrient intake and risk of malnutrition and dehydration. Participants may also curtail their participation in shared dining, a common social activity, due to fear or anxiety of choking. These functional limitations reflect the activity and participation restrictions components of the International Classification of Functioning, Disability and Health (ICF) framework, and show the extent to which these age-related changes affect the individual's life with wide-ranging consequences for their well-being.

A recent cross-sectional study by Gascon et al. (2024) showed elderly adults with voice and swallowing difficulties reported considerable negative impacts on their health-related quality of life and these problems were often overlooked by clinicians, highlighting the need for early screening and intervention. Similarly, Pereira et al. (2025) reported that elderly adults at risk for dysphagia had lower quality of life and higher psychological distress. These studies collectively support that age-related changes in speech and swallowing are not just a physiological consideration but a key element in the healthy ageing, independence and well-being of elderly adults.

## 2.5 Diaphragmatic breathing exercises

Diaphragmatic breathing exercises (DBE) were designed to retrain the diaphragm as the primary muscle of inspiration, which leads to abdominal expansion with inspiration and reduces the work of the accessory muscles. The physiological basis for the use of DBE is that it enhances alveolar ventilation, increases lung compliance and strengthens the respiratory muscles through controlled loading of the diaphragm (Hamasaki, 2020). Hamasaki (2020) performed a narrative review of the effects of DBE and found that vital capacity, tidal volume, inspiratory reserve volume and PEFR improved across diverse populations including elderly individuals, healthy young adults, athletes, virtual reality motion-sickness susceptible healthy individuals, patients with COPD and asthma, and post-surgical patients, individuals with stroke, heart failure, GERD, hypertension, migraine, anxiety, cancer, dysfunctional breathing syndromes, and smokers with exertional dyspnea. It attributed the effects to increased diaphragmatic movement and respiratory muscle stamina that occurs with regular practice.

Chukwu et al. (2025) reported that eight weeks of DBE led to significant improvements in FVC, $FEV_1$, $FEV_1$/FVC ratio and PEF in healthy vocalists. These respiratory improvements correlated significantly with increased MPT, suggesting that the increased lung capacity provided better support for sustained phonation. This study showed evidence of the direct relationship between respiratory gains following DBE and improved voice endurance. Prathanee et al. (2025) studied the impact of a respiratory muscle training program which included diaphragmatic breathing and quadriceps strengthening exercises among community-dwelling elderly adults in Thailand. In this study, MPT improved by as much as 55%, maximum counting duration improved by 41%, and peak expiratory flow improved by 84%. This demonstrates the capacity of breathing exercises to significantly improve respiratory function in elderly adults.

Abdullahi et al. (2024) conducted a systematic review and meta-analysis to examine the efficacy of DBE in stroke patients. The study reported significant improvements in FVC, $FEV_1$, and PEF following the intervention. Similarly, Maki et al. (2018) found that respirator rehabilitation incorporating diaphragmatic breathing in frail elderly adults with musculoskeletal disorders significantly improved $FEV_1$, PCF, maximal expiratory pressure (MEP), and (MIP) compared to controls. Guo et al. (2025) found that a respiratory training programme combining diaphragmatic breathing and expiratory resistance significantly improved diaphragmatic excursion (1.8 cm to 3.2 cm), $FEV_1$, $FEV_1$/FVC, and quality of life in elderly COPD patients with sarcopenia in China. Ahmad et al. (2025) combined inspiratory muscle training (IMT) with DBE, and found improvements in diaphragm excursion, inspiratory muscle strength, fatigue symptoms, and pulmonary dysfunction index (PDI) than DBE alone in subjects with multiple sclerosis of mild to moderate disability. Hence, validating the efficacy of DBE in elderly clinical populations.

Sedaghati et al. (2023) conducted a randomized controlled trial in elderly individuals with a history of COVID-19 infection on respiratory function, investigating the impact of corrective and breathing exercises, including diaphragmatic breathing. The results showed significant improvement in $FEV_1$ and $FEV_1$/FVC ratio in the intervention group relative to controls. Yong et al. 2017 found that even a short session of diaphragmatic breathing in healthy young adults can produce immediate increase in FVC and SVC. This highlights the rehabilitative benefits of DBE. Arnal-Gómez et al. (2022), conducted a RCT of institutionalised elderly adults (mean age ~76 years) in Spain, found that combined DBE and musculoskeletal exercises produced clinically significant FVC and FEV1 increase (≥11-12%) compared to a control group. Abo Elyazed et al. (2024), compared DBE with incentive spirometry in patients with post-COVID-19 diaphragmatic dysfunction, confirmed that DBE produced significant improvements in FVC, FEV1 and SVC. Yamaguti et al. (2012) demonstrated that structured DBE training significantly improved abdominal motion during natural breathing in COPD patients compared to controls, confirming that DBE produces a lasting change in resting tidal breathing pattern, not merely in forced efforts.

An Indian study by Shirodkar and Deo (2024) reported gains in PEFR, oxygen saturation (SpO2) and quality of life following DBE in people with COPD. The known improvements in lung volumes, expiratory pressure and diaphragmatic movement following DBE can be expected to produce gains not only in respiratory function but also in the subsystems of speech production dependent upon respiratory support.

**2.6 Effects of respiratory training on speech**

Respiratory function and voice quality are physiologically interrelated. By facilitating better control of the diaphragm, improvements in subglottal pressure were observed and reported to stabilise vocal fold vibration, decrease perturbations and increase MPT (Titze & Martin, 1998). Chukwu et al. (2025) demonstrated that improvements in FVC and $FEV_1$ following DBE resulted in increased MPT in healthy singers. This established the connection between respiratory improvements and MPT. Sawaya et al. (2022), in a cross-sectional study of 140 elderly Japanese adults, found that FVC was the only spirometric variable independently associated with MPT in partial correlation and multiple regression analyses, directly confirming the mechanistic link between DBE-induced respiratory gains and MPT improvement. Desjardins and Bonilha (2020) reviewed the effects of respiratory exercises on vocal performance through a systematic review of various populations and types of respiratory exercise.

The review concluded that while diaphragmatic breathing alone may not be intensive enough to produce respiratory changes in all cases, its consistent integration with phonatory tasks and reading aloud significantly enhanced breath-phonation coordination. Thereby making it a clinically valuable component of voice rehabilitation programs, particularly for elderly populations where respiratory-phonatory coupling is compromised.

The theoretical and clinical framework for combining diaphragmatic breathing with phonation and connected speech tasks was grounded in the principles outlined by Stemple et al. (2020). Wherein respiratory support was identified as a foundational component of voice therapy, with breath management exercises forming the basis of phonatory rehabilitation in both clinical and preventive contexts. The DBE program used in this study was based on this framework.

A systematic review by Saccente-Kennedy et al. (2024) using the Rehabilitation Treatment Specification System (RTSS) further confirmed that voice therapy incorporating respiratory approaches significantly improved multidimensional voice outcomes in presbyphonia. This includes improvements in aerodynamic measures and acoustic perturbation, which supports the theoretical rationale for combining diaphragmatic breathing with phonation task as adopted in the present study.

Lopes et al. (2024) examined the immediate effects of incentive spirometry, a device assisted form of respiratory training, in women with healthy voices. They found that maximum expiratory volume immediately improved, and jitter and shimmer were significantly reduced. This showed more controlled vocal fold vibration following the respiratory exercise. This implied that brief periods of respiratory loading resulted in improvements in acoustic voice measurements.

Leão et al. (2023) conducted a survey of Brazilian speech-language pathologists' practices using voice therapy with respiratory approaches for elderly adults. The study reported the use of Vocal Function Exercises (VFE), Lee Silverman Voice Treatment (LSVT) and semi-occluded vocal tract exercises (SOVT) to include the use of respiratory control. Findings reported positive outcomes in elderly adults in terms of frequency, resonance, loudness and coordination of breathing and phonation. This underlines the importance of respiratory training in vocal rehabilitation among the elderly.

Expiratory muscle strength training (EMST), which uses high-resistance expiratory pressure, is another form of respiratory-based speech intervention. Templeman and Roberts (2020) reviewed studies that reported EMST significantly improved MEP, with an average improvement of 16 $cmH_2O$. But had variable effects on FVC and $FEV_1$. Antonsson et al. (2024) investigated the impact of 12 weeks of EMST in people with Parkinson's disease and multiple sclerosis. They found increased MEP effects which were maintained over time and increased DDK rate. This has clear application to speech therapy for persons with neurological diseases. In India, Kulkarni and Kolase (2020) undertook a pilot intervention study in community-living adults aged more than 60 years in rural Maharashtra to evaluate the impact of a one-week EMST protocol on PEFR and MEP. This study found that the intervention led to a substantial improvement in PEFR, with a positive trend for MEP, confirming that short-duration EMST protocols can yield an immediate improvement in expiratory flow capacity of elderly adults in India. However, protocols of longer duration were advised for long-term gains.

The gains in vocal endurance, articulation, and breath-phonation coordination resulting from training in individuals with and without disease supports the potential benefits of such training on swallowing function given the shared neuromuscular mechanisms involved.

## 2.7 Effects of respiratory training on swallowing and airway protection

Loss of expiratory muscle strength due to ageing leads to weaker coughs, which is a critical airway protection mechanism during swallowing. Troche et al. (2010) demonstrated that EMST increased voluntary cough strength and swallowing function in patients with Parkinson's disease, with subsequent reductions in aspiration. Similarly, Pitts et al. (2008) documented improvements in voluntary cough flow and swallowing safety following EMST in Parkinson's disease. This underscores the importance of expiratory strengthening for airway protection. In multiple sclerosis, Srp et al. (2021) implemented an EMST program which allowed severely disabled multiple sclerosis patients to reach normal rates of voluntary cough flow after three months. This evidence supports the physiological basis of using DBE, which also focuses on the expiratory muscles. Therefore, acts as an airway protection training tool in the elderly.

By strengthening the diaphragm and improving expiratory control, DBE is expected to improve the coordination of the respiratory muscles to achieve the exhale-swallow-exhale pattern required for safe swallowing and airway clearance after swallowing. Valenzano et al. (2020) highlighted the significance of this pattern among healthy adults for different liquid consistencies. They found that a disruption in the exhalation phase of the respiratory-swallowing cycle was associated with aspiration. The ability of DBE to restore and reinforce this pattern in the elderly represents a significant therapeutic goal. The capacity of DBE to re-establish and strengthen this pattern in the elderly is an important therapeutic outcome.

The collective evidence reviewed from these areas highlights not only the impact of age-related changes in the respiratory system but also the potential benefits of targeted respiratory interventions, however there are several clear gaps in the literature, particularly with regard to healthy elderly adults and the Indian population.

The literature confirms a documented trajectory of age-related decline across the respiratory, phonatory, articulatory and swallowing systems in elderly adults. There is strong evidence of sarcopenic changes in respiratory muscles negatively affecting lung volumes, expiratory force, and cough efficacy, which in turn affect speech and swallowing safety. Presbyphonia and presbyphagia have been confirmed as being common in the general elderly adult population throughout the world, with meta-analytic estimates suggesting prevalence of presbyphagia at around 30.8% (Cai et al., 2024).

Diaphragmatic breathing training has been confirmed to enhance lung volumes, phonation endurance, and swallowing safety in a range of clinical populations including patients with chronic obstructive pulmonary disease (COPD), stroke, Parkinson's disease and frailty (Hamasaki, 2020; Abdullahi et al., 2024; Maki et al., 2018). Meta-analytic evidence has also confirmed the efficacy of respiratory training in improving swallowing function and risk for aspiration in elderly adults with dysphagia (Dai et al., 2024; Su et al., 2025). Research has reported DDK rates in Kannada and Telugu speakers (John et al., 2014; Patil & Manjula, 2014), and the prevalence of dysphagia in the community-dwelling Indian elderly has been established (Dodderi et al., 2024; Agnes et al., 2024). Respiratory norms have been established in adult speakers of Dravidian languages (Annapurana, 2009), and a culturally relevant swallowing screening questionnaire, the ‘SASQ-IE’ has been developed for the Indian elderly (Mohandas, 2023). A recent study in India (Sharma & Rajaselvi, 2026) showed the beneficial effects of DBE in elderly patients with hypertension, suggesting a growing awareness of the potential use of DBE in the Indian elderly population.

However, despite this emerging evidence, some critical gaps remain. Firstly, no study has yet systematically investigated the impact of a structured course of DBE on speech production (respiratory, phonatory and articulatory) outcomes in healthy elderly adults in the community. Second, the combined effect of DBE on speech and swallowing in the same population has not been examined, resulting in limited knowledge regarding whether the effects of DBE on the respiratory system translate to improvements in speech and swallowing. Third, there is a lack of evidence from the Indian elderly population, in whom the effects may be confounded by language-specific, cultural and/or physiological factors, and thus it is not possible to draw any culturally and clinically relevant conclusions for this population.

This study aims to contribute to this evidence base by exploring the impact of a four-week structured program of DBE on speech and swallowing functions in community-dwelling Indian elderly (62 to 70 years) in a single-group ABA repeated measures study design, with pre-intervention, post-intervention, and four-week follow-up sessions. Through this, we sought to provide the first systematic, multi-domain evidence regarding the impact of DBE on speech and swallowing in Indian elderly adults.

# CHAPTER III

# METHOD

## 3.1 Ethical consideration

The study followed the approval of the *Ethical guidelines for bio-behavioural research involving human subjects (Version 2.0)* (All India Institute of Speech and Hearing, 2023). The caregivers of the participants provided consent, following which they were enrolled. The study was approved by the AIISH Bio-Behavioural Ethical Committee (reference: SH/IRB/M.5/SLP.15/2025-26) (Appendix I). All required measures were taken to ensure the safety and confidentiality of participant data, and the caregivers of study participants were provided with comprehensive information about the study.

## 3.2 Study design

This study employed a single-group, repeated-measures multiple-baseline ABA research design. All participants underwent a sequential procedure that comprised baseline assessment (A), a four-week intervention (B, 3 sessions per week), and a 4-week follow-up assessment (A). Outcome measures were collected pre-intervention, post-intervention (end of week 4), and follow-up (4 weeks post-intervention). No intervention was provided during the interval between post-intervention and follow-up assessment. This design used each participant as their own control, allowing comparison of outcome measures across different time points, thereby eliminating the confounding influence of interindividual variability. It also enabled systematic tracking of both the magnitude of change and the durability of treatment effects over time, which was essential for establishing clinical significance in addition to statistical significance. The repeated-measures approach maximized statistical power within a small sample and allowed for both group-level descriptive analysis and individual response profiling.

### 3.3. Participants

Five community-dwelling elderly adults (aged 62–70 years; two females, three males) participated in the study. All participants were native speakers of Malayalam (n = 4) or Tamil (n = 1), passed the Montreal Cognitive Assessment (MoCA) screening, and reported no history of smoking or tobacco use. None had a diagnosed neurological, respiratory, or swallowing disorder, and no contraindications to spirometry or diaphragmatic breathing exercise (DBE) were identified. All participants met the inclusion criteria and completed all three phases of the ABA design: pre-intervention (A1), post-intervention (B), and four-week follow-up (A2). Detailed demographic and clinical characteristics are presented in Table 3.1.

***Inclusion criteria:***

- Age ≥ 60 years
- Ability to follow basic directions [Montreal Cognitive Assessment (MoCA; Nasreddine et al., 2005) score ≥23/30] was administered to rule out cognitive impairments.

***Exclusion criteria:***

- Smokers
- Vocal fold pathology
- Neurological or progressive neuromuscular conditions
- recent speech-language therapy
- cognitive impairment
- Any medical condition deemed inappropriate for spirometry or breathing exercises, such as recent surgeries, cardiac conditions, severe COPD/asthma, severe uncontrolled hypertension, severe GERD, etc.

**Table 3.1**

*Participant demographic and screening characteristics*

| Participant | Age | Sex | Height (cm) | Weight (kg) | Language | MoCA Pass | Comorbidities / Contraindications | Completed All Phases |
|---|---|---|---|---|---|---|---|---|
| P1 | 62 | Male | 186 | 79 | Tamil | Yes | None | Yes |
| P2 | 70 | Female | 152 | 61 | Malayalam | Yes | None | Yes |
| P3 | 62 | Female | 168 | 62 | Malayalam | Yes | None | Yes |
| P4 | 67 | Male | 173 | 75 | Malayalam | Yes | None | Yes |
| P5 | 70 | Male | 162 | 52 | Malayalam | Yes | None | Yes |

Note. MoCA = Montreal Cognitive Assessment

## 3.4 Procedure

### *3.4.1. Pre-intervention assessment (baseline evaluation)*

Each participant underwent a baseline evaluation to determine their baseline speech (respiratory, phonatory, articulatory) and swallow function characteristics (Table 3.2). The assessment session was completed in a single sitting of approximately 20-30 minutes, with adequate rest intervals to prevent fatigue.

*3.4.1.1 Assessment of respiratory function*

Respiratory function was assessed using the handheld SPIRO FLO device (SF100) and the dry-type digital spirometer software Spiro Q (version 1.0.0(D20200302)). The following parameters were measured:

A. *Forced Vital Capacity (FVC)*

- It is the maximal forced exhalation volume following a deep inspiration.
- Participants were instructed to take a deep, full breath and then exhale as rapidly and forcefully as they could, expelling as much air as possible. This measures the maximum volume of air expelled after full inspiration.
- The spirometer device automatically evaluated the following parameters by performing forced vital capacity maneuver:

*a. Forced Expiratory Volume ($FEV_1$):* The volume of air exhaled during the first second of the forced expiratory maneuver.

*b. $FEV_1$/FVC Ratio:* Determines airflow restriction by measuring the percentage of FVC exhaled in the first second.

*c. Peak Expiratory Flow Rate (PEFR):* Measures the peak airflow generated during a forceful exhalation or cough from complete lung inflation.

*B. Slow Vital Capacity (SVC)*

- It is the maximal volume of air that can be exhaled slowly and completely following a full inspiration, without forced effort.
- Participants were instructed to take a deep breath and then slowly and completely exhale.
- The spirometer device automatically evaluated the *tidal volume (TV).* It is the volume of normal, relaxed breath.

*Testing Procedure:*

- Participants were seated comfortably and a demonstration of the correct technique was provided, followed by one to two supervised practice trials to ensure proper performance.
- The parameters were measured using three maximal-effort trials with a minimum rest period between the trials to prevent fatigue and provide a reliable measurement.
- For analysis, the highest value in the three trials was recorded.

*3.4.1.2 Assessment of phonatory function*

Phonatory function was assessed using the following measures: Maximum Phonation Duration (MPT) and Acoustic Voice Analysis.

- Maximum Phonation Time: Following the maximal inspiration, each subject was instructed to maintain the vowel /a/ as long as they could at a comfortable pitch and loudness level.

Three trials were carried out, separated by at least 30 seconds. A digital stopwatch was used to record the duration, and analysis was done using the average of three trials.

- Acoustic Voice Analysis: The most stable and sustained sample of /a/ was recorded through a high-quality voice recorder (Sony IC recorder) that was positioned 10 cm away the lips in a noisy free environment with controlled ambient noise. The recording was then analyzed with the help of the PRAAT software (version 6.4.25; Boersma & Weenink, 2024) to obtain the following acoustic parameters:

  *a. Fundamental Frequency (F0):* Average pitch (Hz) during a sustained vowel.

  *b. Jitter (%):* Cycle-to-cycle frequency perturbation (%) during sustained vowel, an indicator of irregularities in the vibration of vocal folds.

  *c. Shimmer (%):* Cycle-to-cycle amplitude perturbation (%) during sustained vowel, reflecting variability in vocal intensity.

*3.4.1.3 Assessment of articulatory function*

Articulatory function was evaluated using three standardized measures that assessed speech clarity, oral motor coordination, and temporal aspects of speech production.

a. *Speech intelligibility:*

Participants were asked to read aloud a standardized passage in their native language, i.e, a standard passage (Savithri & Jayaram, 2008) for native Tamil speakers, and the Thengu passage (Dokhe et al., 2021) for native Malayalam speakers, at their comfortable speaking rate and loudness level. The speech samples were audio-recorded in a quiet, acoustically controlled environment. Speech intelligibility was rated by two speech-language pathologists using the Ali Yavar Jung National Institute of Hearing Handicapped (AYJNIHH) intelligibility rating scale, a 7-point scale ranging from 0 (Normal intelligibility) to 7 (Cannot be understood at all even when the content is known) (AYJNISHD,2003). Inter-rater reliability was established, and the average of both ratings was used as the final intelligibility score for each participant.

*b. Verbal Diadochokinesis (DDK):*

Verbal DDK was assessed to evaluate the speed, regularity, and coordination of rapid, repetitive articulatory movements. For the Alternate Motion Rate (AMR), participants were asked to produce rapid, repetitive productions of single syllables ("pa," "ta," and "ka") in isolation, each over a 10-second interval. A rest period of 30 seconds was provided between each of the three trials per syllable. For Sequential Motion Rate *(SMR)*, participants were asked to repeatedly articulate the trisyllabic sequence "pa-ta-ka" with maximal speed and consistency for 10 seconds, with a 5-second rest period between each of the three trials.

All productions were audio-recorded and subsequently analyzed to determine the number of syllables articulated per second for each task. The average of three trials was calculated for each syllable sequence. These tasks assessed the speed, coordination, and consistency of articulatory movements involving the lips, tongue tip, and tongue dorsum. Healthy adults generally have AMR rates of 5-7 syllables per second and SMR rates of 5-8 syllables per second (Pierce et al., 2013) and these values form a normative reference point in interpreting the values obtained. The language-specific and age-related variations in DDK rates have been reported in Indian studies. Normative data of healthy elderly Kannada-speaking individuals (61-80 years) indicate that the DDK rate varies approximately between 4.6 and 5.8 syllables/s across different syllables, with the mean of /pə/ as 5.1-5.3 syllables/s. The results showed that there were no significant age-related differences between elderly subgroups, indicating relative stability of articulatory rate during aging (Mahesh et.al, 2023). John et al. (2014) found that the DDK rates of adults speaking Kannada aged 51-60 years were the lowest across age groups (males: 2.72/s; females: 3.25/s), which confirmed the slowing of articulatory in old age. Similarly, Patil and Manjula (2014) observed a declining trend in DDK from 5.38 syllables/s (40-50 years) to 5.28 syllables/s (50-60 years) in Telugu-speaking adults. Jothi and Amritha (2019) reported that in healthy adults aged 20-25 years, mean AMR values of Tamil speakers were in the range of 3.89-4.08 syllables/s and of Malayalam speakers were in the range of 4.72-4.98 syllables/s and SMR values of 2.89 and 3.46 syllables/s respectively, which reflect the language-specific differences in articulatory rate. Therefore, the DDK rates are predictive of neuromuscular agility and timing; and are highly sensitive in detecting even subtle alterations in articulatory control following respiratory-phonatory training.

c. *Speech rate:*

Speech rate was calculated in words per minute (WPM) from the standardized reading passage used during the intelligibility assessment. The following formula was used:

Speech rate = (total number of intelligible words ÷ total speaking time) × 60

Total speaking time was calculated by excluding pauses longer than 2 seconds from the total recording duration. Normal conversational speech in adults is about 150-200 words per minute. This measure reflected the temporal coordination of the respiratory, phonatory and articulatory subsystems in connected speech and was likely to decrease with age-related slowing, thus providing a sensitive index of intervention efficacy.

d. *Reliability of articulatory measures:*

To establish the reliability of these articulatory measures inter-rater and intra-rater reliability were determined. Inter-rater reliability was assessed between the primary investigator (Rater 1) and two certified speech-language pathologists (Rater 2 and 3) who independently rated the same set of audio recordings. Inter-rater reliability data were collected on a representative subset comprising 40% of the sample (n = 2; P2 and P4), with recordings drawn from all three time points of assessment, yielding six measurements per rater per measure. Intra-rater reliability was established by the primary investigator (Rater 1), who re-analysed the same subset of recordings after two weeks of interval, blind to the original ratings.

*3.4.1.4 Assessment of swallow function*

The swallowing function was assessed through the following validated measures that evaluate airway protection mechanisms and aspiration risk in elderly participants, which include:

*a. Screening for dysphagia in elderly:*

Dysphagia screening was conducted for all participants using the Swallow Abilities Screening Questionnaire for the Indian Elderly (SASQ-IE) (Mohandas, 2023) (Appendix II). This questionnaire comprised two sections: Section A (Demographic information), capturing basic participant details, and Section B (Assessment items), consisting of 25 questions organized across three domains: Activity limitation, difficulties in the oral, pharyngeal, and esophageal phases, and participation restrictions. All the items were rated in terms of frequency of the symptoms: always (score of 1), sometimes (score of 0.5), never (score of 0). Item scores were summed to generate the overall pre-intervention SASQ-IE score.

b. *Assessment of cough strength*:

An objective measure of cough strength was obtained using a spirometer (Model: Spiro Q software (version 1.0.0) with handheld SPIRO FLO device (SF100). The participants were instructed to hold the mouthpiece, inhale as deeply as possible and then cough spontaneously and as hard as possible. The primary objective index of cough strength and risk of aspiration was measured as PEFR since it has been identified as one of the most reliable predictors of aspiration (Hammond et al., 2008).

In addition, a subjective measure of cough strength was obtained using the Semiquantitative Cough Strength Score (SCSS) (Khamiees et al., 2001) (Appendix III). The participants were asked to cough as forcefully as possible, and the examiner rated the cough perceptually on a scale of 0 to 5: 0 indicated no cough on command, 1 indicated audible air movement but no audible cough, 2 indicated a weakly (barely) audible cough, 3 indicated a clearly audible cough, 4 indicated a stronger cough; and 5 indicated multiple sequential strong coughs.

c. *Assessment of voluntary swallow:*

Repetitive Saliva Swallowing Test (RSST) was administered following the protocol established by Oguchi et al. (2000). The subjects were seated upright at a 90 degree angle and asked to swallow their saliva as many times as possible within 30 seconds without taking up additional water or food. The examiner palpated the laryngeal prominence to count the number of complete swallows within 30 seconds, which will be measured using a stopwatch, defined by a clear upward and downward excursion of the larynx. A score of ≥3 swallows in 30 seconds was considered within the normal range for healthy elderly adults (Oguchi et al., 2000). This task evaluated the coordination and efficiency of the oral and pharyngeal phases of swallowing. Following Table 3.2 summarises the outcome parameters that were measured in the study

An assessment proforma (Appendix IV) including the participant's demographic details, cognitive status and the measurement values obtained across the three assessment phases (pre-intervention, post-intervention and follow-up) was used to record the data systematically.

**Table 3.2**

*Summary of the outcome measures*

| Domain | Measures |
|---|---|
| Respiratory | FVC, $FEV_1$, $FEV_1$/FVC ratio, SVC, TV. |
| Phonatory | MPT, F0, jitter, shimmer |
| Articulatory | Verbal DDK rate, speech intelligibility, speech rate |
| Swallowing | SASQ-IE score, PEFR, SCSS, RSST |

*Note.* FVC = forced vital capacity; FEV1 = forced expiratory volume in 1 second; FEV1/FVC = forced expiratory volume in 1 second/ forced vital capacity; SVC = slow vital capacity; TV = tidal volume; MPT = maximum phonation time; F0 = fundamental frequency; DDK = diadochokinetic rate; SASQ-IE = swallow abilities screening questionnaire for the indian elderly; PEFR = peak expiratory flow rate; SCSS = semiquantitative cough strength Score; RSST = repetitive saliva swallowing test.

### *3.4.2 Instrumentation:*

1. Spirometer

A portable spirometer, model: SPIRO FLO device (SF100) and Spiro Q software (version 1.0.0) was used to measure the respiratory measures and cough strength, detail of which is mentioned in Table 3.3.

**Table 3.3**

*Details of the Parameters Measured Using Spirometer*

| Parameters | Unit |
|---|---|
| Forced vital capacity [FVC] | L |
| Forced expiratory volume [$FEV_1$] | L |
| $FEV_1$/FVC ratio | % |
| Slow vital capacity [SVC] | L |
| Tidal volume | L |
| Peak expiratory flow rate [PEFR] | L/s |

2. PRAAT software

   Acoustic voice data was captured and analyzed with PRAAT (version 6.4.25) (Boersma & Weenink, 2024), a free software for voice analysis. Participants sustained the vowel /a/ to evaluate: fundamental frequency (F0), jitter (%) and shimmer (%).

3. Stopwatch and voice recorder

   To measure MPT and verbal DDK, a stopwatch and voice recorder were used. And for assessing speech intelligibility and speech rate, a voice recorder was used.

***3.4.3 Intervention***

The intervention program was provided over twelve 15-30 minutes session over 4 weeks (3/ week). The initial two sessions were conducted offline at the participants' homes by the investigator, to ensure correct technique acquisition and provide direct feedback. The remaining ten sessions were delivered via an online video-conferencing platform (Zoom) to improve accessibility and reduce participant burden.

During the first session, the investigator demonstrated each breathing exercise, provided hands-on guidance, and offered immediate corrective feedback to ensure accurate technique in the presence of a caregiver. During the second session, the investigator monitored the participant's performance and assessed the caregiver's ability to guide the participant through the exercises independently. All participants were asked to perform the exercises twice daily, in addition to the scheduled therapy sessions. A structured daily log checklist (Appendix V) was provided at the commencement of the intervention program to monitor and document home practice adherence. The participants were oriented to the checklist and asked the caregivers to help the participants complete the checklist in a consistent manner during the four-week period. A session log for examiner (Appendix VI) was also used to record the information regarding each session.

***Session structure***

Each 15-30 minute therapy session comprised of a warm-up phase, followed by the breathing exercise program.

*Warm-up phase*

Each session started with a short warm-up routine to physically prepare the participants to the targeted exercises. The following instructions were given to the participants in their native language: To prepare your body to the therapy session, we will start with some gentle exercises. These should feel comfortable and never cause strain. Please let me know immediately if you experience any discomfort anytime during the session.

The warm-up included:

1. Comfortable sitting position: Participants were seated upright in a chair, feet flat on the floor, shoulders relaxed, and spine straight to adhere to 90-90-90 posture.
2. Head and neck relaxation: Gentle and slow circular movements, lateral tilting, and slow forward-backward movements were performed.
3. Shoulder relaxation: Gentle and slow shrugging upward and downward, followed by rolling forward and backwards, were performed.
4. Diaphragm awareness breathing: With the dominant hand placed on the abdomen and the other hand on the chest, participants inhaled slowly for about 3 seconds (allowing abdomen to rise while the chest remained relatively still), followed by a slow exhalation over 4-5 seconds. This was repeated for three cycles.

*Breathing exercise program*

The primary program comprised the following three breathing exercises:

1. Diaphragmatic breathing exercises

This exercise aimed at working the diaphragm to enhance expansion of the lung volume and respiratory efficiency, thus strengthening the breath support of speech and improving airway protection during swallowing in the following steps:

1. Positioning: Participants sat upright with shoulders relaxed and back supported. A semi-reclined position was used initially, where needed, for easier learning.
2. Hand placement: The non-dominant hand was placed on the upper chest and the dominant hand on the abdomen.
3. Inhalation: The participants inhaled slowly, paying attention to the abdomen to achieve the expansion and keeping the chest as still as possible.
4. Exhalation: Participants exhaled gently for 4–6 seconds, feeling the abdomen fall inward.

Two sets of five repetitions with a 30-second rest between sets in a session were performed. This moderate dosage was adopted to prevent hyperventilation, based on previous protocols where Sedaghati et al. (2023) used two sets of three repetitions and Maki et al. (2018) utilized 30 contractions each session

2. Diaphragmatic breathing with phonation

This practice combined diaphragmatic breathing with sustained phonation to enhance breath support and improve voicing in the following steps:

1. Positioning: Participants sat upright, feet flat on the floor and shoulders relaxed.
2. Hand placement: The dominant hand was placed on the abdomen and the other on the chest for feedback.
3. Inhalation: The participants were required to breathe in slowly through the nose and to expand the abdomen to the full capacity without straining.
4. Phonation: Immediately after inhalation, participants sustained the vowel /a/ at a comfortable pitch and loudness until the air was naturally exhausted. Participants

were asked to create smooth and unstrained phonation and not to strain the voice towards the end of the breath.

Two sets of five repetitions were performed per session with a 30-second rest between each set.

3. Diaphragmatic breathing with reading passage

This exercise integrated diaphragmatic breathing with connected speech to enhance respiratory control, phonatory stability, and speech intelligibility in the following steps. Standardized reading passages were used to ensure consistency across participants: a standard passage (Savithri & Jayaram, 2008) for native Tamil speakers, and the Thengu passage (Dokhe, 2021) for native Malayalam speakers. This was performed as follows:

1. Positioning: The participants were seated upright in a chair with the feet flat on the floor, back supported and shoulders relaxed.
2. Hand placement: The dominant hand was placed on the abdomen and the non-dominant hand on the chest to monitor breathing pattern.
3. Inhalation: A slow diaphragmatic breath was inhaled through the nose, and this expands the abdomen but leaves the chest relatively still.
4. Reading with exhalation: The participants started reading the standardized passage aloud immediately upon the onset of exhalation. Steady loudness, smooth phrasing and avoidance of unnecessary pauses were encouraged. Reading was continued until breath support naturally tapered and a new breath was taken before continuing.

The passage was read three times per session, with a 30-second rest interval between each reading.

The table 3.4 shows the details of the dosage of training and instructions for the participants for the three exercises.

**Table 3.4**

*Summary of the treatment dosage and participant instruction for the three exercises*

| **Exercise** | **Treatment Dosage** | **Sources** | **Instruction** |
|---|---|---|---|
| Diaphragmatic breathing (Duration:7 minutes) | 2 sets of 5 repetitions each with 30 s rest between each repetition | Chukwu et al. (2025), Maki et al.(2018), Sedaghati et al. (2023), Stemple et al. (2020),Abdullahi et al. (2024) | "Sit comfortably with your feet flat on the ground and place your dominant hand on your stomach and the other on the chest. Breathe out gently first. Now, take a slow, deep breath in through the nose, allowing your stomach to rise while keeping your chest as still as possible. Then slowly breathe out, letting your stomach fall. Repeat this breathing pattern slowly and comfortably." |
| Diaphragmatic breathing with phonation (Duration:8 minutes) | 2 sets of 5 repetitions each with 30 s rest between each repetition | Chukwu et al. (2025), Stemple et al. (2020) | "Sit comfortably with your feet flat on the floor and keep your dominant hand on the stomach and the other hand on upper chest. Now, take a slow, deep breath in through the nose, letting your stomach rise while keeping chest as still as possible. As soon as you finish inhaling, say the sound /a/ in one continuous voice at a comfortable loudness, until |

| | | | |
|---|---|---|---|
| | | | you run out of air. Do not force the voice at the end, just stop when the breath is finished. Relax before the next trial.” |
| Diaphragmatic breathing with reading passage (Duration:10 minutes) | 3 times, 30 s rest between each repetition | Stemple et al. (2020) | “Sit comfortably with your feet flat on the floor and place your dominant hand on your stomach and the other hand on your upper chest. Take a slow, deep breath in through your nose, allowing your stomach to rise while keeping your chest as still as possible. As soon as you finish inhaling, begin reading the passage aloud at a steady pace and comfortable loudness, letting your voice flow out naturally with your breath. Do not rush or strain. Pause only when you need to take the next breath. After you complete the reading, relax before the next trial.” |

### *3.4.4 Post-intervention assessment*

Following the completion of the 4-week intervention program, all baseline assessments mentioned in Table 3.2 were re-administered to evaluate the improvements in speech and swallow functioning.

### *3.4.5 Follow-up assessment*

Participants underwent a follow-up assessment of all the outcome measures mentioned in Table 3.2, which was administered four weeks after the intervention program, during which no additional training were provided. This was conducted to determine the retention and maintenance of gains achieved during the intervention phase, thereby providing the durability of the treatment effects over time. The same standardized assessment protocol that was used at pre- and post- intervention was followed to ensure comparability of data across all three time points. Figure 3.1 summarises the study procedure.

**Figure 3.1**

*Flow chart illustrating the study procedure*

**Pre-Intervention**

Outcome measures measured:

1. Respiratory measures: FVC, $FEV_1$, $FEV_1$/FVC ratio , SVC and TV
2. Phonatory measures: MPT, F0, jitter and shimmer
3. Articulatory measures: DDK rate, Speech intelligibility and Speech rate
4. Swallowing measures: SASQ-IE score, PEFR , SCSS and RSST score

**Intervention**

3days/week for 4 weeks

a. Warm-up phase (5 minutes)

b. Breathing exercise program (25 minutes): (1) Diaphragmatic Breathing, (2) Diaphragmatic Breathing with phonation, (3) Diaphragmatic Breathing with reading passage

**Post-Intervention**

After 4 weeks or 12 sessions (outcome measures as Pre-Intervention)

**Follow up**

4 weeks after program (outcome measures as Pre-Intervention)

*Note.* FVC = forced vital capacity; FEV1 = forced expiratory volume in 1 second; FEV1/FVC = forced expiratory volume in 1 second/ forced vital capacity; SVC = slow vital capacity; TV = tidal volume; MPT = maximum phonation time; F0 = fundamental frequency; DDK = diadochokinetic rate; SASQ-IE = swallow abilities screening questionnaire for the indian elderly; PEFR = peak expiratory flow rate; SCSS = semiquantitative cough strength Score; RSST = repetitive saliva swallowing test.

### 3.5 Statistical analysis

All data were analysed using IBM SPSS Statistics, Version 26.0. Individual participant profiles were described using raw scores at each time point, and group level data were described using median and interquartile range. Friedman test was used as the primary inferential statistic to examine the differences across the three time points of assessment for all outcome measures. For the outcome measures, where a significant Friedman test was obtained, Bonferroni-corrected pairwise comparisons were conducted to identify specific time points at which differences were significant, with the adjusted significance threshold set at $p < 0.017$.

# CHAPTER IV

# RESULTS & DISCUSSION

This chapter reports the findings of the study examining the effect of a structured four-week diaphragmatic breathing exercise (DBE) programme on speech and swallowing functions in five community-dwelling Indian elderly individuals aged between 60 and 70 years. A within-subjects repeated measures design was employed across three time points: pre-intervention (A1), immediately post-intervention (B), and four-week follow-up (A2). Descriptive statistics are reported as Median (Mdn) and Interquartile Range (IQR). Since the data did not meet the assumptions of parametric testing due to the small sample size ($n = 5$), Friedman test (non-parametric equivalent of one-way repeated measures ANOVA) was used to determine whether statistically significant differences existed across the three time points for each parameter. Where a significant Friedman test was obtained, Bonferroni-corrected pairwise comparisons were conducted to identify specific time points at which differences were significant, with the adjusted significance threshold set at $p < 0.017$. All analyses were performed using IBM SPSS Statistics, Version 26.0.

## 4.1 Objective 1: Comparison of respiratory measures pre-, post-, and four weeks after the intervention in Indian elderly

### 4.1.1 Respiratory measures (litres): FVC, FEV1, SVC and TV

The respiratory volume measures namely Forced Vital Capacity (FVC), Forced Expiratory Volume in one second (FEV1), Slow Vital Capacity (SVC), and Tidal Volume (TV) are measured in litres. Individual participant values, median and IQR across the three assessment phases are presented in Table 4.1 and Figures 4.1-4.5.

**Table 4.1**

*Individual participant values for respiratory volume measures (litres) across assessment phases for all five participants*

| | Pre-Intervention | | | | Post-Intervention | | | | Follow-up | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Participant** | ***FVC*** | ***FEV1*** | ***SVC*** | ***TV*** | ***FVC*** | ***FEV1*** | ***SVC*** | ***TV*** | ***FVC*** | ***FEV1*** | ***SVC*** | ***TV*** |
| P1 | 1.68 | 1.59 | 2.12 | 0.46 | 1.76 | 1.71 | 4.97 | 0.85 | 1.69 | 1.61 | 5.07 | 0.53 |
| P2 | 1.35 | 1.33 | 4.57 | 0.41 | 1.61 | 1.61 | 4.17 | 0.75 | 1.56 | 1.56 | 3.88 | 0.66 |
| P3 | 1.37 | 1.25 | 3.29 | 0.37 | 1.43 | 1.39 | 3.66 | 0.40 | 1.43 | 1.30 | 3.45 | 0.38 |
| P4 | 1.78 | 1.67 | 3.86 | 0.20 | 1.88 | 1.85 | 4.74 | 0.46 | 1.84 | 1.81 | 4.48 | 0.39 |
| P5 | 1.73 | 1.68 | 3.20 | 0.43 | 1.88 | 1.87 | 4.48 | 0.76 | 1.83 | 1.81 | 3.53 | 0.62 |
| **Median** | **1.68** | **1.59** | **3.29** | **0.41** | **1.76** | **1.71** | **4.48** | **0.75** | **1.69** | **1.61** | **3.88** | **0.53** |
| **IQR** | **0.39** | **0.38** | **1.55** | **0.16** | **0.36** | **0.36** | **0.94** | **0.37** | **0.34** | **0.38** | **1.29** | **0.26** |

*Note*. FVC = forced vital capacity; FEV1 = forced expiratory volume in 1 second; SVC = slow vital capacity; TV = tidal volume. Values are reported in litres. IQR = interquartile range.

Table 4.1 shows the individual participant values for FVC, $FEV_1$, SVC, and TV across the three assessment phases. The corresponding individual participant graphs are shown in Figures 4.1-4.5, which illustrate the change in each respiratory measure across pre-intervention (A1), post-intervention (B), and four-week follow-up (A2) for each participant.

FVC and $FEV_1$ showed a consistent pattern of improvement immediately after the four-week DBE programme, with partial maintenance of gains at four-week follow-up. All five participants demonstrated increased FVC and $FEV_1$ post-intervention. At follow-up, four of five participants maintained values above baseline, while one participant's values returned close to baseline.

At the sample level (N = 5), median FVC increased from 1.68 L (IQR = 0.39) pre-intervention to 1.76 L (IQR = 0.36) post-intervention, then declined slightly to 1.69 L (IQR = 0.34) at follow-up. Median $FEV_1$ followed a similar trajectory, increasing from 1.59 L (IQR = 0.38) to 1.71 L (IQR = 0.36) post-intervention, and decreasing to 1.61 L (IQR = 0.38) at follow-up. The Friedman test indicated a statistically significant difference across time points for FVC ($\chi^2 = 9.579$, df = 2, $p = 0.008$). Bonferroni-corrected pairwise comparisons revealed a significant pre–post difference (adjusted $p = 0.008$), whereas pre–follow-up (adjusted $p = 0.246$) and post–follow-up (adjusted $p = 0.618$) comparisons were non-significant. A similar pattern was observed for $FEV_1$ ($\chi^2 = 10.000$, df = 2, $p = 0.007$), with a significant pre–post difference (adjusted $p = 0.005$) and non-significant pre–follow-up and post–follow-up comparisons (adjusted $p = 0.342$ for both).

The SVC values demonstrated considerable inter-individual variability. Participant P1 showed a markedly larger increase from baseline to post-intervention (2.12 L to 4.97 L) compared with all other participants, likely reflecting a technique-related factor or measurement variability at baseline. Another participant (P2) showed a progressive decrease across time points. The remaining three participants showed modest increases post-intervention with partial retention at follow-up.

Group-level medians increased from 3.29 L (IQR = 1.55) pre-intervention to 4.48 L (IQR = 0.94) post-intervention, then declined to 3.88 L (IQR = 1.29) at follow-up. The Friedman test was not statistically significant ($\chi^2 = 3.600$, df = 2, $p = 0.165$); the null hypothesis of no differences across time points was retained. The non-significant result is likely due to high inter-individual variability, particularly P1's outlying trajectory, which obscured any consistent group-level trend.

Tidal Volume (TV) showed a consistent pattern of increase post-intervention across all participants, with partial retention at follow-up. All five participants demonstrated higher TV post-intervention compared with baseline, and all follow-up values remained above baseline. Median TV increased from 0.41 L (IQR = 0.16) pre-intervention to 0.75 L (IQR = 0.37) post-intervention, then decreased to 0.53 L (IQR = 0.26) at follow-up. The Friedman test was statistically significant ($\chi^2 = 10.000$, df = 2, $p = 0.007$). Bonferroni-corrected pairwise comparisons identified a significant pre–post difference (adjusted $p = 0.005$), while pre–follow-up (adjusted $p = 0.342$) and post–follow-up (adjusted $p = 0.342$) comparisons were non-significant.

These findings suggest that a short-term, structured DBE programme can produce immediate improvements in vital capacity and expiratory volume in healthy elderly adults, with partial retention of gains four weeks after the intervention. The direction and consistency of change are consistent with previous studies demonstrating that diaphragmatic breathing and respiratory muscle training improve lung volumes and respiratory muscle strength elderly adults and clinical populations (Hamasaki, 2020; Guo et al., 2025; Ahmad et al., 2025). The fact that gains were not statistically significant at follow-up compared to baseline may reflect the relatively short duration of the intervention (four weeks), the absence of a maintenance or booster phase, and the small sample size, which limits statistical power to detect more subtle long-term effects. Nevertheless, the fact that all five participants showed post-intervention improvement in FVC and $FEV_1$, and four of five maintained values above baseline at follow-up, suggests a clinically meaningful trend that warrants further investigation in larger samples with longer follow-up.

Abdullahi et al. (2024), in a meta-analysis of DBE in stroke patients, documented significant improvements in FVC (Mean difference [MD] = 0.90 L) and $FEV_1$ (MD = 0.32 L). Sedaghati et al. (2023) confirmed significant $FEV_1$ improvement ($p = 0.002$) and improved oxygen saturation ($p = 0.001$) in elderly COVID-19 survivors following DBE with a large effect size ($\eta^2 = 0.51$). Abo Elyazed et al. (2024) also demonstrated that DBE produced significant improvements in FVC, $FEV_1$ and SVC compared to standard care alone in patients with diaphragmatic dysfunction. Shetty et al. (2020), in an Indian study in Mangalore, confirmed the largest FVC gain (+21.27%) in the DBE group among other respiratory interventions. Arnal-Gómez et al. (2022) documented clinically significant FVC and $FEV_1$ increases (≥11-12%) in institutionalised elderly following combined diaphragmatic and musculoskeletal exercise, and Chukwu et al. (2025) confirmed significant FVC and $FEV_1$ improvements in healthy vocalists following eight weeks of DBE.

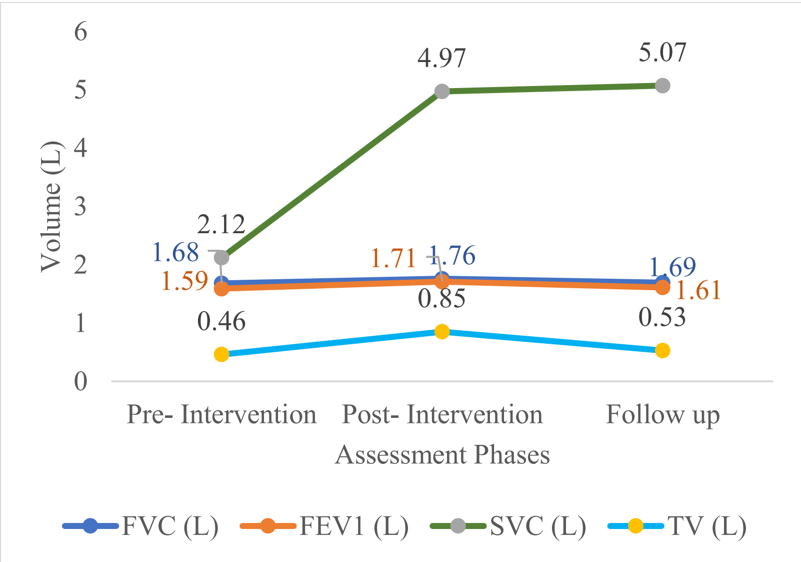
According to Hamasaki (2020), progressive diaphragmatic strengthening enhances alveolar ventilation and expands functional reserve volume. The partial return toward baseline at follow-up, without falling to pre-intervention levels, could suggest sustained physiological adaptation requiring continued practice for maximal maintenance. From a clinical perspective, even slight increase in FVC and $FEV_1$ may translate into improved breath support for speech and swallowing, potentially enhancing voice intensity, endurance, and airway protection during swallowing. This aligns with the mechanistic rationale that DBE targets respiratory musculature, which underpins both phonation and deglutition.

Abo Elyazed et al. (2024) specifically confirmed that DBE produced significant SVC improvements compared to standard care in patients with post-COVID diaphragmatic dysfunction, establishing that DBE improved SVC. The SVC manoeuvre is more susceptible to learning effects and intra-individual variability than the forced spirometric manoeuvre, particularly in elderly adults who are unfamiliar with spirometric testing, making it more sensitive to technique inconsistency across sessions. Standardised SVC coaching and familiarisation sessions prior to baseline assessment are recommended in future studies to reduce this variability.

Hamasaki (2020) identified increased TV as the most consistent and immediate effect of DBE. Yamaguti et al. (2012), in a randomised controlled trial, demonstrated that structured DBE significantly improved abdominal motion during natural breathing in COPD patients compared to controls, confirming that DBE produces durable changes in resting tidal breathing pattern, not only in forced efforts. Improved TV extends clinical benefit to both speech and swallowing. That is, deeper diaphragmatic breaths generate more consistent subglottic pressure reserves for phonation and articulatory effort, and adequate lung volume at swallowing initiation is critical for effective laryngeal closure and airway protection. The partial return at follow-up confirms that the behavioural component of the breathing pattern shift begins to revert without continued practice, underscoring the importance of home maintenance exercises.

**Figure 4.1**

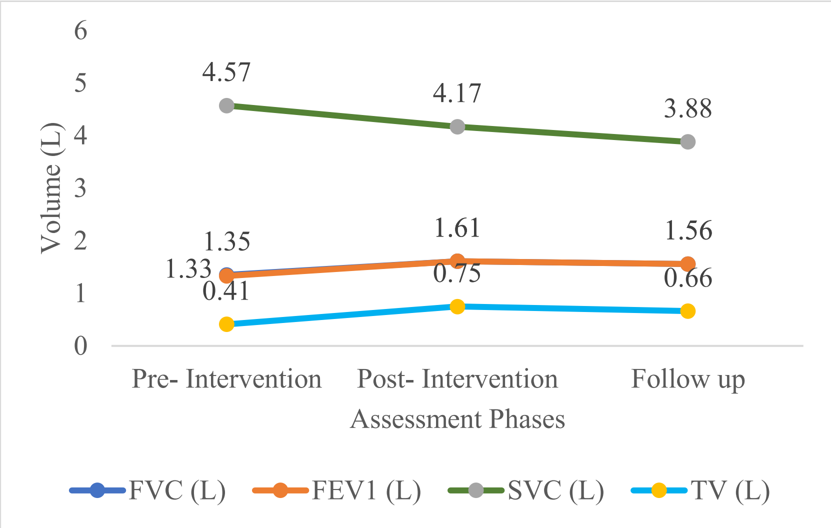
*Respiratory volume measures (FVC, FEV1, SVC, and TV in litres) across assessment phases for P1*




*Note.* FVC = forced vital capacity; FEV1 = forced expiratory volume in 1 second; SVC = slow vital capacity; TV = tidal volume.

**Figure 4.2**

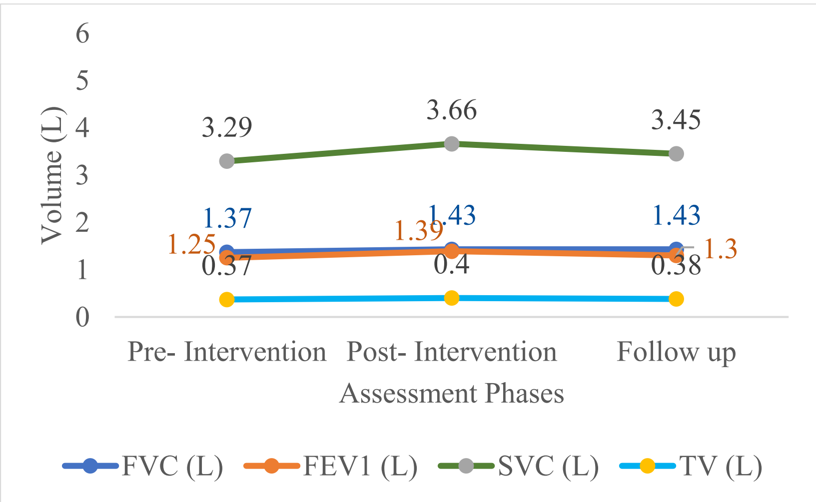
*Respiratory volume measures (FVC, FEV1, SVC, and TV in litres) across assessment phases for P2*




*Note.* FVC = forced vital capacity; FEV1 = forced expiratory volume in 1 second; SVC = slow vital capacity; TV = tidal volume.

**Figure 4.3**

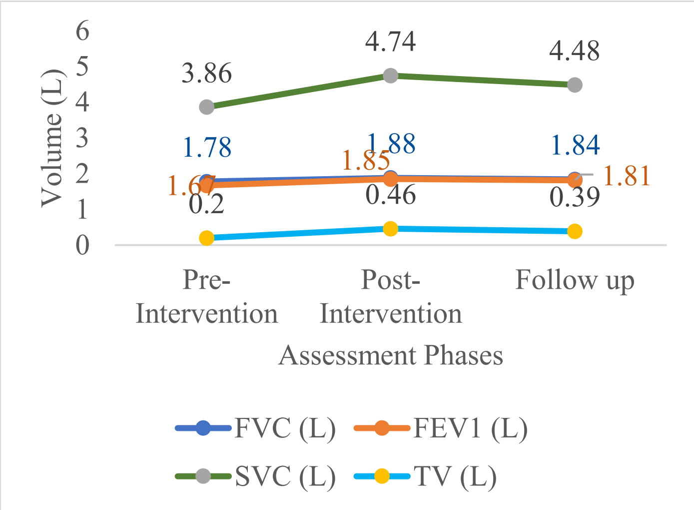
*Respiratory volume measures (FVC, FEV1, SVC, and TV in litres) across assessment phases for P3*




*Note.* FVC = forced vital capacity; FEV1 = forced expiratory volume in 1 second; SVC = slow vital capacity; TV = tidal volume

**Figure 4.4**

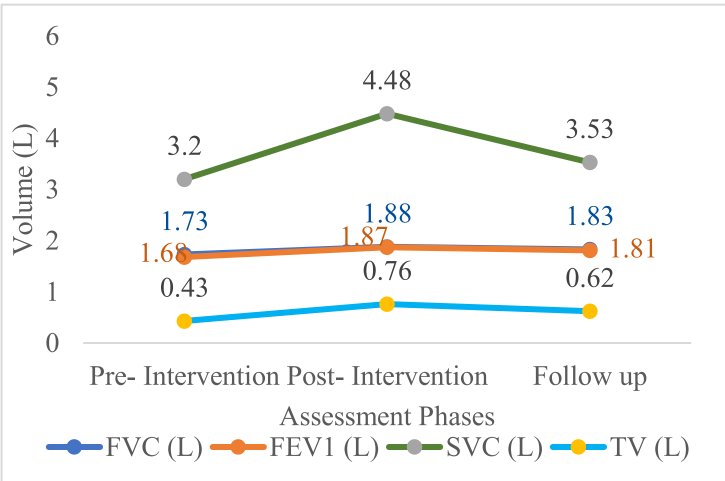
*Respiratory volume measures (FVC, FEV1, SVC, and TV in litres) across assessment phases for P4*




*Note.* FVC = forced vital capacity; FEV1 = forced expiratory volume in 1 second; SVC = slow vital capacity; TV = tidal volume.

**Figure 4.5**

*Respiratory volume measures (FVC, FEV1, SVC, and TV in litres) across assessment phases for P5*




*Note.* FVC = forced vital capacity; FEV1 = forced expiratory volume in 1 second; SVC = slow vital capacity; TV = tidal volume.

### 4.1.2 Respiratory measures (%): FEV1/FVC ratio

The FEV1/FVC ratio represents the proportion of forced vital capacity exhaled within the first second and serves as an indicator of obstructive airway patterns. Values for all participants across the assessment phases, median and IQR are presented in Table 4.2 and Figures 4.6.

**Table 4.2**

*Individual participant values for FEV1/FVC ratios (%) across assessment phases for all five participants*

| Participant | Pre-Intervention | Post-Intervention | Follow-up |
|---|---|---|---|
| P1 | 94.64 | 97.16 | 95.27 |
| P2 | 98.51 | 100.00 | 100.00 |
| P3 | 91.33 | 97.19 | 91.42 |
| P4 | 94.09 | 98.61 | 98.28 |
| P5 | 97.11 | 98.11 | 98.74 |
| **Median** | **94.64** | **98.11** | **98.28** |
| **IQR** | **5.10** | **2.13** | **6.03** |

*Note.* FEV1/FVC = forced expiratory volume in 1 second/ forced vital capacity. Values are reported in %. IQR = interquartile range.

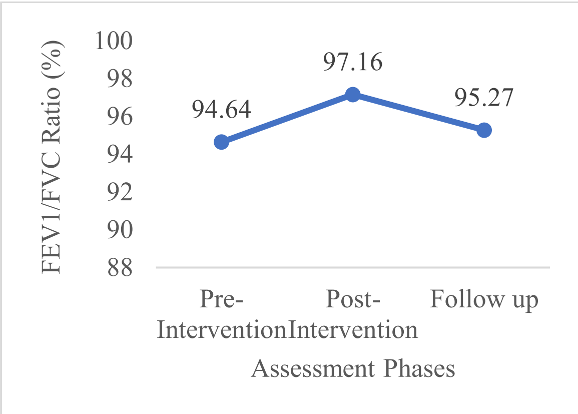
FEV1/FVC showed a consistent pattern of improvement from pre-intervention to post-intervention, with values remaining elevated at the four-week follow-up. All five participants demonstrated higher ratios at post-intervention compared to baseline, and follow-up values remained above or near pre-intervention values, suggesting sustained improvement in expiratory airflow efficiency. Group-level median FEV1/FVC increased from 94.64% (IQR=5.10) at pre-intervention to 98.11% (IQR=2.13) at post-intervention, and remained at

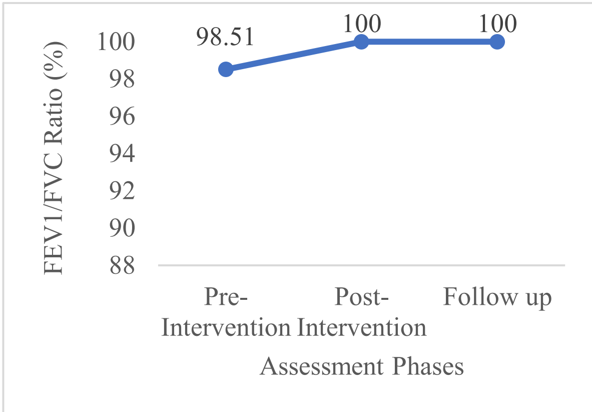
98.28% (IQR=6.03) at follow-up. Although the Friedman test was statistically significant ($\chi^2$ = 8.316, $df = 2$, $p = 0.016$), the pre-post comparison (adjusted $p = 0.022$) narrowly exceeded the Bonferroni-corrected threshold of $p < 0.017$, and therefore did not reach significance. The pre-follow up (adjusted $p = 0.119$) and post-follow up (adjusted $p = 1.000$) comparisons were also non-significant.

The near-significant pre-post improvement in FEV1/FVC ratio suggests that the DBE programme enhanced expiratory airflow efficiency. Chukwu et al. (2025) documented significant FEV1/FVC improvements in vocalists following DBE, and Sedaghati et al. (2023) specifically reported a significant improvement in FEV1/FVC ratio (p=0.003) in elderly adults with a history of COVID-19 following DBE, which confirm that DBE can produce measurable improvements in expiratory airflow efficiency in elderly populations. The failure to reach Bonferroni-corrected significance in the present study is attributable to the inherent ceiling effect of this ratio. As values approach 100%, the scope for further detectable improvement is limited, particularly in a healthy elderly sample without obstructive pathology. P2 achieved ratios of 100% at both post-intervention and follow-up, consistent with the small lung volumes in this participant (height 152 cm, aged 70 years) rather than pathological airflow obstruction. Hamasaki (2020) and Guo et al. (2025) noted that FEV1/FVC improvements following DBE are more likely to achieve statistical significance in populations with demonstrable airflow limitation at baseline. In the context of speech and swallowing, the maintenance of near-normal FEV1/FVC confirms that the expiratory airflow pattern is preserved across the breath cycle, which is relevant to sustaining adequate subglottic pressure for phonation and generating the expiratory flow required for effective voluntary cough and airway clearance during and after swallowing.

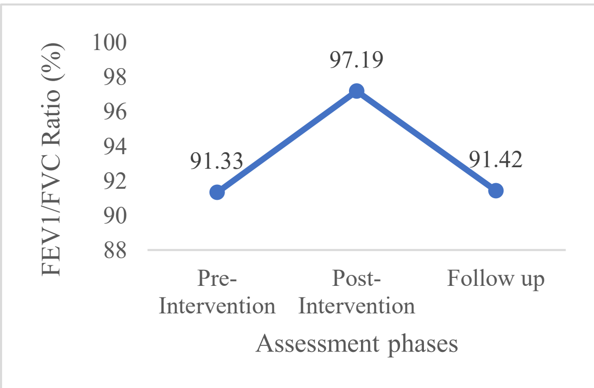
**Figure 4.6**

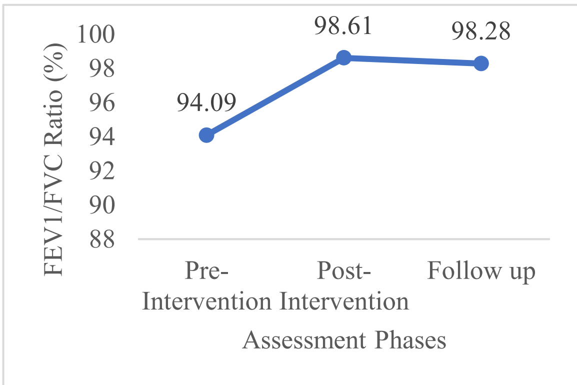
*FEV1/FVC ratio (%) across pre, post and follow up phases for (a) P1, (b) P2, (c) P3, (d) P4, (e) P5*



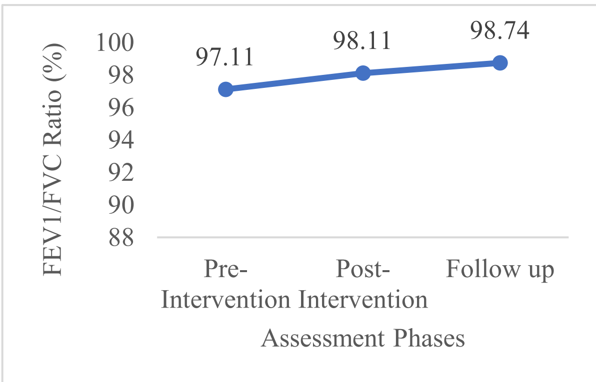




*(a)* *(b)*




*(c)* *(d)*




*(e)*

## 4.2 Objective 2: Comparison of phonatory measures pre-, post-, and four weeks after the intervention in Indian elderly

### 4.2.1 Phonatory measure (s): MPT

MPT values for all participants across the pre-, post-, and four weeks after the intervention phases, with median and IQR are presented in Table 4.3 and represented in Figures 4.7.

**Table 4.3**

*Individual participant values for MPT (s) across assessment phases for all five participants*

| Participant | Pre-Intervention | Post-Intervention | Follow-up |
|---|---|---|---|
| P1 | 12.33 | 17 | 15.6 |
| P2 | 10.44 | 13.9 | 11.83 |
| P3 | 10.8 | 14.6 | 12.74 |
| P4 | 10.2 | 13.81 | 11.7 |
| P5 | 12.34 | 15.72 | 13.62 |
| **Median** | **10.8** | **14.6** | **12.74** |
| **IQR** | **2.02** | **2.5** | **2.84** |

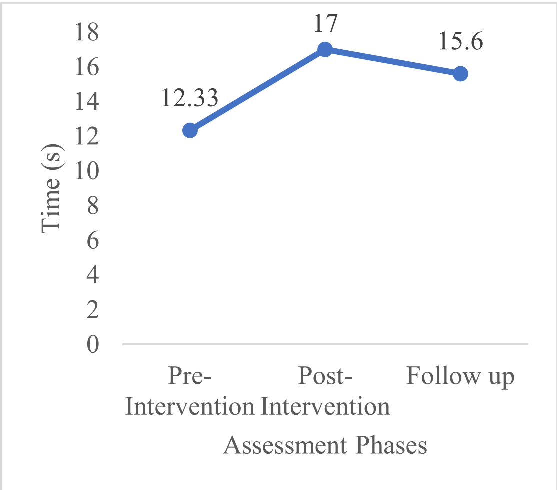
*Note.* MPT = maximum phonation time. Values are reported in seconds (s). IQR = interquartile range.

MPT values demonstrated a consistent pattern of improvement post-intervention across all five participants, with partial maintenance of gains at follow-up. All participants achieved their highest MPT values at post-intervention, and all follow-up values exceeded pre-intervention baseline. Group-level median MPT increased from 10.80 s (IQR=2.02) at pre-intervention to 14.6 s (IQR=2.5) at post-intervention, declining partially to 12.74 s (IQR=2.84) at follow-up, representing a group-level improvement of 35.2% at post-intervention with sustained but reduced gains at follow-up. The Friedman test yielded a statistically significant result ($\chi^2 = 10.000$, $df = 2$, $p = 0.007$). Bonferroni-corrected pairwise comparisons confirmed a significant pre-post difference (adjusted $p = 0.005$), while pre-follow up (adjusted $p = 0.342$) and post-follow up comparisons (adjusted $p = 0.342$) were non-significant.

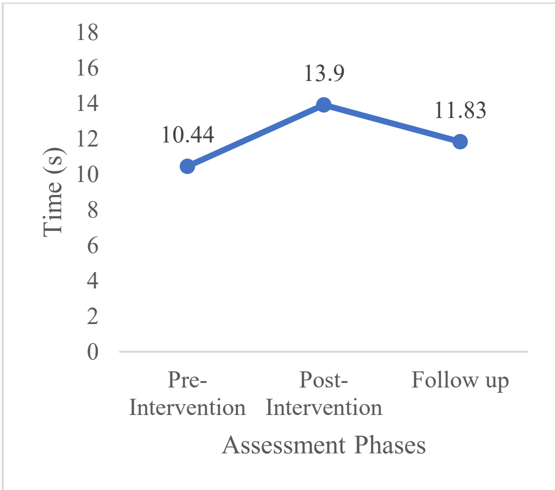
These findings align with the theoretical framework established by Titze and Martin (1998), who demonstrated that MPT is primarily determined by the volume of air available for phonation and the efficiency of its aerodynamic conversion at the laryngeal level, both directly targeted by DBE. The baseline MPT values in the present study (Mdn=10.8 s) are within the lower range reported for healthy elderly populations, consistent with the age-related decline in phonatory endurance documented by Goy et al. (2013). The systematic review and meta-analysis by Saccente-Kennedy et al. (2024) across 23 voice therapy intervention studies for presbyphonia documented a mean posttherapy increase in MPT of 5.37 s ($p < 0.00001$; 95% CI: 3.52–7.22), with treatments targeting organ function including respiratory approaches, yielding the largest mean gains of 7.52 s, providing meta-analytic evidence that MPT is a highly treatment responsive outcome measure in elderly populations. The 3.8 s median gain observed in the present study falls within this range and is clinically meaningful. Prathanee et al. (2025) reported improvements of up to 55% in MPT in community-dwelling elderly adults following respiratory muscle training incorporating diaphragmatic breathing, and Chukwu et al. (2025) documented significant MPT increase in vocalists following DBE that were significantly correlated with improvements in FVC and FEV1. Sawaya et al. (2022) further confirmed that FVC was the only spirometric variable independently associated with MPT in partial correlation and multiple regression analyses in Japanese elderly adults, directly supporting the mechanistic link between the respiratory gains and the MPT improvements observed in the present study. Desjardins and Bonilha (2020), in a systematic review of respiratory exercises and voice outcomes, concluded that integration of diaphragmatic breathing with phonatory and reading tasks produces significantly enhanced breath-phonation coordination, which aligns with the DBE protocol adopted in the present study. The partial return toward baseline at the follow-up without falling below pre-intervention levels suggests that some phonatory-respiratory adaptation was retained beyond the active training period, though continued practice would likely be required to sustain maximal gains.

**Figure 4.7**

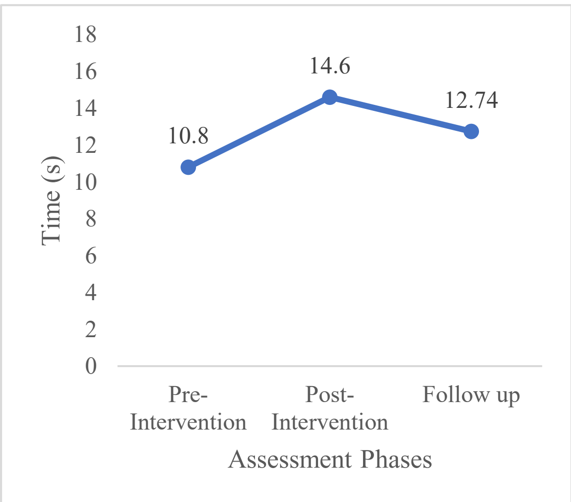
*MPT (s) across pre, post and follow up phases for (a) P1, (b) P2, (c) P3, (d) P4, (e) P5*



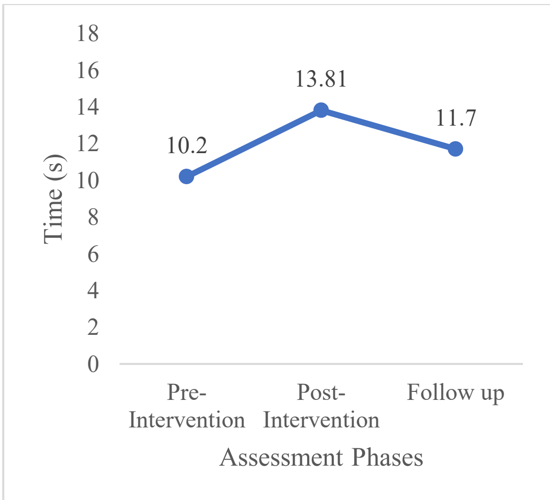

*(a)*



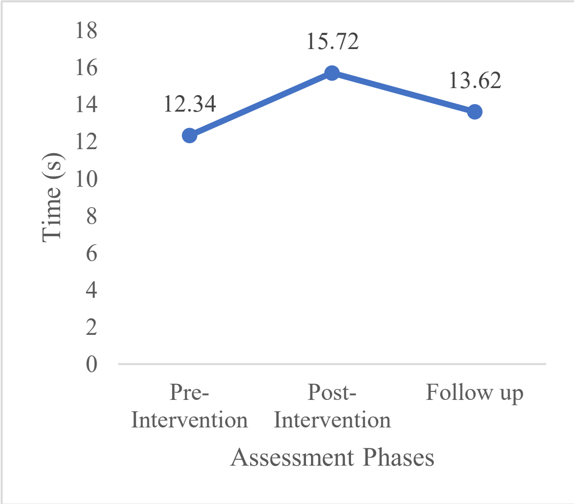

*(b)*




*(c)*




*(d)*




*(e)*

### 4.2.2 Phonatory measure (Hz): F0

F0 values for all participants across the assessment phases, median and IQR are presented in Table 4.4 and Figures 4.8.

**Table 4.4**

*Individual participant values for F0 (Hz) across assessment phases for all five participants*

| Participant | Pre-Intervention | Post-Intervention | Follow-up |
|---|---|---|---|
| P1 | 127 | 131.48 | 130 |
| P2 | 215.6 | 216.37 | 214.15 |
| P3 | 178 | 181.02 | 179.2 |
| P4 | 131 | 132.6 | 131.83 |
| P5 | 122.37 | 124.82 | 123.75 |
| **Median** | **131** | **132.6** | **131.83** |
| **IQR** | **72.12** | **70.55** | **69.8** |

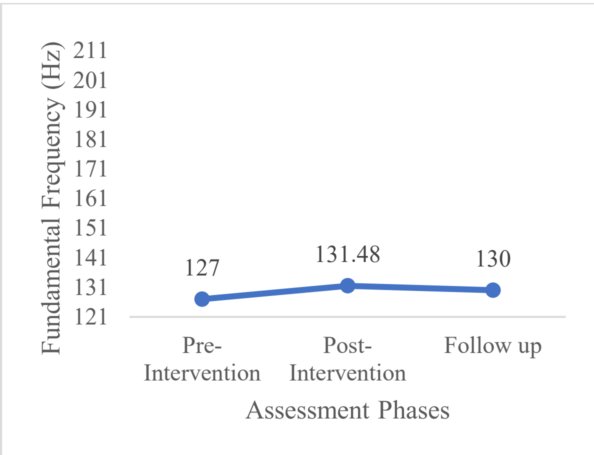
*Note.* F0 = fundamental frequency. Values are reported in hertz (Hz). IQR = interquartile range.

F0 values showed a small but consistent pattern of increase from pre-intervention to post-intervention, with stable retention at follow-up. No participant demonstrated a reduction in F0 at post-intervention relative to baseline, and follow-up values remained at or above post-intervention levels for most participants. Group-level median F0 increased from 131.00 Hz (IQR=72.12) at pre-intervention to 132.60 Hz (IQR=70.55) at post-intervention, with stable retention at 131.83 Hz (IQR=69.80) at follow-up. The wide IQR across all time points reflects the expected gender-based difference in F0, with the two female participants contributing substantially higher values than the three male participants. The Friedman test was statistically significant ($\chi^2 = 8.400$, $df = 2$, $p = 0.015$). Bonferroni-corrected pairwise comparisons revealed significant pre-post difference (adjusted $p = 0.013$). The pre-follow up (adjusted $p = 1.000$) and post-follow up comparisons (adjusted $p = 0.173$) were non-significant.

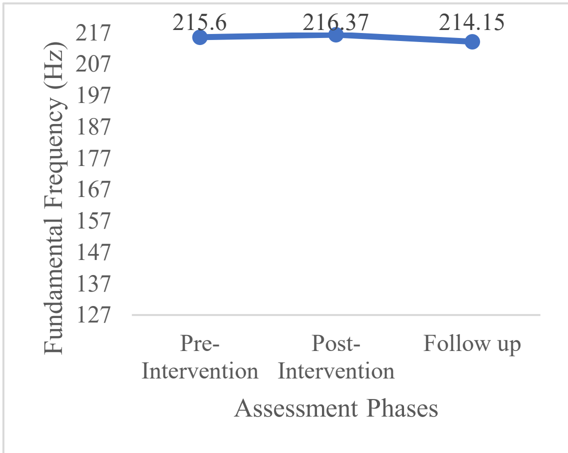
The significant F0 change following DBE is a novel finding, as no prior published study has directly demonstrated F0 changes following DBE in elderly speakers. The baseline F0 values for three male participants (127 Hz, 131 Hz, and 122.37 Hz), are consistent with the expected range of 120-135 Hz for elderly males (Goy et al., 2013). The two female participants demonstrated baseline F0 values of 215.6 Hz and 178 Hz respectively, consistent with the expected post-menopausal female range, with P2's higher value reflecting individual physiological variation within the normal range. The marginal magnitude of the F0 change across both genders is consistent with the understanding that DBE does not structurally alter vocal fold tissue and therefore would not produce substantial absolute shifts in habitual F0. This effect reflects improvement in the stability and consistency of F0 control rather than a fundamental shift in habitual pitch. The observed improvements can be physiologically explained by improved subglottic pressure consistency following respiratory retraining. Titze and Martin (1998) established that subglottic pressure is the primary aerodynamic determinant of vocal fold vibration frequency and periodicity, more consistent expiratory pressure following DBE training would be expected to produce more stable and regular F0 across the utterance. The stable retention of F0 gains at follow-up, in contrast to the partial decline observed in other respiratory and volume measures, may reflect the consolidation of improved respiratory motor patterns into habitual phonatory behaviour. Future studies with larger samples would allow more precise characterisation of the nature of DBE-induced improvements in pitch control.

**Figure 4.8**

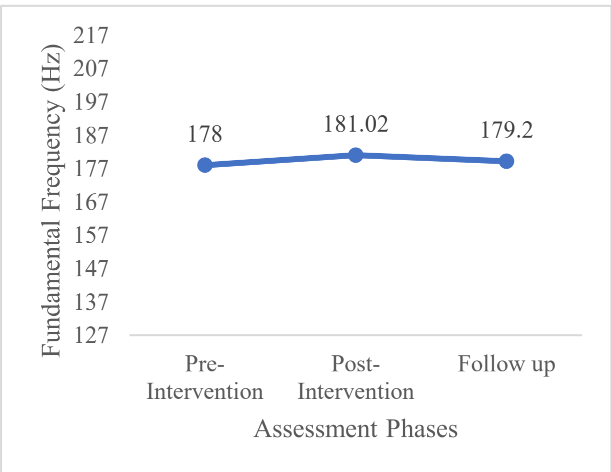
*F0 (Hz) across pre, post and follow up phases for (a) P1, (b) P2, (c) P3, (d) P4, (e) P5*



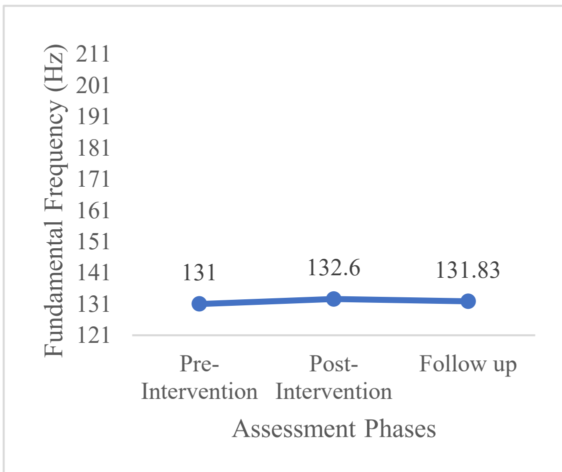

*(a)*



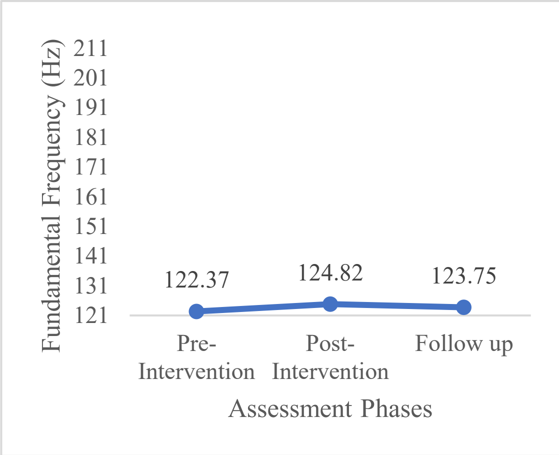

*(b)*




*(c)*




*(d)*




*(e)*

### 4.2.3 Phonatory measure (%): Jitter and Shimmer

Jitter and shimmer values for all participants across the assessment phases, median and IQR are presented in Table 4.5 and Figures 4.9-4.13.

**Table 4.5**

*Individual participant values for perturbation measures (%) across assessment phases for all five participants*

| | Pre-Intervention | | Post-Intervention | | Follow-up | |
|---|---|---|---|---|---|---|
| **Participant** | ***Jitter (%)*** | ***Shimmer (%)*** | ***Jitter (%)*** | ***Shimmer (%)*** | ***Jitter (%)*** | ***Shimmer (%)*** |
| P1 | 0.36 | 4.80 | 0.34 | 4.39 | 0.36 | 4.60 |
| P2 | 0.37 | 3.26 | 0.32 | 2.30 | 0.44 | 3.03 |
| P3 | 0.28 | 2.30 | 0.24 | 1.80 | 0.29 | 2.20 |
| P4 | 0.52 | 4.22 | 0.37 | 2.68 | 0.39 | 3.11 |
| P5 | 0.42 | 4.69 | 0.37 | 3.50 | 0.40 | 3.60 |
| **Median** | **0.37** | **4.22** | **0.34** | **2.68** | **0.39** | **3.11** |
| **IQR** | **0.15** | **1.97** | **0.09** | **1.90** | **0.10** | **1.48** |

Note. Values represent percentage (%). IQR = interquartile range.

Jitter was within or near the normal range across all participants at all time points. At the group level. Group-level median jitter decreased from 0.37% (IQR=0.15) at pre-intervention to 0.34% (IQR=0.09) at post-intervention, followed by a partial return to 0.39% (IQR=0.10) at follow-up. The Friedman test was statistically significant ($\chi^2 = 7.895$, $df = 2$, $p = 0.019$). However, Bonferroni-corrected pairwise comparisons did not yield significance at the adjusted threshold for any pair: pre-post (adjusted $p = 0.053$), pre-follow up (adjusted $p = 1.000$), and post-follow up (adjusted $p = 0.053$). The failure to reach Bonferroni-corrected significance is attributable to the small absolute change in jitter values (0.03 percentage points), the already normal baseline levels, and the statistical stringency of the correction in the context of a small sample. This finding is consistent with the conclusion that jitter, as a measure of cycle-to-cycle frequency perturbation, is less directly responsive to DBE than amplitude related perturbation. Since the primary mechanism through which DBE could reduce perturbation is via improved subglottic pressure consistency, which more directly influences amplitude stability (shimmer) than pitch regularity (jitter). This differential responsiveness is supported by Goy et al. (2013), they found that jitter and shimmer show distinct age-related patterns, with shimmer being more sensitive to changes in respiratory-based vocal support.

Lopes et al. (2024) demonstrated that incentive spirometry produced significant improvements in jitter in vocally healthy women, confirming that respiratory exercises can influence acoustic perturbation through improved aerodynamic support for vocal fold vibration. This suggests that the respiratory-perturbation relationship is observable even in healthy voices, directly paralleling the healthy elderly population in the present study. The systematic review by Saccente-Kennedy et al. (2024) showed the effects of voice therapy interventions in presbyphonia and identified statistically significant reductions in jitter of 0.62% ($p < 0.001$; 95% CI: 0.26%-0.97%) following intervention, providing meta-analytic evidence that targeted treatment addressing the respiratory and phonatory substrates of voice can reduce acoustic perturbation in elderly. Prathanee et al. (2025) further confirmed that jitter improved significantly alongside MPT, shimmer and respiratory parameters following respiratory muscle training incorporating DBE in community dwelling elderly, directly paralleling the present findings. The small but consistent directional reduction in jitter across the majority of participants warrants further investigation in larger samples with extended intervention durations.

Shimmer values showed a consistent pattern of reduction from pre-intervention to post-intervention across all five participants, with all follow-up values remaining below their respective pre-intervention values. This represents the most uniform pattern of improvement among the perturbation measures. Group level median shimmer decreased from 4.22% (IQR=1.97) at pre-intervention to 2.68% (IQR=1.90) at post-intervention, followed by a partial return to 3.11% (IQR=1.48) at follow-up, representing a reduction of 36.5% in median shimmer at post-intervention. The Friedman test was statistically significant ($\chi^2 = 10.000$, $df = 2$, $p = 0.007$). Bonferroni-corrected pairwise comparisons identified a significant pre-post difference (adjusted $p = 0.005$). Pre-follow up (adjusted $p = 0.342$) and post-follow up comparisons (adjusted $p = 0.342$) were non-significant.

The significant reduction in shimmer is consistent with the mechanism proposed by Titze and Martin (1998), where diaphragmatic strength and expiratory pressure improved consistency following DBE and produced more uniform amplitude of vocal fold vibration across successive cycles, reducing cycle-to-cycle amplitude variation. This finding is supported by Desjardins and Bonilha (2020), where they reported in their systematic review that respiratory exercises incorporating breath management improved acoustic voice quality, particularly perturbation measures, in populations with voice-related problems. Similarly, Saccente-Kennedy et al. (2024) documented significant reductions in shimmer of 1.05% ($p < 0.00001$; 95% CI: 0.67%–1.44%) across voice therapy intervention studies for presbyphonia, confirming that shimmer is more responsive to treatment than jitter and is directly improved by interventions that enhance respiratory support and phonatory stability. These findings support the results of present study.

Spazzappan et al. (2024), in a Brazilian Portuguese normative study across lifespan, confirmed that shimmer is specifically sensitive to vocal changes in elderly male speakers, directly supporting the interpretation that the male participants in the present study showed the most clinically meaningful shimmer changes in response to DBE. Baseline shimmer values were at the higher end of the normative range, with all three participants achieving within normal values post-intervention. This highlights the utility of DBE as a preventive phonatory intervention for elderly males at risk of age-related shimmer elevation. Prathanee et al. (2025) confirmed that shimmer improved significantly following DBE in community dwelling elderly, directly paralleling the present findings. The greater responsiveness of shimmer compared to jitter in this study supports the theoretical prediction that shimmer is more directly influenced by aerodynamic support than jitter. The partial return toward baseline at follow-up, while remaining below pre-intervention levels, is consistent with the pattern observed across other measures and suggests that regular continued practice would be necessary to sustain maximal gains in shimmer reduction.

**Figure 4.9**

*Jitter and Shimmer (%) across assessment phases for P1*

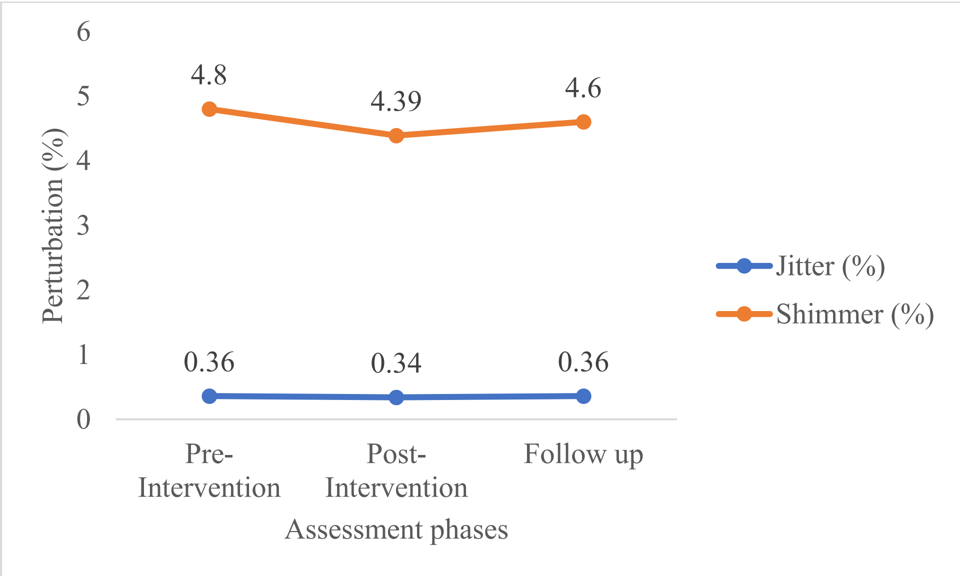



**Figure 4.10**

*Jitter and Shimmer (%) across assessment phases for P2*

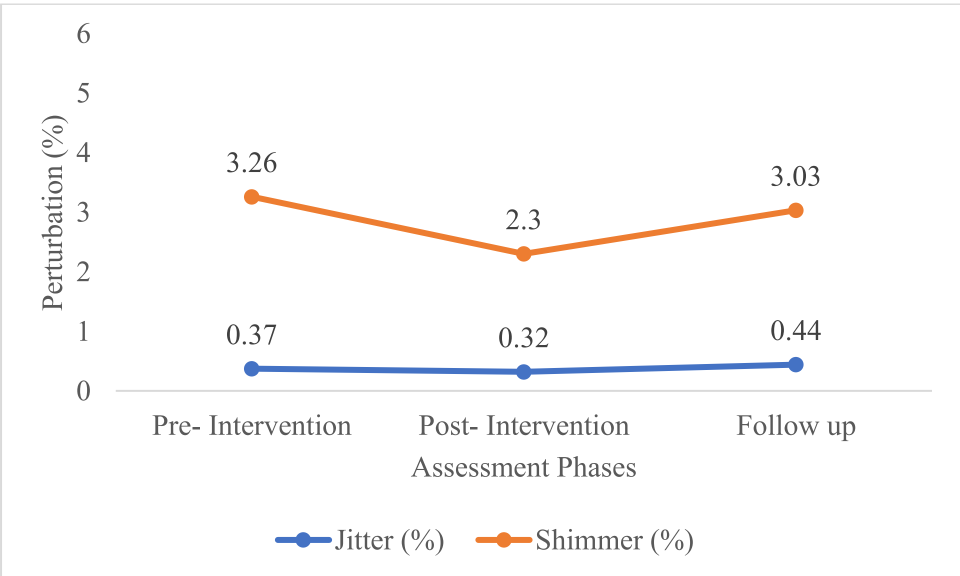


**Figure 4.11**

*Jitter and Shimmer (%) across assessment phases for P3*

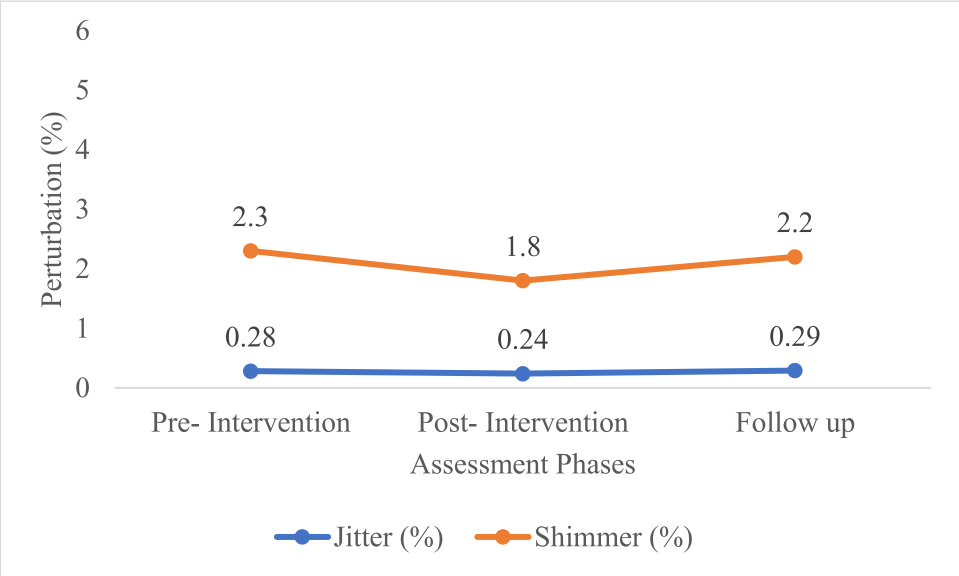



**Figure 4.12**

*Jitter and Shimmer (%) across assessment phases for P4*

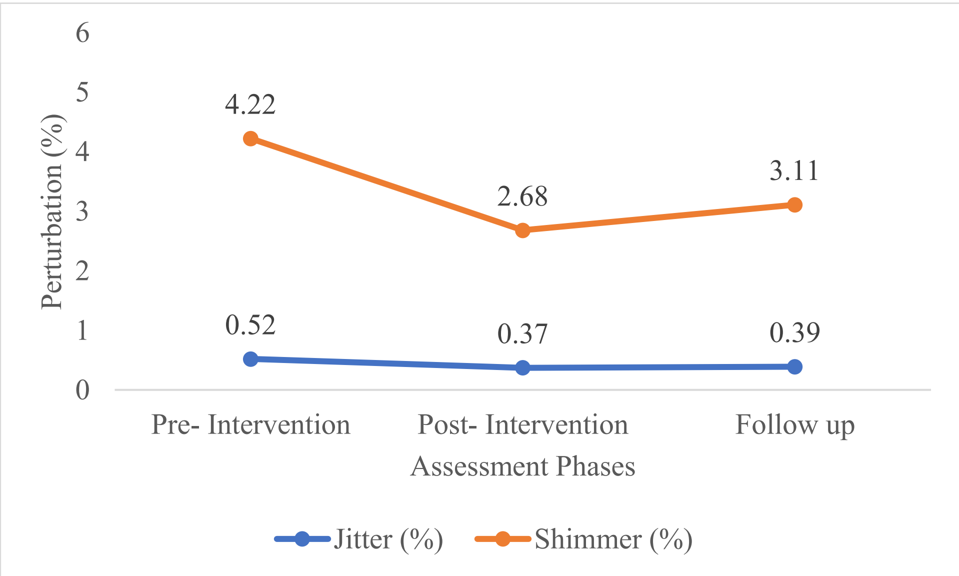
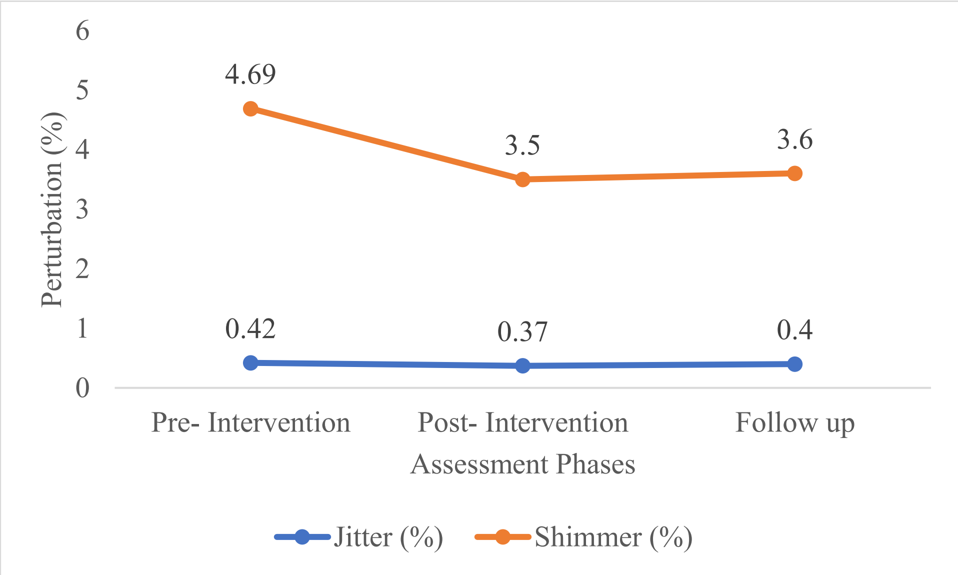


**Figure 4.13**

*Jitter and Shimmer (%) across assessment phases for P5*




### 4.3 Objective 3: Comparison of articulatory measures pre-, post-, and four weeks after the intervention in Indian elderly

#### 4.3.1 Articulatory measures (syllables/s): AMR /pa/, AMR /ta/, AMR /ka/, SMR /pataka/

AMR and SMR values for all participants across the assessment phases, median and IQR are presented in Table 4.6 and Figures 4.14-4.18.

**Table 4.6**

*Individual participant values for DDK (syllables/ s) across assessment phases for all five participants*

| Participant | Pre-Intervention | | | | Post-Intervention | | | | Follow-up | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ***AMR /pa/*** | ***AMR /ta/*** | ***AMR /ka/*** | ***SMR /pataka/*** | ***AMR /pa/*** | ***AMR /ta/*** | ***AMR /ka/*** | ***SMR /pataka/*** | ***AMR /pa/*** | ***AMR /ta/*** | ***AMR /ka/*** | ***SMR /pataka/*** |
| P1 | 6.00 | 5.45 | 4.90 | 3.10 | 6.30 | 5.70 | 5.17 | 3.57 | 6.13 | 5.53 | 5.10 | 3.53 |
| P2 | 5.90 | 5.70 | 5.60 | 2.83 | 6.30 | 6.10 | 5.83 | 3.00 | 6.23 | 6.06 | 5.80 | 2.87 |
| P3 | 5.10 | 4.93 | 5.03 | 2.03 | 5.93 | 5.97 | 5.97 | 2.73 | 5.80 | 5.70 | 5.97 | 2.50 |
| P4 | 6.00 | 5.83 | 5.53 | 2.40 | 6.53 | 6.23 | 5.90 | 3.10 | 6.47 | 6.20 | 5.90 | 3.00 |
| P5 | 5.37 | 5.30 | 4.90 | 2.40 | 5.87 | 5.82 | 5.33 | 2.90 | 5.76 | 5.69 | 5.30 | 2.82 |
| **Median** | **5.90** | **5.45** | **5.03** | **2.40** | **6.30** | **5.97** | **5.83** | **3.00** | **6.13** | **5.70** | **5.80** | **2.87** |
| **IQR** | **0.77** | **0.65** | **0.66** | **0.75** | **0.51** | **0.41** | **0.69** | **0.52** | **0.57** | **0.52** | **0.74** | **0.60** |

*Note.* AMR = alternating motion rate; SMR = sequential motion rate. Values are reported in syllables per second. IQR = interquartile range.

All four DDK measures, AMR for /pa/, /ta/, /ka/, and SMR for /pataka/ showed a consistent pattern of improvement post-intervention across all five participants, with partial to near-complete maintenance of gains at the four week post intervention follow-up. For AMR /pa/, group level median increased from 5.90 syllables/s (IQR=0.77) to 6.30 syllables/s (IQR=0.51), retaining at 6.13 syllables/s (IQR=0.57) at follow-up. AMR /ta/ increased from 5.45 syllables/s (IQR=0.65) to 5.97 syllables/s (IQR=0.41), retaining at 5.70 syllables/s (IQR=0.52) at follow-up. AMR /ka/ increased from 5.03 syllables/s (IQR=0.66) to 5.83 syllables/s (IQR=0.69), with near complete retention at 5.80 syllables/s (IQR=0.74) at follow-up. SMR /pataka/ increased from 2.40 syllable/s (IQR=0.75) to 3.00 syllables/s (IQR=0.52), retaining at 2.87 syllables/s (IQR=0.60) at follow-up. The Friedman test was statistically significant for all four measures (AMR /pa/: $\chi^2 = 10.000$, $p = 0.007$; AMR /ta/: $\chi^2 = 10.000$, $p = 0.007$; AMR /ka/: $\chi^2 = 9.333$, $p = 0.009$; SMR: $\chi^2 = 10.000$, $p = 0.007$), Bonferroni-corrected pairwise comparison confirming significant pre-post difference for all (adjusted p = 0.005, 0.005, 0.013, and 0.005 respectively). Pre-follow up and post-follow up comparisons were non-significant across all measures.

The observed improvements in AMR and SMR following DBE represent a novel finding, as no prior published study has examined DDK rates as an outcome of DBE in any population. The proposed mechanism draws on the relationship between respiratory support and articulatory motor performance documented by Huber and Spruill (2008). They demonstrated that elderly speakers show significantly altered respiratory patterns during speech, with reduced flexibility in adapting breath group durations. By improving FVC, $FEV_1$, and TV, DBE extended the available expiratory breath support underlying DDK tasks, enabling longer breath groups and more efficient articulatory motor control. The novelty of this finding is underscored by the comprehensive scoping review of Kent et al. (2022), which synthesized DDK normative data across 360 studies over the lifespan and documented age-related declines in AMR and SMR rates, confirming the clinical significance of any intervention that reverses this trajectory. This biomechanical rationale is further supported by Shetty et al. (2020), who documented that DBE produced significant improvements in maximal inspiratory pressure in Indian stroke patients. Maximal inspiratory pressure determines the lung volume onset at the onset of each DDK breath group, directly regulating the duration and consistency of expiratory support available for rapid syllable repetition. Baseline AMR values in the present study (median 5.03-5.90 syllable/s) are consistent with Indian normative data reported by John et al. (2014), who found DDK rates of approximately 4.86-5.52 syllable/s for Kannada-speaking elderly males, supporting the clinical validity of the study's baseline values. SMR showed parallel improvements to AMR, confirming that sequential motor sequencing of /pataka/ benefits from the same improved respiratory substrate as alternating tasks. The stronger retention of AMR /ka/ gains at follow-up compared to /pa/ and /ta/ may reflect greater sensitivity of the velar closure gesture to improved respiratory support. The present study provides the first evidence that DBE produces measurable DDK improvements in community-dwelling Indian elderly, warranting further investigation.

**Figure 4.14**

*Articulatory measures (AMR /pa/, AMR /ta/, AMR /ka/, SMR /pataka/ in syllables/s) across assessment phases for P1*

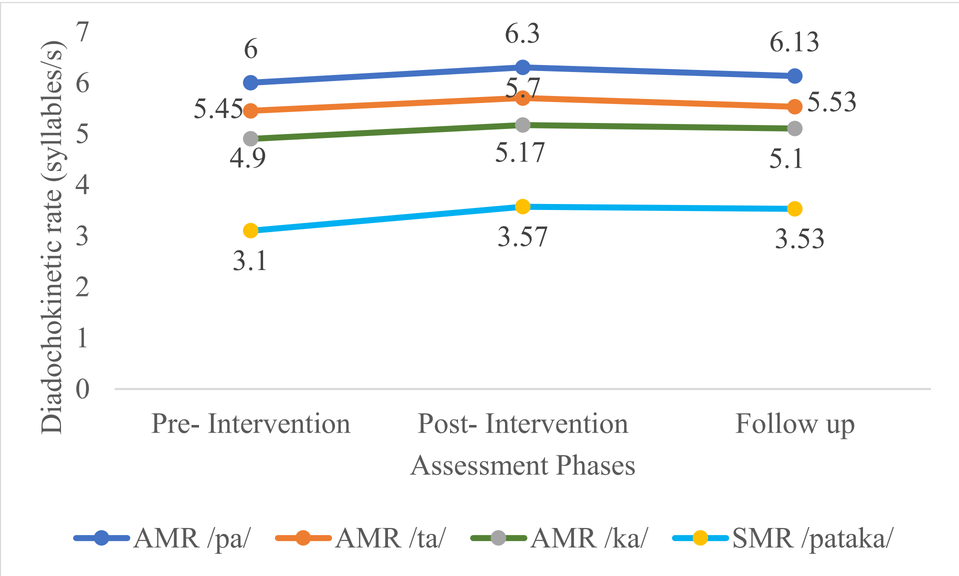



**Figure 4.15**

*Articulatory measures (AMR /pa/, AMR /ta/, AMR /ka/, SMR /pataka/ in syllables/s) across assessment phases for P2*

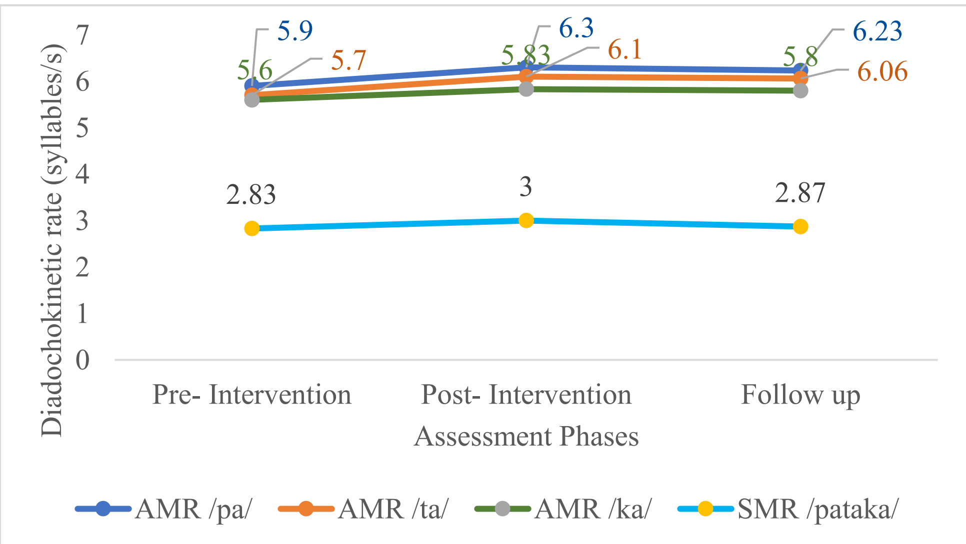


**Figure 5.16**

*Articulatory measures (AMR /pa/, AMR /ta/, AMR /ka/, SMR /pataka/ in syllables/s) across assessment phases for P3*

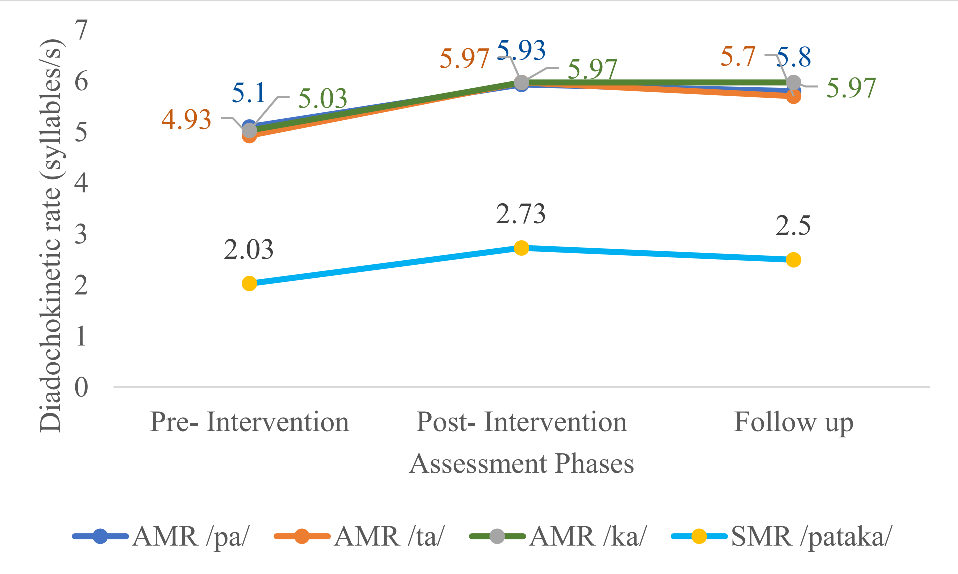



**Figure 4.17**

*Articulatory measures (AMR /pa/, AMR /ta/, AMR /ka/, SMR /pataka/ in syllables/s) across assessment phases for P4*

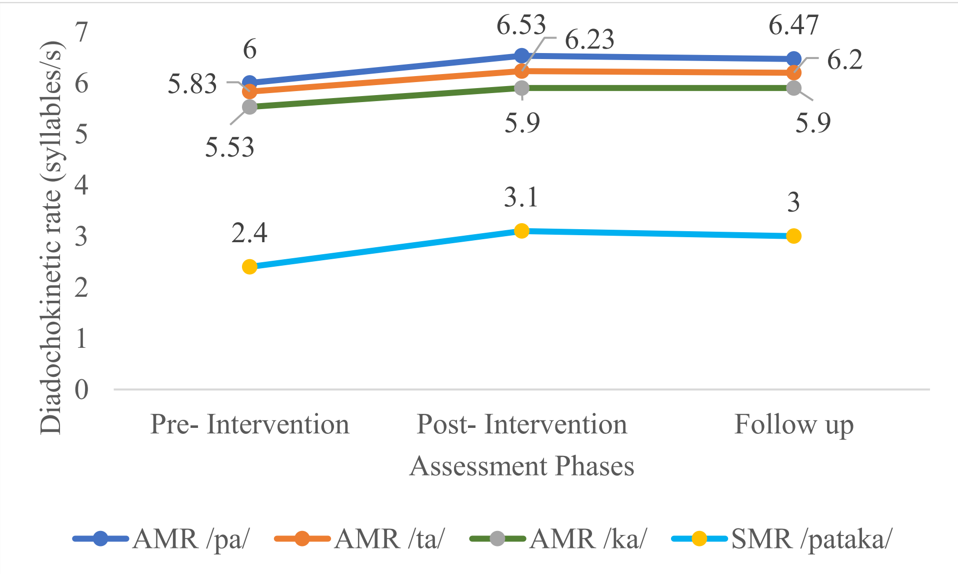
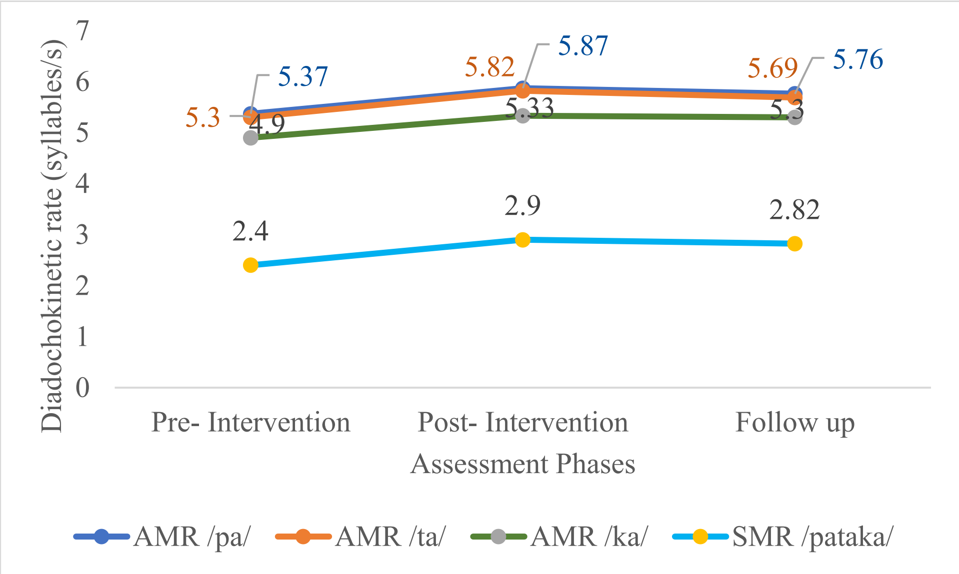


**Figure 4.18**

*Articulatory measures (AMR /pa/, AMR /ta/, AMR /ka/, SMR /pataka/ in syllables/s) across assessment phases for P5*




**4.3.2 Articulatory measure (words/minute): speech rate**

Speech rate, measured in words per minute (WPM), reflects the overall speed of connected speech production and is influenced by both articulatory proficiency and respiratory-phonatory support. Values for all participants across the assessment phases, median and IQR are presented in Table 4.7 and Figure 4.19.

**Table 4.7**

*Individual participant values for speech rate (WPM) across assessment phases for all five participants*

| Participant | Pre-Intervention | Post-Intervention | Follow-up |
|---|---|---|---|
| P1 | 66 | 73.33 | 73.33 |
| P2 | 86.15 | 98.82 | 97.28 |
| P3 | 86.15 | 101.82 | 93.59 |
| P4 | 81.95 | 105 | 101.82 |
| P5 | 82.56 | 98.26 | 94.43 |
| **Median** | **82.56** | **98.82** | **94.43** |
| **IQR** | **12.18** | **17.61** | **16.09** |

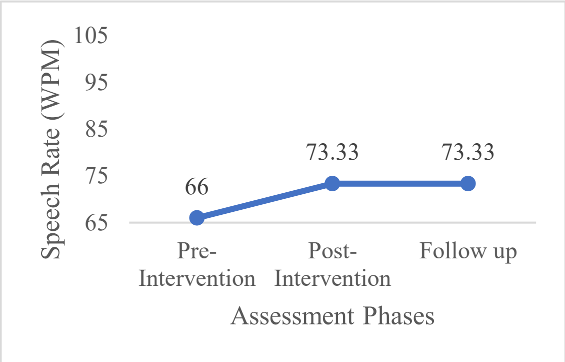
*Note.* WPM = words per minute. IQR = interquartile range.

Speech rate showed a consistent pattern of increase post-intervention across all five participants with generally strong retention at the four-week follow-up. All participants demonstrated higher speech rates post-intervention compared to baseline, and all follow-up values remained above their pre-intervention values, indicating durable improvement. Group level median speech rate increased from 82.56 WPM (IQR=12.18) to 98.82 WPM (IQR=17.61) at post-intervention, followed by partial maintenance at 94.43 WPM (IQR=16.09) at follow-up. The Friedman test was statistically significant ($\chi^2$ = 9.579, *df* = 2, *p* = 0.008). Bonferroni-corrected pairwise comparisons revealed a significant pre-post difference (adjusted *p* = 0.008). Pre-follow up (adjusted *p* = 0.245) and post-follow up comparisons (adjusted *p* = 0.618) were non-significant.

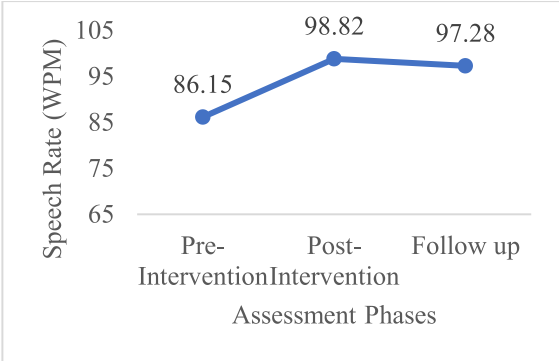
The improvement in speech rate is consistent with the theoretical framework proposed by Huber and Spruill (2008). They described how reduced respiratory capacity in the elderly constrains the length and continuity of breath groups during connected speech, resulting in more frequent pauses and a slower overall rate. Improved TV and FVC following DBE provide greater breath support for sustained speech production. This enables longer utterances per breath and a more efficient connected speech rate. Prathanee et al. (2025) also documented a 41% improvement in maximum counting duration in community dwelling elderly following respiratory muscle training incorporating DBE, providing the most directly relevant evidence that respiratory gains generalise to functional connected speech production in target population. The markedly lower baseline speech rate of P1 (66.00 WPM compared to 81-86 WPM for other participants), combined with the smallest absolute improvement, suggests individual differences in habitual speech rate and articulatory pattern that may moderate response magnitude. The strong retention of speech rate gains at follow-up (Mdn = 94.43 WPM) compared to the more modest retention seen for some respiratory measures reflect the consolidation of improved breathing for speech patterns as a habitual motor behavior, consistent with the principle that motor learning transfer to functional tasks may outlast the underlying physiological gains that initially enabled it.

**Figure 4.19**

*Speech rate (words/minute) across pre, post and follow up phases for (a) P, (b) P2, (c) P3, (d) P4, (e) P5*




*(a)*

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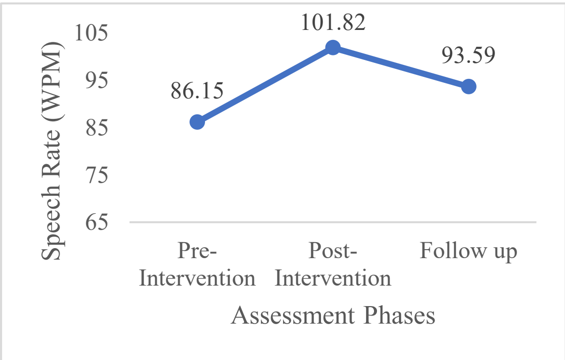


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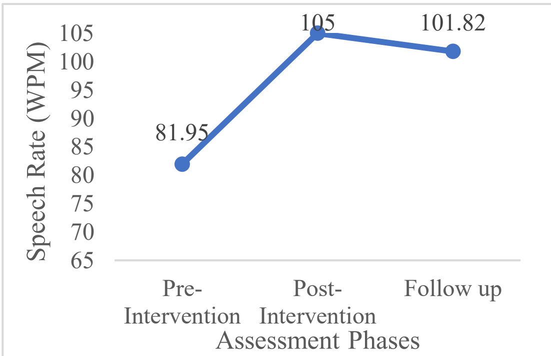


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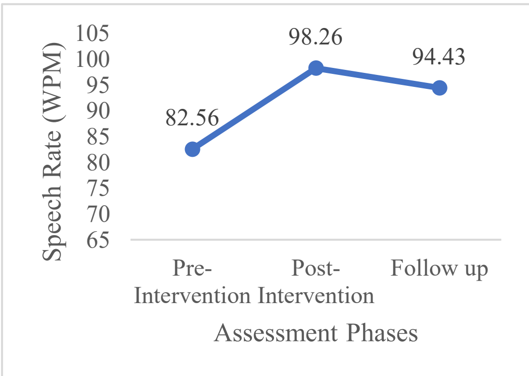



*(e)*

### 4.3.3 Articulatory measure: speech intelligibility

All five participants scored 0 across all three time points on the AYJNIHH intelligibility scale, indicating fully intelligible speech at baseline and across all assessment phases. This ceiling effect is consistent with the inclusion criteria of community-dwelling elderly individuals without speech pathology. As there was no variability in this measure, inferential statistical analysis was not applicable.

While the absence of change in this measure may appear unremarkable, it confirms that the present participants did not present with clinically overt intelligibility deficits at any point during the study, validating the preventive intervention orientation. While fully preserved it does not reflect the subclinical respiratory and articulatory changes measurable through more sensitive acoustic and kinematic indices, which were captured through AMR, SMR, speech rate, and phonatory measures. Future investigations may consider employing more sensitive intelligibility measures such as speech in noise tasks or connected speech ratings at degraded listening conditions to detect subtle functional improvements in this populations, where floor effects are expected on conventional intelligibility scales.

## 4.4 Objective 4: Comparison of swallowing measures pre-, post-, and four weeks after the intervention in Indian elderly

### 4.4.1 Swallowing measure: SASQ-IE

All five participants scored 0 on the SASQ-IE across all assessment time points, indicating complete absence of self-reported swallowing difficulties at all three phases. This finding is consistent with the inclusion of community dwelling healthy elderly without overt swallowing complaints, confirming the study population as representative of a presbyphagia risk group rather than a clinically dysphagic group. The uniformly zero SASQ-IE scores precluded inferential analysis and reflect the preventive orientation of the present study.

While no treatment induced change was detectable on this measure, the uniformly zero scores serve an important confirmatory function, that is, they establish that the objective improvements observed in PEFR and RSST occurred in the absence of any self-perceived symptoms. This is consistent with the observation by Cai et al. (2024) that presbyphagia exists as a functional continuum wherein objective swallowing changes are often present well before they cross the threshold of subjective awareness. The SASQ-IE, as a recently developed and validated Indian-specific instrument (Mohandas, 2023), may demonstrate greater responsiveness as an outcome measure in future studies that recruit elderly participants with mild, self-reported swallowing concerns.

### 4.4.2 Swallowing measure: SCSS

SCSS values for all participants across the assessment phases, median and IQR are presented in Table 4.8 and Figures 4.20.

**Table 4.8**

*Individual participant values for SCSS score across assessment phases for all five participants*

| Participant | Pre-Intervention | Post-Intervention | Follow-up |
|---|---|---|---|
| P1 | 4 | 5 | 5 |
| P2 | 3 | 5 | 5 |
| P3 | 3 | 5 | 5 |
| P4 | 3 | 5 | 5 |
| P5 | 4 | 5 | 5 |
| **Median** | **3** | **5** | **5** |

| | | | |
|---|---|---|---|
| **IQR** | **1** | **0** | **0** |

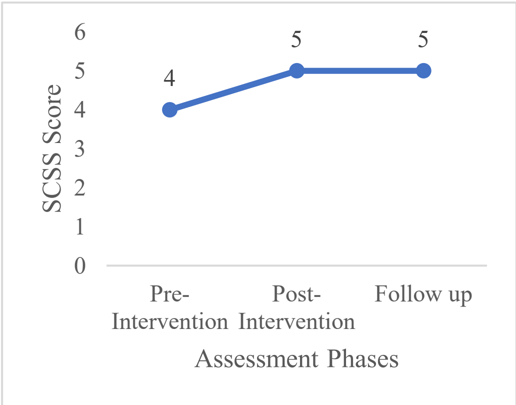
*Note.* SCSS = Semiquantitative Cough Strength Score. Scores are ordinal (0-5 scale); higher scores indicate better cough strength. IQR = interquartile range.

SCSS scores demonstrated a consistent pattern of post-intervention improvement across participants, with all follow-up values maintained at post-intervention levels. All participants achieved the ceiling score of 5 at post-intervention and maintained this score at the four-week follow-up, indicating durable improvement in voluntary cough. Group level median SCSS increased from 3 (IQR=1.00) at pre-intervention to 5 (IQR=0.00) at post-intervention, with the ceiling score maintained at follow-up (Mdn=5, IQR=0.00). The Friedman test was statistically significant ($\chi^2 = 10.000$, $df = 2$, $p = 0.007$). However, Bonferroni-corrected pairwise comparisons did not reach the adjusted significance threshold for any pair due to the ceiling effect: pre-post (adjusted $p$ = 0.053), pre-follow up (adjusted $p$ = 0.053), and post-follow up (adjusted $p$ = 1.000). The clinical significance remains considerable as reflected by the simultaneous highly significant cough PEFR improvement which is directly supported by the evidence on respiratory training and cough function.

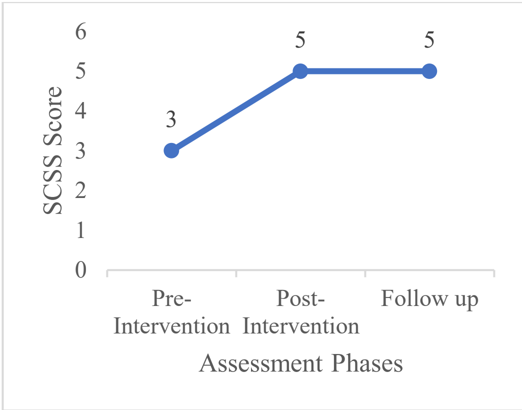
Kaneko et al. (2022)'s RCT of 53 elderly adults without airflow limitations, demonstrated that targeted cough and respiratory training produced significant increase in cough peak flow, confirming that respiratory training in healthy elderly without respiratory disease can meaningfully strengthen cough. The SCSS ceiling attainment at post-intervention and its full maintenance at follow-up, unlike the partial return observed for most other measures suggests that cough strength improvements may be among the most durable effects of DBE, likely because the expiratory muscular hypertrophy underlying improved cough is a structural adaptation that persists beyond the cessation of active training.

**Figure 4.20**

*SCSS score across pre, post and follow up phases for (a) P, (b) P2, (c) P3, (d) P4, (e) P5*




*(a)*

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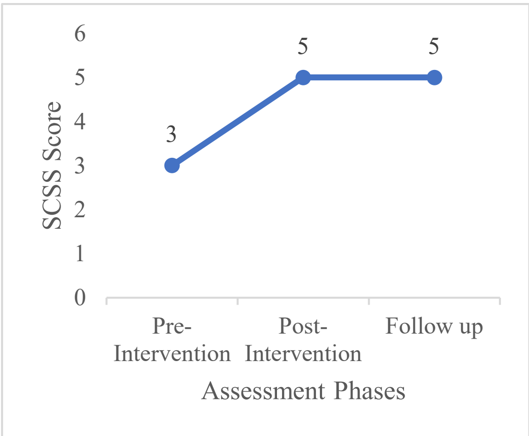


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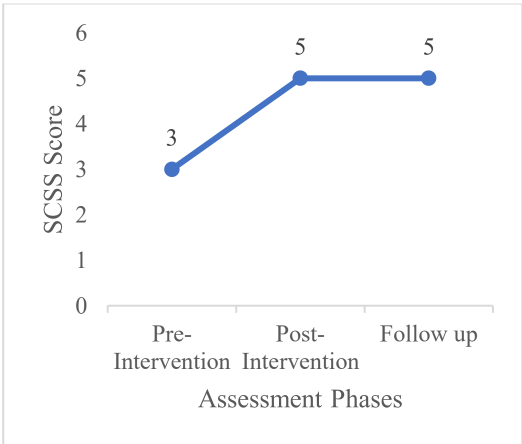


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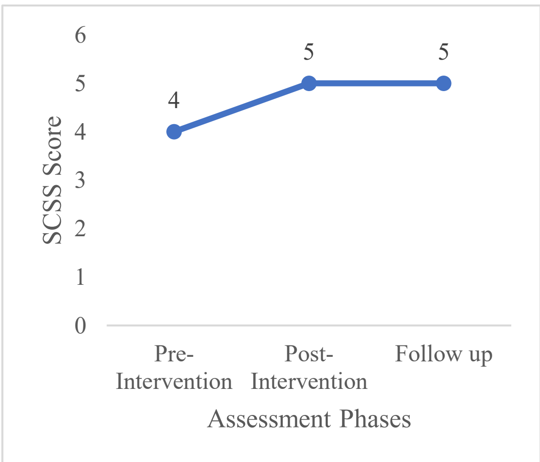



*(e)*

### 4.4.3 Swallowing measure (L/s): PEFR

Peak Expiratory Flow Rate (PEFR) during cough provides an objective measure of cough strength and airway protective function, both of which are relevant to safe swallowing. Values for all participants across the assessment phases, median and IQR are presented in Table 4.9 and Figure 4.21.

**Table 4.9**

*Individual participant values for PEFR (L/s) across assessment phases for all five participants*

| Participant | Pre-Intervention | Post-Intervention | Follow-up |
|---|---|---|---|
| P1 | 2.34 | 2.94 | 2.8 |
| P2 | 3.54 | 4.25 | 3.57 |
| P3 | 2.97 | 3.59 | 3.5 |
| P4 | 4.35 | 6.71 | 6.12 |
| P5 | 3.74 | 4.8 | 4.4 |
| **Median** | **3.54** | **4.25** | **3.57** |
| **IQR** | **1.39** | **2.49** | **2.11** |

*Note.* PEFR = peak expiratory flow rate. Values are reported in litres per second (L/s). IQR = interquartile range.

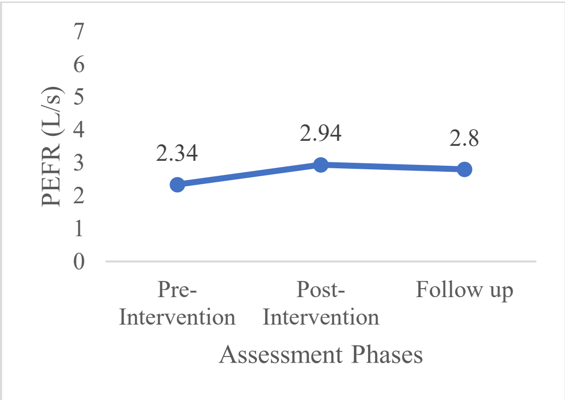
PEFR as an objective index of cough strength demonstrated consistent improvement post-intervention across participants. At follow-up, majority of participants retained values above their pre-intervention baseline, though P2 returned near to pre-intervention levels. Group level median PEFR increased from 3.54 L/s (IQR=1.39) at pre-intervention to 4.25 L/s (IQR=2.49) at post-intervention, followed by partial maintenance at 3.57 L/s (IQR=2.11) at follow-up. The Friedman test was statistically significant ($\chi^2$ = 10.000, $df$ = 2, $p$ = 0.007).

Bonferroni-corrected pairwise revealed a significant pre-post difference (adjusted $p = 0.005$). Pre-follow up (adjusted $p = 0.342$) and post-follow up comparisons (adjusted $p = 0.342$) were non-significant.

These findings align with of the study by Shirodkar and Deo (2024) where they reported significant improvements in PEFR following DBE in Indian patients with COPD, and with Hamasaki (2020)'s study that identified PEFR improvement as a consistent physiological outcome of DBE through strengthening of the diaphragm and accessory expiratory musculature. Shetty et al. (2020) documented a 33.16% improvement in PEFR in stoke patients who have undergone DBE in Karnataka. Kaneko et al. (2022) in their RCT in healthy elderly without airflow limitations, documented significant improvements in cough peak flow following respiratory training. Maki et al. (2018) also documented similar improvements in peak cough flow in frail elderly following respiratory rehabilitation. Smina et al. (2003) reported that values above 160 L/min or 2.67 L/s is considered as the minimum for effective cough based airway clearance. From a swallowing safety perspective, the improvement in PEFR is clinically significant as it reflects enhanced ability to clear material from the supraglottic and glottic regions during and following deglutition, thereby reducing aspiration risk. The improvement in PEFR, occurring simultaneously with significant RSST gains and the uniform ceiling attainment, provides convergent evidence that DBE strengthened the expiratory musculature sufficiently to improve airway protection capacity across all three swallowing safety measures.

**Figure 4.21**

*PEFR (L/s) across pre, post and follow up phases for (a) P, (b) P2, (c) P3, (d) P4, (e) P5*

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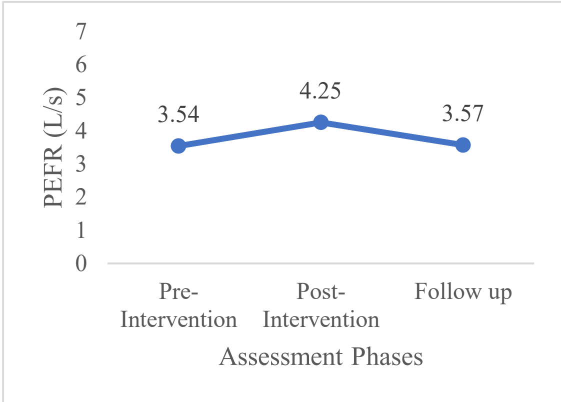


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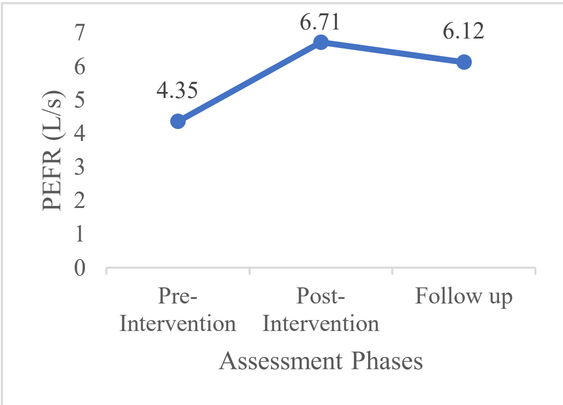


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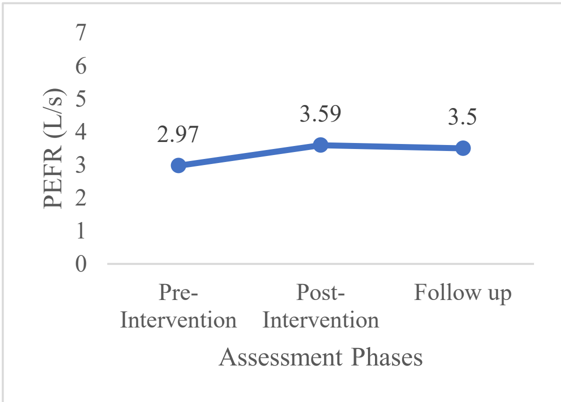


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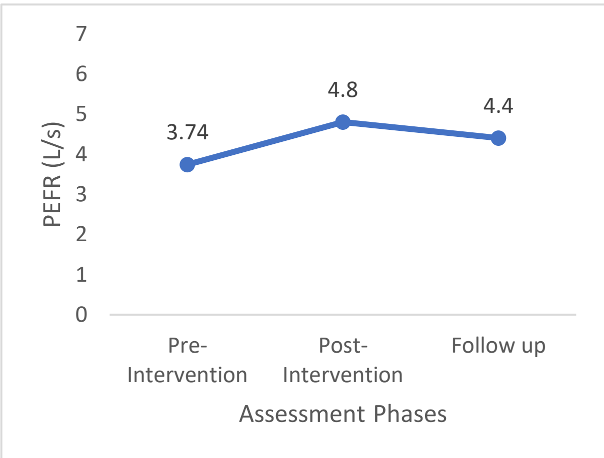


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### 4.4.4 Swallowing measure (swallows/30 s): RSST

The Repetitive Saliva Swallowing Test (RSST) is a clinical measure of swallowing frequency, wherein the number of dry swallows completed within 30 seconds reflects swallowing motor function and capacity. Values for all participants across the assessment phases are presented in Table 4.10 and Figures 4.22.

**Table 4.10**

*Individual participant values for RSST score across assessment phases for all five participants*

| Participant | Pre-Intervention | Post-Intervention | Follow-up |
|---|---|---|---|
| P1 | 6 | 8 | 7 |
| P2 | 4 | 7 | 5 |
| P3 | 5 | 6 | 6 |
| P4 | 6 | 8 | 7 |
| P5 | 6 | 8 | 8 |
| **Median** | **6** | **8** | **7** |
| **IQR** | **2** | **2** | **2** |

*Note.* RSST = Repetitive Saliva Swallowing Test. Scores reflect the number of swallows completed in 30 seconds; higher scores indicate better swallowing function. Scores are ordinal. IQR = interquartile range

RSST values showed consistent improvement post-intervention across all participants, with partial to complete maintenance at the four-week follow-up. All participants demonstrated higher RSST values post-intervention compared to baseline, and all follow-up values remained near or above pre-intervention baseline. Group level median RSST increased from 6 swallows/30 s (IQR=2.00) at pre-intervention to 8 swallows/30 s (IQR=2.00) at post-intervention, with partial maintenance at 7 swallows/30 s (IQR=2.00) at follow-up. The

Friedman test was statistically significant ($\chi^2 = 9.333$, $df = 2$, $p = 0.009$). Bonferroni-corrected pairwise comparisons revealed a significant pre-post difference (adjusted $p = 0.013$). Pre-follow up (adjusted $p = 0.173$) and post-follow up comparisons (adjusted $p = 1.000$) were non-significant.

All baseline RSST values (range: 4-6 swallows) exceeded the clinical threshold of ≥3 swallows established by Oguchi et al. (2000) as the criterion for normal swallow function, confirming that participants did not present with clinically significant swallowing impairment at baseline.

This finding is novel in the present study, as no prior published investigation has directly reported RSST improvements following DBE. The proposed mechanism draws on the evidence base established by Wang et al. (2015), they found that elderly individuals initiated swallowing at lower lung volumes than younger adults, with delayed swallow reflex onset and reduced laryngeal closure efficiency, all attributable to reduced respiratory muscle capacity. DBE is proposed to restore more optimal lung volumes at the initiation of swallowing, improving the efficiency of respiratory-swallowing coordination. Martin-Harris et al. (2008) documented the importance of expiration-swallow-expiration pattern in maintaining airway protection, and the disruption of this pattern in those with reduced expiratory capacity. The systematic reviews by Dai et al. (2024) and Su et al. (2025) provided meta-analytic evidence that respiratory training broadly improves swallowing function and reduces aspiration risk in elderly populations with dysphagia; the present study extends this finding to healthy community dwelling elderly using DBE specifically.

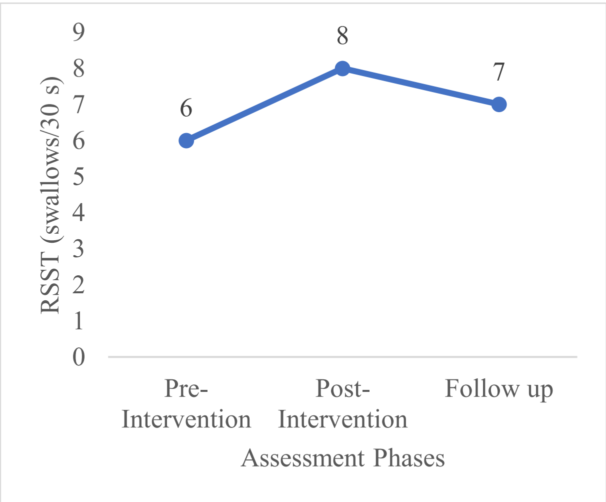
The meta-analytic evidence of Dai et al. (2024) warrants specific consideration. Across six RCTs, respiratory training produced a large effect on post-swallow pharyngeal residue (standardised mean difference SMD ≈ -1.67), a moderate effect on the Penetration-Aspiration

Scale (PAS; SMD ≈ 0.69), and a clinically meaningful improvement on the Functional Dysphagia Scale (FDS; mean difference ≈ -3.15) compared to controls. These large effect sizes, derived from populations with established dysphagia, provide the strongest available evidence base for hypothesising that DBE-induced improvements in expiratory force as observed in the present study through cough PEFR and RSST may contribute to improved swallowing safety and efficiency when applied to a higher-risk dysphagic elderly population.

Ben-Hayoun et al. (2024) reported that male had higher RSST score than females ($7.6 \pm 3.04$ compared to $6.47 \pm 2.56$, $p = 0.001$) which aligns with the present study findings. The partial return toward baseline at follow-up (pre-follow up: adjusted $p = 0.173$) is consistent with the pattern observed across other measures and suggests that regular continued practice would be necessary to sustain improvements beyond the active training period.

**Figure 4.22**

*RSST (swallow/30 s) across pre, post and follow up phases for (a) P, (b) P2, (c) P3, (d) P4, (e) P5*

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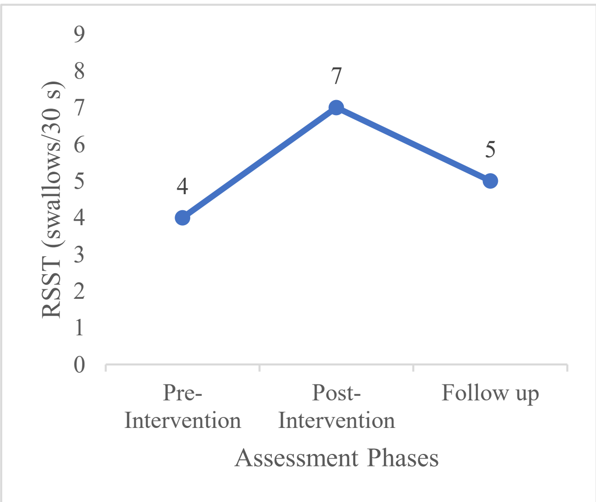


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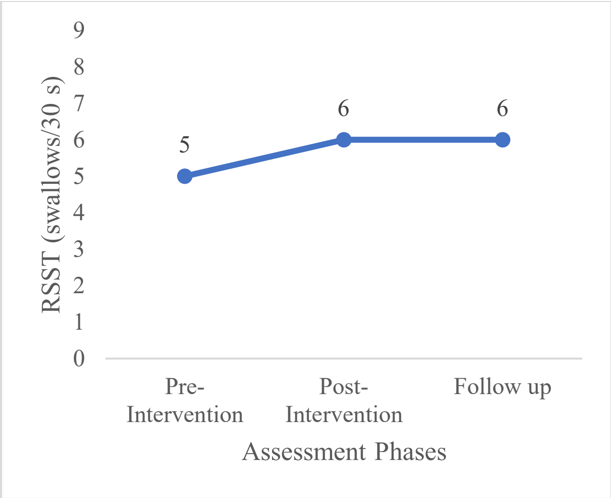


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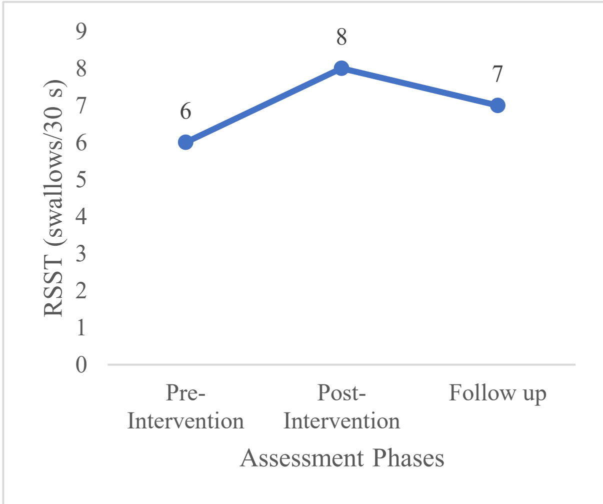


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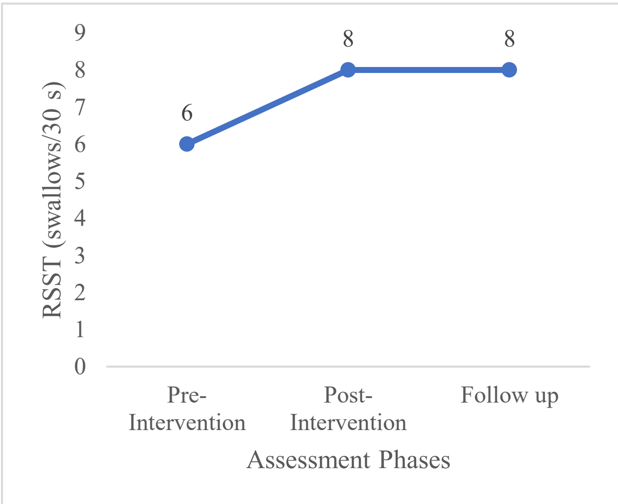


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### 4.5 Intra-rater reliability

To assess intra-rater reliability, the primary rater (investigator) re-scored a randomly selected 40% of the data sample (n=2 participants; P2 and P4) across all three assessment phases, on two separate sessions (Trial 1: R1T1; Trial 2: R1T2), with two weeks apart between the scoring sessions. Intra-rater reliability was evaluated for the articulatory measures: AMR /pa/, AMR /ta/, AMR /ka/, SMR /pataka/, and speech rate. Speech intelligibility scores were not included in the reliability analysis as all participants scored 0 across all time points.

Investigator's judgements appeared highly consistent across both trials. For AMR, /pa/, AMR /ta/, and AMR /ka/, the values assigned in Trial 1 and Trial 2 were closely aligned across both participants and all three time points, with minimal discrepancy observed between sessions. SMR /pataka/ scores similarly showed close correspondence across trials. Speech rate values also demonstrated high consistency between the two trials. Therefore, the pattern of scores across both trials suggests stability in the scoring of the articulatory and speech rate measures across a two-week interval.

**4.6 Inter-rater reliability**

For inter-rater reliability, two additional speech-language pathologists (Rater 1 and Rater 2) independently scored the same randomly selected 40% subsample (P2 and P4) across all three phases and the same five measures. Neither Rater 1 nor Rater 2 had prior access to the scores assigned by the Rater 1 or to each other's ratings.

The scores provided by Rater 1 and Rater 2 were largely congruent with those of investigator. Minor score differences were observed for a small number of data points, particularly for SMR /pataka/ and speech rate,which are more sensitive to subtle differences in timing identification. However, these differences were small in magnitude and did not appear to reflect systematic disagreement. The directional patterns of change across assessment phases that is, improvements from pre-intervention to post-intervention and partial retention at follow-up were consistently captured by all three raters. This suggests that the observer-rated measures employed in this study were reliably scored across the raters.

# CHAPTER V

## SUMMARY AND CONCLUSIONS

The present study examined the effects of a structured four-week DBE programme on speech and swallow functions in community-dwelling Indian elderly individuals. Age-related decline across the respiratory, phonatory, articulatory, and swallowing subsystems collectively described as presbyphonia and presbyphagia is prevalent in the elderly population, yet evidence-based preventive interventions targeting all four functional domains simultaneously in healthy elderly individuals within the Indian context remain absent. To address this gap, a single-group ABA repeated measures design was employed with five community dwelling elderly individuals aged between 62 and 70 years from Mysore were assessed at pre-intervention, post-intervention, and four-week follow-up. The twelve session DBE delivered over four weeks through a hybrid in-person and Zoom video-conferencing mode, comprised of (i) diaphragmatic breathing with expansion and contraction, (ii) diaphragmatic breathing with sustained phonation, and (iii) diaphragmatic breathing with a reading task.

Seventeen outcome measures of respiratory, phonatory, articulatory, and swallowing domains were analysed using Friedman test with Bonferroni-corrected pairwise comparisons. The DBE programme showed improvements with gains in lung volumes and airflow measures, reflecting enhanced diaphragmatic strength and respiratory muscle efficiency following training. Phonatory function also improved, with increased MPT and better voice quality, indicating stronger respiratory-phonatory coordination and more consistent subglottic pressure. Articulatory function showed gains in DDK rates and speech rate, suggesting that improved respiratory support positively influenced oromotor speed and regularity. Swallowing safety improved as evidenced by higher PEFR and RSST scores, reflecting better airway protection and swallowing frequency; self-reported swallowing difficulty and clinical swallowing scores remained at optimal levels throughout, consistent with the healthy profile of the sample. Across all domains, gains were most pronounced immediately post-intervention, with partial maintenance at the four-week follow-up.

Respiratory function was assessed using SPIRO FLO SF100 spirometer (FVC, FEV1, FEV1/FVC ratio, SVC, TV). Phonatory function was assessed using PRAAT acoustic analysis software version 6.4.25 (MPT, F0, jitter, shimmer). Articulatory function was assessed through verbal DDK (AMR for /pa/, /ta/, /ka/; SMR for /pataka/), speech rate in WPM, and speech intelligibility using AYJNIHH scale. Swallowing function was assessed using SASQ-IE (Mohandas, 2023), PEFR, SCSS, and RSST. Data were analysed using Friedman test and Bonferroni-corrected pairwise comparison, with an adjusted significance of $p < .017$. Inter-rater and intra-rater reliability for articulatory measures were carried out using additional two SLPs.

DBE programme demonstrated statistically significant improvements across the majority of respiratory, phonatory, articulatory, and swallowing outcome measures. Findings align with studies showing DBE improves lung volumes and respiratory muscle strength in older adults and clinical populations (Hamasaki 2020; Guo et al. 2025; Ahmad et al. 2025; Abdullahi et al. 2024; Sedaghati et al. 2023; Abo Elyazed et al. 2024; Shetty et al. 2020). Thus, the study indicated that even slight increases in FVC/$FEV_1$ improves breath support for speech and swallowing by enhancing voice intensity, endurance, and airway protection.

Immediate improvements were also seen in the phonatory measures with DBE intervention. The findings support better respiratory phonatory coordination for speech. Enhanced subglottic pressure consistency improves voice quality seen as reduced shimmer values and improved phonatory endurance found as increased MPT in the study findings.

This study to our knowledge was the first study to examine DDK rates as an outcome of DBE. DDK improvements suggest DBE enhances oromotor function and articulatory motor speed/regularity in elderly, potentially improving speech clarity and intelligibility. Stronger retention of AMR /ka/ gains at follow-up vs. /pa/ and /ta/ may reflect greater sensitivity of velar closure gesture to improved respiratory support. DDK improvements suggested that DBE enhances oromotor function and articulatory motor speed/regularity in elderly, potentially improving speech clarity and intelligibility.

This study support that by strengthening the respiratory musculature using DBE produces measurable functional gains across the four domains in healthy Indian elderly. All participants demonstrated clinically meaningful improvements at post-intervention, with partial maintenance at four week follow-up, suggesting that continued practice beyond the active training period is necessary to sustain gains. The present study is the first to provide multi-domain evidence on the effects of DBE in community dwelling Indian elderly, and its findings lay the empirical foundation for the integration of structured DBE programmes into evidence-based, accessible, and culturally appropriate preventive speech-language pathology services for the rapidly growing elderly population of India.

**Limitations of the study**

The present study has certain methodological limitations that should be acknowledged. The small sample size of five participants, while appropriate for a single-group ABA repeated-measures investigation, limits the statistical power and generalizability of the findings. The maximum possible Friedman chi-square statistic for N= 5 participants and k=3 conditions is 10.00, placing a ceiling on inferential sensitivity. The Bonferroni correction, while appropriate for controlling Type I error inflation, may have been overly conservative given the small sample and the exploratory nature of the study.

The absence of a control group, inherent to the single-group design, limits the causal interpretation of the findings, as maturation and practice effects cannot be entirely ruled out. The four-week follow-up period, while sufficient to examine the immediate post training retention, does not address long term maintenance trajectories.

The heterogeneous height and weight of participants introduced inter-individual variability in baseline spirometric values, which may have influenced the non-significant SVC result. Finally, the ceiling effect in SCSS and floor effect in SASQ-IE and speech intelligibility restricted the range of detectable change on these measures in a healthy population.

**Clinical implications of the study**

The findings of the present study highlights clinically meaningful implications for geriatric speech-language pathology practice in India. The significant and consistent improvements across respiratory, phonatory, articulatory, and swallowing domains following a four-week structured DBE programme suggest that DBE is a feasible, non-invasive, and efficacious preventive intervention for community dwelling Indian elderly with age-related functional decline. The programme's hybrid delivery model combining initial in-person sessions with subsequent Zoom video conferencing sessions is particularly relevant for the Indian context, where access to clinic-based SLP services is limited in community and rural settings.

The improvement in PEFR and RSST has direct implications for aspiration risk reduction in this population. The novel findings regarding DDK rate and speech rate improvements suggest that DBE offers additional articulatory benefits beyond its established respiratory effects, warranting further investigation. Given the high prevalence of presbyphonia and presbyphagia documented in Indian elderly populations (Dodderi et al., 2024; Patro et al., 2019), the integration of structured DBE programmes into community based healthy ageing initiatives could serve as a cost-effective approach to maintaining communication and swallowing function and preventing disability in this rapidly growing demographic.

Beyond the speech and swallowing outcomes investigated in the present study, the available evidence also supports broader health and quality of life benefits of DBE in elderly populations, further reinforcing its utility as a community-based preventive intervention. Collectively, these findings suggest that the clinical benefits of DBE extend across multiple health domains in elderly populations and support its integration into community health promotion programmes targeting healthy ageing.

The present findings highlight the need for structured dissemination strategies to translate evidence into accessible community practice. Development of a DBE pamphlet by detailing exercises, rationale, frequency, and self-monitoring cues in regional languages could serve as a low-cost, scalable tool to empower elderly individuals to practice DBE independently, particularly where access to SLP services is limited. Active expansion of structured DBE programmes into old age homes, elderly welfare associations, and community geriatric wellness centres would enable supervised, socially supported access for a larger elderly population. Collaboration with gerontological social workers, geriatricians, and community health workers in these settings would facilitate programme implementation, adherence monitoring, and timely referral to SLP services. Embedding DBE within the existing healthy ageing initiatives or government run elder care programmes would support scalability and long term public health impact, enabling elderly individuals across diverse socioeconomic and geographic contexts to maintain communication, swallowing function, quality of life and functional independence.

**Future directions**

Based on the findings and limitations of the present study, the following directions are recommended for future research:

- Future studies should employ larger sample sizes and include a matched control group to establish causal inference and improve statistical power.
- A longer intervention duration of eight to twelve weeks and an extended follow-up period of three to six months would clarify whether DBE produces durable, long-term improvements in speech and swallowing function.
- Future studies should include participants with mild presbyphonia and early presbyphagia to examine whether DBE produces greater gains in those with subclinical impairment compared to healthy elderly.
- Studies comparing DBE with other respiratory training approaches including Respiratory Muscle Strength Training in the elderly population would help establish the relative efficacy and specificity of each intervention modality.
- Community based implementation studies, incorporating DBE programmes within existing Indian geriatric wellness initiatives, are warranted to examine the scalability, adherence, and long-term public health impact of this intervention at a population level.

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**APPENDIX I**

**Ethical clearance certificate for the study**

**All India Institute of Speech and Hearing**
(An autonomous Institute under the
Ministry of Health and Family Welfare, Govt. of India)
Center of Excellence - Assessed & Accredited by NAAC with 'A' Grade
ISO 9001:2015 Implemented Institute
Manasagangothri, Mysuru-570006

ಅಖಿಲ ಭಾರತ ವಾಕ್ ಮತ್ತು ಶ್ರವಣ ಸಂಸ್ಥೆ
ಮಾನಸಗಂಗೋತ್ರಿ, ಮೈಸೂರು–570006
अखिल भारतीय वाक् श्रवण संस्थान
मानसगंगोत्री, मैसूरु - 570 006

**INSTITUTE REVIEW BOARD (IRB) APPROVAL FOR BIO-BEHAVIOURAL RESEARCH PROPOSAL INVOLVING HUMAN SUBJECTS AT AIISH**

**AIISH Institute Review Board (IRB)**

**Ref: SH/IRB/M.5/SLP.15/2025-26** **Date: 11.03.2026**

| | |
|---|---|
| **Title of the Dissertation** | : Effect of Diaphragmatic Breathing Exercises on Speech and Swallow Functions in Indian Elderly |
| Name of the Student | : Ms. Fathima Fasna C |
| Guide | : Ms. Sindhusha Chandran |
| Co-Guide (if any) | : Nil |
| Proposed Duration of the Project | : 06 months |
| Source of funding | : Non-funded Master's dissertation |
| Estimated budget | : Nil |
| Reference Number of the Project | : Nil |
| Date on which the IRB meeting was held | : 05.03.2026 |
| **A clear statement of the decision reached IRB meeting (In the event of the proposal is not approved, a statement of reasons for the same must be indicated)** | **: APPROVED** |
| **Advice & suggestions (if any)** | : Nil |

Signature & Name of the Member Secretary-IRB
Dr. Animesh Barman
Professor of Audiology
All India Institute of Speech and Hearing, Mysore-570006

संस्थागत समीक्षा बोर्ड
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## APPENDIX II

### Swallow Abilities Screening Questionnaire for the Indian Elderly (SASQ-IE)

**Questionnaire Questions: To be administered by the professional.**

**Mark whether the symptoms present as- always, sometimes or never.**

| Domains | S.no | Questions | Never 0 | Sometimes 0.5 | Always 1 |
|---|---|---|---|---|---|
| **Activity Limitations** | **Q1** | Do you have any difficulty with swallowing? | | | |
| | **Q2** | Have you made any changes in your diet due to swallowing difficulties? For example- eating mashed food instead of hard solids | | | |
| | **Q3** | Has the quantity of food eaten per meal reduced because of swallowing difficulty? | | | |
| | **Q4** | Have you lost weight over the years unintentionally due to reduced intake of food? | | | |
| | **Q5** | Have you stopped eating spicy food? | | | |
| **Difficulties in Oral Phase, Pharyngeal Phase and Esophageal Phase** | **Q6** | Do you have dry mouth? | | | |
| | **Q7** | Does your mouth feel dry while chewing or swallowing solid food? | | | |
| | **Q8** | Does food spill out of your mouth while eating or drinking? | | | |
| | **Q9** | Does water spill out of your mouth while eating or drinking? | | | |
| | **Q10** | Do you have trouble chewing solid food like Chakli, peanut barfi, etc? | | | |
| | **Q11** | Do you chew the food more slowly and carefully, taking longer time to complete the meal? | | | |
| | **Q12** | Do you find difficulty in moving food inside your mouth? | | | |
| | **Q13** | Do you find it difficult to initiate a swallow after the food is chewed? | | | |

| | | | | | |
|---|---|---|---|---|---|
| | **Q14** | Do you find food particles remaining in your mouth even after many swallows? | | | |
| | **Q15** | Do you cough/ choke/ clear your throat while/ before/ after swallowing? (mention when) | | | |
| | **Q16** | Do you cough/ choke/ clear your throat while watching TV/ mobile/ newspaper while eating? | | | |
| | **Q17** | Do you cough/choke/ clear your throat more often while you're talking to other people when eating? | | | |
| | **Q18** | Do you feel like that the food you ate is stuck in your throat? (specify consistency) | | | |
| | **Q19** | Do you think you need to swallow hard for it to go? (specify consistency) | | | |
| | **Q20** | Do you need to take water more often during meal time for the food to go into your stomach? | | | |
| | **Q21** | Do you feel the need to swallow many times to push the food into your stomach? | | | |
| | **Q22** | Do you frequently get burps with sour liquid or food coming back into your throat? | | | |
| **Participation Restrictions** | **Q23** | Do you avoid eating in public places due to difficulties in eating/drinking or swallowing? | | | |
| | **Q24** | Do you feel embarrassed/ uncomfortable to eat in social gatherings? | | | |
| | **Q25** | Do you feel upset that you are unable to eat like others? | | | |

'Never' contains a score of 0, 'Sometimes' contains a score of 0.5 and 'Always' contains 1.

The scores for each question must be added up to obtain the Total SASQ-IE Score.

## APPENDIX III

### SCSS Semi-quantitative Cough Strength Scale

| Score | Description of cough strength |
|---|---|
| 0 | No cough on command |
| 1 | Audible movement of air through the endotracheal tube but no audible cough |
| 2 | Weakly (barely) audible cough |
| 3 | Clearly audible cough |
| 4 | Stronger cough |
| 5 | Multiple sequential strong coughs |

# APPENDIX IV

## Assessment proforma

Assessment Proforma used for recording the speech and swallowing outcome measures obtained from the participants across pre-intervention, post-intervention and follow-up phases.

**Study Title:** Effect of Diaphragmatic Breathing Exercises on Speech and Swallow Functions in Indian Elderly.

**Investigator:**

### PART A – Demographic Details

Name of participant:

Age/Gender:

Education:

Primary language:

Height(cm): Weight(kg):

Smoking status: Never/Former/Current

MOCA: Passed/Failed

Contraindications for spirometry: YES/NO

| **Contraindicators** | **Yes/No** |
|---|---|
| Recent surgeries | |
| Cardiac conditions | |
| COPD/asthma | |
| Severe uncontrolled hypertension | |
| Severe GERD | |

### PART B – Assessment Scores

**I. Respiratory Measures (spirometry)**

| **Parameter** | **Pre Therapy (Date: )** | | | **Post Therapy (Date: )** | | | **Follow Up (Date: )** | | |
|---|---|---|---|---|---|---|---|---|---|
| FVC (L) | | | | | | | | | |
| FEV1 (L) | | | | | | | | | |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| FEV1/FVC ratio (%) | | | | | | | | | |
| SVC (L) | | | | | | | | | |
| TV (L) | | | | | | | | | |

**II. Phonatory Measures**

| Parameter | Pre Therapy | | | | Post Therapy | | | | Follow Up | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MPT (s) | | | | | | | | | | | | |
| F0 (Hz) | | | | | | | | | | | | |
| Jitter (%) | | | | | | | | | | | | |
| Shimmer (%) | | | | | | | | | | | | |

**III. Articulatory Measures**

| Parameter | Pre-Intervention | | | | Post-Intervention | | | | Follow up | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AMR (syllables/s) | | | | | | | | | | | | |
| | | | | | | | | | | | | |
| | | | | | | | | | | | | |
| SMR (syllables/s) | | | | | | | | | | | | |
| Speech intelligibility | | | | | | | | | | | | |
| Speech rate (words/min) | | | | | | | | | | | | |

**IV. Swallowing Measures**

| Parameter | Pre Therapy | | | | Post Therapy | | | | Follow Up | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PEFR (L/min) | | | | | | | | | | | | |
| SASQ-IE Total score | | | | | | | | | | | | |
| SCSS | | | | | | | | | | | | |
| No. of swallows in 30 seconds | | | | | | | | | | | | |

## APPENDIX V

### Participant log

The structured daily log checklist that was provided to the participants at the commencement of the intervention program to monitor and document home practice adherence.

**Name:** **Age/Gender:**
**Start Date:**

| Day | Date | Warm-up Exercises (5 min) | Diaphragmatic Breathing (2×5 repetitions) (Sit comfortably, relax shoulders. Place one hand on stomach, one on chest. Breathe in slowly through your nose, stomach should move outward. Then breathe out gently, stomach will move inward. Repeat 5 times slowly for 2 sets.) | DB with Phonation (2×5 repetitions) (Breathe in slowly through your nose, stomach should move outward. Say /a/ in one smooth sound until breath finishes. Stop gently, don't push voice. Repeat 5 times slowly for 2 sets.) | DB with Reading Passage (3×) (Breathe in slowly, stomach should move outward. Read aloud smoothly at steady pace and comfortable loudness. Let voice flow naturally. Pause only to breathe. Read the passage 3 times.) | How did you feel before/ during/ after exercise? (Fatigue/ Discomfort/ Any other) |
|---|---|---|---|---|---|---|
| 1 | | | ☐ ☐ ☐ | ☐ ☐ ☐ | ☐ ☐ ☐ | |
| 2 | | | ☐ ☐ ☐ | ☐ ☐ ☐ | ☐ ☐ ☐ | |
| 3 | | | ☐ ☐ ☐ | ☐ ☐ ☐ | ☐ ☐ ☐ | |
| 4 | | | ☐ ☐ ☐ | ☐ ☐ ☐ | ☐ ☐ ☐ | |
| 5 | | | ☐ ☐ ☐ | ☐ ☐ ☐ | ☐ ☐ ☐ | |
| 6 | | | ☐ ☐ ☐ | ☐ ☐ ☐ | ☐ ☐ ☐ | |
| 7 | | | ☐ ☐ ☐ | ☐ ☐ ☐ | ☐ ☐ ☐ | |
| 8 | | | ☐ ☐ ☐ | ☐ ☐ ☐ | ☐ ☐ ☐ | |
| 9 | | | ☐ ☐ ☐ | ☐ ☐ ☐ | ☐ ☐ ☐ | |
| 10 | | | ☐ ☐ ☐ | ☐ ☐ ☐ | ☐ ☐ ☐ | |

| | | | | | | |
|---|---|---|---|---|---|---|
| 11 | | | ☐ ☐ ☐ | ☐ ☐ ☐ | ☐ ☐ ☐ | |
| 12 | | | ☐ ☐ ☐ | ☐ ☐ ☐ | ☐ ☐ ☐ | |
| 13 | | | ☐ ☐ ☐ | ☐ ☐ ☐ | ☐ ☐ ☐ | |
| 14 | | | ☐ ☐ ☐ | ☐ ☐ ☐ | ☐ ☐ ☐ | |
| 15 | | | ☐ ☐ ☐ | ☐ ☐ ☐ | ☐ ☐ ☐ | |
| 16 | | | ☐ ☐ ☐ | ☐ ☐ ☐ | ☐ ☐ ☐ | |
| 17 | | | ☐ ☐ ☐ | ☐ ☐ ☐ | ☐ ☐ ☐ | |
| 18 | | | ☐ ☐ ☐ | ☐ ☐ ☐ | ☐ ☐ ☐ | |
| 19 | | | ☐ ☐ ☐ | ☐ ☐ ☐ | ☐ ☐ ☐ | |
| 20 | | | ☐ ☐ ☐ | ☐ ☐ ☐ | ☐ ☐ ☐ | |
| 21 | | | ☐ ☐ ☐ | ☐ ☐ ☐ | ☐ ☐ ☐ | |
| 22 | | | ☐ ☐ ☐ | ☐ ☐ ☐ | ☐ ☐ ☐ | |
| 23 | | | ☐ ☐ ☐ | ☐ ☐ ☐ | ☐ ☐ ☐ | |
| 24 | | | ☐ ☐ ☐ | ☐ ☐ ☐ | ☐ ☐ ☐ | |
| 25 | | | ☐ ☐ ☐ | ☐ ☐ ☐ | ☐ ☐ ☐ | |
| 26 | | | ☐ ☐ ☐ | ☐ ☐ ☐ | ☐ ☐ ☐ | |

*Perform each exercise three times daily (morning, afternoon, evening).

*Maintain correct body posture during the exercise.

# APPENDIX VI

## Session log for examiner

Examiner session log used to document the participant attendance, completion of DBE sessions, number of sets completed, and observations recorded by the examiner throughout the intervention period.

**Name:** **Age/Gender:** **Start Date:**

| Day | Date | Warm-up Exercises | Diaphragmatic Breathing (2×5 repetitions) | DB with Phonation (2×5 repetitions) | DB with Reading Passage (3×) | Notes |
|---|---|---|---|---|---|---|
| 1 | | | | | | |
| 2 | | | | | | |
| 3 | | | | | | |
| 4 | | | | | | |
| 5 | | | | | | |
| 6 | | | | | | |
| 7 | | | | | | |
| 8 | | | | | | |
| 9 | | | | | | |
| 10 | | | | | | |
| 11 | | | | | | |
| 12 | | | | | | |