STM JOURNALS

Research & Reviews: Journal of Computational Biology
ISSN: 2319-3433 (Online), ISSN: 2349-3720 (Print)
Volume 7, Issue 2
www.stmjournals.com

The Contextual Effect of Vowels on Correct Production of Retroflex in Kannada Speaking Children with Speech Sound Disorder: A Case Study

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Abstract

Contextual based interaction of speech sounds, coarticulation, is the main component of intelligible continuous speech. This interaction between speech sounds within and across the words is affected in children with speech sound disorders (SSD). Literature reports on certain contexts facilitating the production of different speech sounds. Thus, these contextual considerations are vital for the selection of target stimuli during articulation therapy for faster learning. As phonotactics and coarticulation are language dependent, such studies are indispensable in linguistically diverse languages. In this context, the present study intended to examine the effect of vowels /a/, /i/, and /u/ in acquisition of retroflexes /ʈ/, /ɖ/, /ɳ/, and /ɭ/ in Kannada speaking children with SSD. Kannada, a syllabic language, is one of the four Dravidian languages and considered to be the official language of Karnataka state in India. Six native Kannada participants in the age range 4 years and 0 months to 5 years and 10 months with fronting errors for retroflexes were recruited for articulation therapy. Target words incorporating retroflexes were elicited using a phonetic placement approach. Responses were audio recorded and transcribed using IPA. Percentage of correct response was analyzed and graphically represented. The results revealed, acquisition of /ʈ/, /ɖ/, and /ɳ/ were highly facilitated in the context of vowel /u/ followed by /i/ and /a/; and lateral retroflex /ɭ/ was highly facilitated in the context of vowel /i/ followed by /u/ and /a/. Validation of the present findings with a larger sample size will serve as essential guidelines to speech-language pathologists for effective SSD intervention program.

Keywords: *Vowel context, retroflex, Kannada, intervention, SSD*

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INTRODUCTION

Articulation in phonetics refers to the peripheral motor process involving, physiological movement of speech articulators (lips, tongue, hard palate, and soft palate) producing various speech-sounds [1]. Articulatory development associates body to mind progression (Frame-content theory) beginning with the initiation of gradual acquisition of the ability to move articulators rapidly and accurately [2]. The articulatory function in neonates is vegetative, gradually evolving in to rhythmic jaw movements during the babbling stage and finally maturing to the precise production of sound sequences during the toddler and preschool stages.

These sound-sequences are continuous, i.e., the articulators are continuously moving from one position to another influencing each other in an utterance. This process is coarticulation which depends on the phonotactic rules of a language. These are the rules for sequencing phonemes with a restraint that not all the phonemes of a language occur in all the phonetic contexts. According to Frame-content theory (FCT), speech sounds/phonemes here, refers to the "content" and phonetic contexts referto the syllable structures or "frames" [3].

Consequently, the FCT explains the context-based interaction of phonemes by providing the key-environments (phonetic contexts) for the production of various phonemes [3]. Phonetic contexts can either be vowels, consonants, or their position in a word. Place of articulation indicates the influence of vowels on consonants. Accordingly, the production of alveolar, velar, and bilabial sounds preferentially co-occurred with front, back, and central vowels respectively during the babbling stage in native English infants [3]. Studies in the Kannada language reveal similar findings and add on as supporting evidence to the literature.

Kannada, a Dravidian language, is the official language of Karnataka in southern India and spoken by approximately 66.8 million population of Karnataka. The total population of Kannada speakers across the world sums up to around 455,389 in Australia and 150,000 in North America [4]. Kannada has a fine grammatical structure and a very complex range of regional, social, and stylistic variations. The different dialects include the Mysore/Bangalore dialect, the coastal dialect (Mangalore), the Dharwar dialect and Kalaburgi dialect [5]. The Kannada lexicon enriched by extreme uninhibited borrowing from Sanskrit, Hindi-Urdu, and English has a total of 49 phonemic letters (Swaragalu-vowels-13 letters; vyanjanagalu-consonants-34 letters; and yogavahagalu- neither consonant nor vowels-2 letters anusvara ◌◌ಂand visarga ◌◌ಃ). Appendix I depicts the vowel and consonant inventory of Kannada. Each written symbol in the Kannada script corresponds to a syllable, in contrast to a phoneme in most of the other languages like English. In Kannada phonemic structure, each consonant has an inherent vowel /a/ and the script is syllabic or alpha syllablary [6]. Typically, Kannada speakers are not typical monolinguals as the spoken Kannada language generally uses more of loan words from English and other languages than native Kannada words like /bassu/ from the word “bus” in English than /vo:ʈa:rubanɖi/ in Kannada.

The literature on typical speech development in Kannada infants and toddlers reports the preferential phonetic contexts for acquiring speech sounds. During the babbling stage, infants highly preferred on vowel /a/ with a majority of consonants and high front vowel /i/ with dentals [7]. Also, in the first fifty-word stage of toddlers, more bilabials were produced in the context of the central vowel /a/, while coronals and velars in the context of the high front vowel /i/ [8]. These reports emphasized the fact that the labial and coronal sounds are acquired during the babbling stage itself due to their visibility in many languages. Retroflex sounds acquisition is in the order of /ɖ/>/ʈ/>/ɳ/>/ɭ/ between 3 years 6 months and 5 years 0 months of age [9]. In the phonetic repertoire of 18-to 24-month’s toddlers, retroflexes /ɖ/, /ʈ/, and /ɳ/ were predominantly in the medial-positions of the word [10].

These studies emphasize speech sound acquisition at different stages of speech development. Thus, the presence of predictable errors is apparent during typical speech development which is attributable to the contextual effect of phonemes on each other. Generally, such errors diminish around 3-to 6-years of age and their persistence beyond the developmental age results in speech sound disorders (SSDs).

The term ‘speech sound disorder' is suggested in clinical setups alternative to misarticulation or phonological disorder [11]. Speech sound disorders (SSD) is a broad term referring to a combination of intricacy in speech perception, speech-motor production, and the phonological representation of speech sounds and segments including phonotactic rules of the language and the prosody that has an impact on speech intelligibility [12]. The effect can either be on the form of speech sounds resulting in articulation/phonetic disorders or on the function of speech sounds within a language resulting in phonological/phonemic disorders.

Diagnostic and statistical manual of mental disorders, DSM-V provides four main criteria for the diagnosis of SSD [13]. These include:

1. Persistent unintelligible speech consisting of phoneme addition, omission, distortion or substitution, which interferes with verbal communication.
2. There is interference with social participation, academic performance, or occupational performance (or any combination of these).
3. The onset of symptoms during childhood.
4. The symptoms cannot be accounted for, by another medical or neurological condition, including traumatic brain injury.

Many theoretical frameworks like Dodd's diagnostic framework (based on speech characteristics) [14], Shriberg's classification (physiological basis) [15], and Bowen's classification (based on underlying levels of difficulty) [1], classify speech sound disorders. Dodd's and Bowen's classifications are described in depth as they are more appropriate for the current study.

Dodd’s Diagnostic Framework

Dodd’s diagnostic framework classifies speech disorder into five sub-groups based on speech characteristics [14]:

1. Articulation disorder: Presence of substitutions and distortions in any phonetic context on any task.
2. Phonological delay: Presence of speech error patterns those are typical of younger children as determined by normative data.
3. Consistent atypical phonological disorder: Consistent use of one or more unusual non-developmental error patterns as determined by normative data.
4. Inconsistent phonological disorder: Multiple phonemic errors for the same lexical item while having no oro-motor difficulties.
5. Childhood Apraxia of speech (CAS): Speech characterized by inconsistency, oro-motor signs (e.g., groping, trouble sequencing articulatory movements) and poorer performance in imitation than spontaneous speech.

Bowen's Classification

Bowen classified SSD based on the underlying levels of difficulty as follows [1]:

1. Anatomic/sensory: Ankyloglossia, cleft lip palate, hearing impairment.
2. Motoric: Execution dysarthria, planning apraxia.
3. Perceptual: Articulation and phonological disorders.
4. Phonetic: Articulation disorder.
5. Phonemic: Phonological disorder.

Assessing individuals with speech sound disorders and categorizing them into one of the above categories is challenging and requires evaluating abilities in various domains like oro-motor, sensory and perception. The analysis of articulatory errors mainly constitutes of SODA classification (Substitution, Omission, Distortion, and Addition), PMV classification (Place, manner, and voicing) or distinctive features. The use of contextual based analysis is infrequent, but in the recent past, there has been an increasing application of it clinically.

ASSESSMENT OF ARTICULATORY ERRORS IN CHILDREN WITH SSD: CLINICAL APPLICATION OF CONTEXTUAL BASED ANALYSIS

Contextual based analysis has been applied clinically, especially for children with speech sound disorders (SSD). Concerning the assessment of articulatory disorders, various articulatory test materials have provided scope for contextual based analysis such as the deep test of articulation in English [16], following the lines, the Deep test of articulation in Kannada-Sentence form [17], Deep test of articulation in Hindi-Picture form [18], Deep test of articulation in Bengali-Picture form [19], Deep test of articulation in Nepali-Picture form [20], and Deep test of articulation in Tamil-Picture form [21].

Clinical application of contextual effects in intervention dates back to 1950s and 1970s [22–25]. Many of these studies have focused on facilitating phoneme positions or vowels in isolation, or both and case studies have been the essence for carrying out such investigations. The following section highlights on the Indian and western literature on effects of vowels on the correct production of target phonemes.

Intervention for Children with SSD: Clinical Application of Vowel Effects

A single-case Indian study investigated the vowel coarticulatory influences on Kannada retroflex /ʈ/ (vowel-/ʈ/, /ʈ/-vowel, consonant-/ʈ/, and /ʈ/-consonant) through pre-post comparison of spectrographic analysis [26]. A 15-year-old female subject misarticulated retroflex /ʈ/ by substituting it with distorted /θ/. The intervention initiated with auditory training and discrimination activities followed by articulation therapy using multisensory-phonetic placement approach in isolation and various contexts at non-word and word levels. The spectrographic analysis comprised the measurement of vowel duration, VOT, transition duration, the speed of transition, and stop duration. Post-intervention results showed a reduction in VOT and transition duration in the context of vowels /a/ and /i/ demonstrating the acoustical evidence for the production of retroflex /ʈ/. Another Indian study in native Malayalam speaking children with hearing impairment found vowel /a/ to be facilitating the correct production of velars [27].

In the past, the efficacy of key-environments in articulation therapy has been verified in other languages as well. A case study method on a 5-year-old Australian English speaking child with delayed receptive and expressive language and misarticulation (substituting /l/ for /j/), revealed that vowels /i/ and /a/ (keyword-/ija/) were the facilitating contexts for the production of glide /j/ [28]. Literature reports, back vowels and word-final positions as the facilitating contexts for the production of palatal fricative [ʃ] and the application of this context for correcting the post-alveolar fronting of fricative [ʃ] in a monolingual English speaking seven-year-old boy did prove to be effective in establishing the correct motor program in children with the phonetic disorder and not in a phonological context [29]. Results also highlighted that selection of vowel context is custom-made to suit the child's needs. Similarly, back vowels facilitated the production of velar phonemes in English speaking children with speech sound disorder in the age range 5-to 7-years [30].

There is documentation of clinical observations on key-environments facilitating the production of specific speech sound classes [31–33]. The context of high front vowels facilitated affricates, fricatives, and alveolar stops; and back vowels facilitated velar stops.

NEED OF THE STUDY

Literature review clearly emphasizes the effectiveness of contextual based analysis and intervention in correcting individuals with SSD. Generally, standard articulation or informal screening tests assess speech sounds in limited contexts. The literature on the application of contextual effects in intervention is majorly centered on clinical observations and lacking empirical evidence [31–33]. Also, it is perceptible with most of the studies being single case studies. So, validation of results on phonetic contexts effect is vital. Abundance literature in English is available on key environments in commonly erred speech sounds, /s/, /ʃ/, and /r/ [28–33]. Phonotactics and coarticulation are language-specific, and hence, these findings necessitate the replication of studies in linguistically diverse languages.

Application of a trial and error intervention method for children with SSD generally leads to an endless series of errors [34]. Effective guidelines on facilitating contexts would fasten the progress of learning accurate articulation. Articulation disorder is one of the most common problems observed in the pediatric Indian population as per prevalence reports. A retrospective study on children in the age range 0-to 12 years at Kasturaba Medical College; Mangalore, India reported 14% of the population having speech disorders, out of which, 48.4% had articulation disorder [35]. The recent annual report of the All India Institute of Speech and Hearing, Mysuru, India, reveals the percentage of articulation disorder is approximately 8.7% in the age range of 4 to 15 years among the clinical population consulting the institute [36]. Hence, early identification and intervention is critical to avoid risk of either short-or long-term difficulties in various academic domains (writing and reading), and emotional fronts that eventually have an impact on occupational opportunities in adulthood [37, 38].

Aim

To investigate the effect of vowel contexts on the correct production of retroflex sounds in children with speech sound disorder.

METHOD

The ethical committee board of All India Institute of Speech and Hearing, Mysuru, India, approved the study. All the ethical requirements were followed as per the guidelines by Basavaraj and Venkatesan [39]. Prior written consent was obtained from the parents of participants.

Participants

A total of six children with SSD (DSM-V criteria) [13]-phonetic type (Bowen's classification) [1], or articulation disorder (Dodd's classification) [14], aged between 4 years, 0 months and 5 years, 10 months (mean age-4 years, 7 months), served as participants. All participants were native speakers of Kannada, Mysuru dialect with English being the medium of education. Participants were early successive bilinguals with exposure to English as their 2nd language at school. The inclusion criteria were that all the participants should be free of associated speech (fluency or voice problems), language, hearing, psychological, neurological, and anatomical or any related cognitive problems. None of the participants should have the motor production of retroflex and should not be enrolled in a speech therapy program earlier. The participants recruited were from the out-patient section of the All India Institute of Speech and Hearing, Mysuru, India. The details of the participants are in Table 1.

Research Method

A case study method was employed to aim at the sustenance of the learned production of the target phonemes involving an assessment of the dependent variable (retroflex) followed by an intervention phase. The independent variable (vowel contexts) introduced was monitored during the intervention phase, and later re-assessed during the post-intervention phase. Although case studies exhibit limitations concerning generalization, replication, and researcher bias, they provide rich qualitative information guiding additional insights in the field of research [40]. Gibbert and Ruigrok published four criteria concerning the internal validity, construct validity, external validity, and reliability to overcome the limitations of case study method and bring in rigidity and accordingly designed the present study method [41].

Stimuli

The present study considered retroflex in the Kannada language as the target because clinical observations report these to be the most commonly erred and also frequently occurring phonemes in Kannada [42]. There are three manners of production of retroflex, i.e., stops, nasal, and lateral in Kannada. Stop retroflexes are classified into unvoiced and voiced and further categorized into aspirated and non-aspirated. The two non-aspirated retroflex stops, /ʈ/ and /ɖ/, nasal retroflex (/ɳ/), and one lateral retroflex (/ɭ/) were considered for the study. Appendix I depicts the Kannada phonetic inventory with encircled targets.

Stimuli word list for each of these target phonemes constituted Kannada and frequently used loan English bi- or tri-syllabic picturable words. The total number of stimuli (Appendix IV) for each target was: /ʈ/ and /ɖ/-18 (6 in the context of following vowel /a/+6 in the context of following vowel /i/+6 in the context of following vowel /u/); /ɳ/ and /ɭ/-9 (3 in the context of following vowel /a/+3 in the context of following vowel /u/+3 in the context of following vowel /i/). Appendix III has a few examples of stimuli.

Procedure

The study was carried out by a native Kannada speaking Speech-Language Pathologist (SLP). Both assessment and intervention procedures were carried out individually for each participant in speech therapy rooms, and the data were audio recorded using a digital recorder Olympus LS-100 and was transcribed using International Phonetic Alphabet [43].

Assessment Procedures

The articulatory abilities were assessed at three data points B1, B2, and B3 before the intervention and at two data points P1 and P2 post-intervention using Kannada Diagnostic Picture Articulation test, KD-PAT [9] and the Deep test of articulation-Sentence form in repetition mode [17]. If the participants exhibited difficulty in repeating the test items, the test item was produced again by the SLP at a slower rate. Participant had to respond to each test item with a maximum of two turns and a score of ‘1' given for perceptually correct response and a score of ‘0' given for a perceptually incorrect response. Percentage-correct-consonants-Revised (PCC-R) [45] for pre-and post-intervention data was calculated using the formula:

(#Consonants Correct/# Consonant Targets)×100

Three baselines were obtained to rule out the developmental influence and to check inconsistency in the production of target stimuli. All the three pre-therapy baselines (B1, B2, and B3) were conducted 8 to 10 days before initiating the intervention. The first post-intervention assessment (P1) was done at the termination of intervention and the second (P2) after a month of intervention and evaluated the maintenance and generalization of the learned phonemes. The pre-intervention assessment revealed misarticulation of the retroflex sound class (substituting with dentals, i.e., fronting errors) and no error types were present. All the participants had very good stimulability in the audio-visual mode.

Table 1: *Participant Details.*

	Age	Gender	Errors with Substitutions
S1.	5 years, 10 months	F	n/ɳ and l/ɭ
S2.	5 years, 0 months	M	t/ʈ, d/ɖ, n/ɳ and l/ɭ
S3.	4 years, 8 months	F	t/ʈ, d/ɖ, n/ɳ and l/ɭ
S4.	5 years, 0 months	M	n/ɳ
S5.	4 years, 0 months	M	n/ɳ
S6.	4 years, 2 months	F	t/ʈ, and d/ɖ

Five out of six participants: misarticulated nasal retroflex /ɳ/, 3-lateral retroflex /ɭ/, 3-unvoiced retroflex /ʈ/ and 3-voiced retroflex /ɖ/. Examples of erred productions are in Appendix II. The Deep Test of Articulation-Sentence form was administered to analyze the erred sounds in various vowel contexts and the presence of facilitating vowel contexts, if any, was documented [17].

The co-occurrence of other associated speech (fluency and voice problems), language, hearing, psychological, neurological and cognitive impairments were ruled out using WHO ten disability screening checklist and from informal conversations with participants [45]. Presence of CAPD was ruled out using 'Screening for central auditory processing disorder, SCAP' [46].

The detailed baseline assessment session was approximately 90 min in duration with a break of 15 min. In between, the subsequent assessment sessions involved only articulation assessment of 30 min duration.

Intervention Procedure

All the six participants enrolled for the individual articulation therapy program met the inclusion criteria. The articulation correction was initiated directly at the word level. The total number of sessions was unfixed as the learning pace generally differs across individuals. Each therapy session lasted for 45 min.

Color picture stimuli along with the orthographical representations were presented using Microsoft Office Power Point (2007) on a laptop, Acer Aspire 5738G, of 15.6 in screen. Word list of the target phoneme was presented randomly in three orders, and the mode of response was repetition. In instances of the child unable to reproduce the target correctly, the correct place of articulation was taught using phonetic placement approach [47]. For example, if the target phoneme is unvoiced velar /k/, the phonetic placement instructions were: "Keep the anterior portion of the tongue behind the lower teeth and elevate the posterior region". A tongue depressor was used to restrict the anterior movement in addition to pictorial representations of tongue placements for the phoneme taught. A target word, if produced incorrectly, was taught for a maximum of five times in each therapy session and the first production of the target word considered for the scoring. Social and tangible reinforcements were given to motivate the child. Percentage of correct responses for each word in every session was calculated, tabulated, and graphically represented using Microsoft Office Excel (2007). The vowel context in which the target sound was learned first documented to be highly facilitating.

Practice effect was ruled out using a different set of wordlist by evaluating participants on every fourth session during the intervention phase. Variability in, home training was minimized by providing sentences with the target phonemes to the parents. A success criterion of 90% perceptually correct production of all target sounds was considered to be the measure for terminating the articulatory therapy program.

Data Analysis

The data were analyzed graphically as the sample size was small. According to Kazdin, in a single-case design, statistical significance as a criterion does not encourage the investigator to obtain transparent, unequivocal experimental control over the behavior [48]. Wilcoxon signed rank test was run on performance raw scores of baseline 3 (B3)-post-intervention 1 (P1) and effect size (according to Andy Field) was calculated to strengthen the study [49]. Furthermore, intra-and inter-judge reliability for percentage correct response scores across first-, mid-, and last-sessions was obtained using Cronbach's Alpha. Results were subjected to statistical analysis using SPSS software version 17.

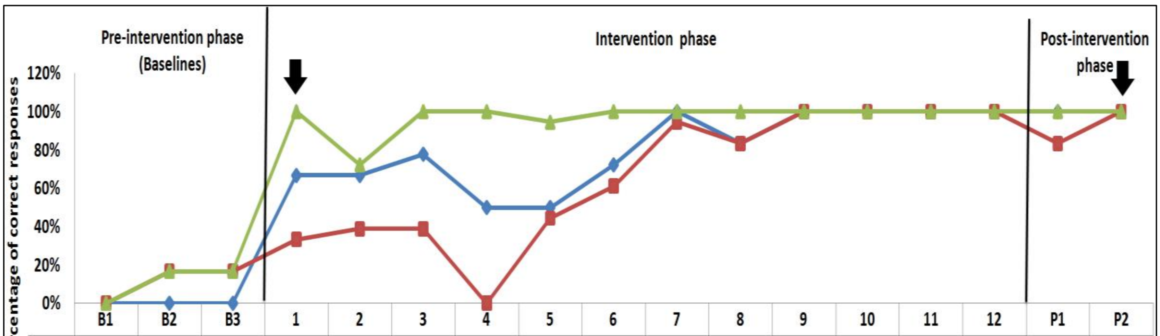
RESULTS

Both intra-(α-.836) and inter-judge (α-.879) reliability were good with Cronbach's Alpha range .8>α>.9. Results of the graphical analysis describe regarding the change in the level and the trend. The minimum number of sessions to attain ≥90%accuracy in production, percentage correct response scores during- and post-intervention served as measures for the change in level. The change in trend was established based on the variability in data across therapy sessions. In graphs (Figures 1–4), vowels /a/, /i/, and/u/ are depicted by dashed, dotted, and plain black lines respectively. The small arrows in the graph indicated the effect of the independent variable (vowels) on the dependent variable (target phonemes). Along with graphical analysis, PCC-R scores of P1 (first post-intervention evaluation) and P2 (second post-intervention evaluation) also served as measures. Variation in performance was minimal across subjects, and hence, only participant S2's (misarticulated all the four retroflex considered for the study) graphs for each target phoneme is represented/illustrated. All the graphs are provided in Appendix V.

Vowel Effect on Voiceless Retroflex /ʈ/

During the pre-intervention phase, the error production of the target was consistent in all the participants (Figure 1), and the same observed for other manners of retroflex as well (Appendix V).

In the first session itself, retroflex /ʈ/ was produced 100% accurately in the context of vowel /u/. There was minimal variability in correct production of the target phoneme in the context of vowel /u/ across therapy sessions (Figure 1). PCC-R scores at P1 reveal both vowels /a/ and /u/ to be facilitating (Table 2). At P2, S2 acquired 100% accuracy in the production of voiceless retroflex in all three vowel contexts. S6 performed similar to S2 but with 80% accurate production in the context of vowel /u/ (Figure 6; Appendix V). However, at P1 and P2, the production of /ʈ/ was retained only in the context of vowels /u/ and /a/respectively (Table 2). During the intervention, in contrast to S2 and S6, S3 performed similarly in all three vowel contexts (Figure 5; Appendix V). Also, post-intervention PCC scores were high in the vowel /i/ context at P1 and similar in all three vowel contexts at P2 (Table 2). However, the higher scores (100% in more sessions) were in the context of the vowel /a/ during the intervention (Figure 5; Appendix V).



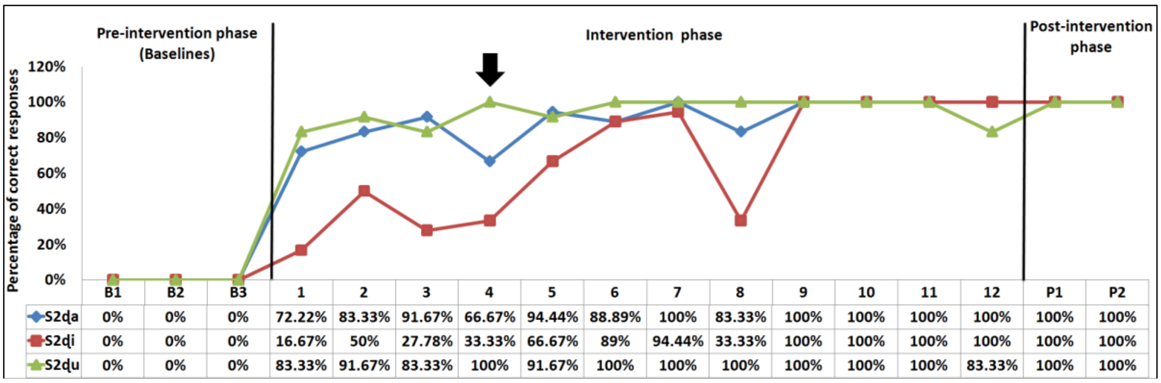
	B1	B2	B3	1	2	3	4	5	6	7	8	9	10	11	12	P1	P2
S2ʈa	0%	0%	0%	66.67%	66.67%	77.78%	50%	50%	72.22%	100%	83.33%	100%	100%	100%	100%	100%	100.00%
S2ʈi	0%	16.67%	16.67%	33.33%	38.89%	38.89%	0%	44.44%	61.11%	94.44%	83.33%	100%	100%	100%	100%	83.33%	100%
S2ʈu	0%	16.67%	16.67%	100%	72.22%	100%	100%	94.44%	100%	100%	100%	100%	100%	100%	100%	100%	100.00%

(S2ʈa: Subject 2, /ʈ/ in the Context of Vowel /a/; S2ʈi: Subject 2, /ʈ/ in Context of Vowel /i/; S2ʈu: Subject 2, /ʈ/ in the Context of Vowel /u/; ⬇: Indicates the Session Number at Which Vowel has Shown the Effect on the Target Sounds /ʈ/)

***Fig. 1:** Percentage Correct Response of Retroflex /ʈ/ Production in the Context of Vowels /a/, /i/, and /u/ by Subject 2 (S2).*

Vowel Effect on Voiced Retroflex /ɖ/
During interventions for both S2 and S6, vowel /u/ context highly facilitated the production of voiced retroflex /ɖ/ (Figure 2), followed by vowel /a/ and then /i/. At P2, for S6, PCC-R score (Table 2) was retained better in the context of vowel /u/ followed by /i/ and /a/ (Figure 8; Appendix V). PCC-R scores at P1 and P2 for S2 and S3 revealed 100% accurate production of the voiced retroflex in all three vowel contexts (Figure 7; Appendix V). However, again in contrast to S2 and S6, vowel /a/ was facilitating the correct production of voiced retroflex for S3 during the intervention (Figure 7; Appendix V).

Vowel Effect on Nasal Retroflex /ɳ/
Vowel /u/ facilitated the correct production of nasal retroflex compared to /a/ and /i/ in all five participants which is evident from both graphical analysis and PCC-R scores. The graphical analysis reveals the higher



(S2ɖa: Subject 2, /ɖ/ in the Context of Vowel /a/; S2ɖi: Subject 2, /ɖ/ in Context of Vowel /i/; S2ɖu: Subject 2, /ɖ/ in the Context of Vowel /u/; ⬇: Indicates the Session Number at Which Vowel has Shown the Effect on the Target Sounds /ɖ/).
***Fig. 2:** Percentage Correct Response of Retroflex /ɖ/Production in the Context of Vowels /a/, /i/, and /u/ by Subject 2(S2).*

***Table 2:** PCC Scores for Target Phonemes in Each Vowel Context during Pre- and Post-Intervention.*

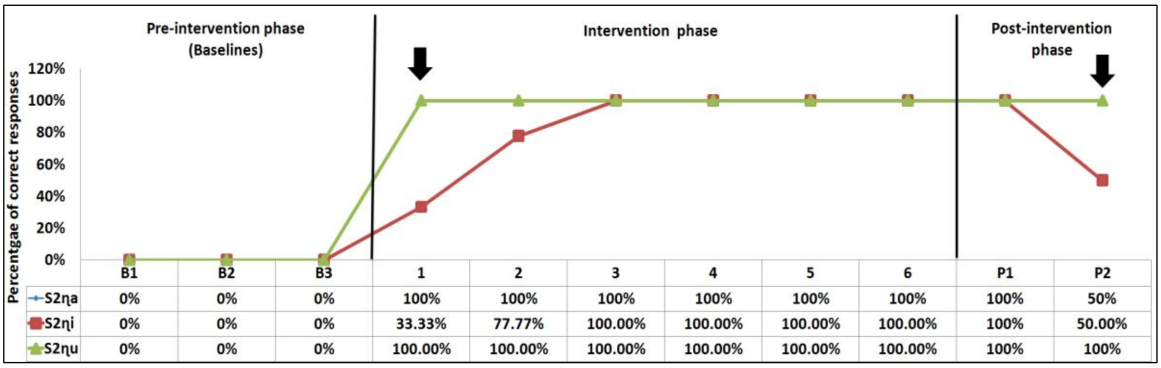
Target Phoneme		Pre-Intervention									Post-Intervention					
		/a/			/i/			/u/			/a/		/i/		/u/	
		B1	B2	B3	B1	B2	B3	B1	B2	B3	P1	P2	P1	P2	P1	P2
/ʈ/	S2	0	0	0	0	17	17	0	17	17	100	100*	83	100*	100	100*
	S3	0	0	0	0	0	0	0	0	0	67	83*	83	83*	67	83*
	S6	0	0	0	0	0	0	0	0	0	50	83*	0	67	67	33
/ɖ/	S2	0	0	0	0	0	0	0	0	0	100	100*	100	100*	100	100*
	S3	0	25	0	0	0	0	0	50	50	100	100*	100	100*	100	100*
	S6	0	0	0	0	0	0	0	0	0	50	50	50	0	100	100*
/ɳ/	S1	0	0	0	0	0	0	0	0	0	100	100*	100	100*	100	100*
	S2	0	0	0	0	0	0	0	0	0	100	50	100	50	100	100*
	S3	0	0	0	0	0	0	0	0	0	50	50	100	100*	50	100*
	S4	0	0	0	0	0	0	0	0	50	50	0	50	0	50	50*
	S5	0	0	0	0	0	0	0	0	0	50	0	100	50	100	100*
/ɭ/	S1	0	0	0	0	0	0	0	0	0	50	100*	50	0	100	0
	S2	0	0	0	0	0	0	0	0	0	100	0	100	50	100	100*
	S3	0	0	0	0	0	0	0	0	0	0	0	50	50*	0	0

**Indicates the Highest PCC Score One-Month Post Cessation of Articulation Therapy. (In the Table, PCC-R Refers to Percentage Consonant Correct-Revised; S1 to S6 Participants; B1, B2, B3: The Three Pre-Intervention Baselines; P1: First Post-Intervention Evaluation; P2: Second Post-Intervention Evaluation).*

magnitude of correct production of the target phoneme in the context of vowel /u/ with minimal variability. PCC-R scores at P2 were also high in the context of vowel /u/ for all the participants (Table 2). But, at P1, relatively vowel /i/ seemed to facilitate the nasal retroflex more compared to vowel /u/. All participants demonstrated higher percentage correct scores within three articulatory therapy sessions in the context of vowel /u/ followed by vowels /i/ and /a/ (Figures 4, 9–12; Appendix V).

Vowel Effect on Lateral Retroflex /ɭ/

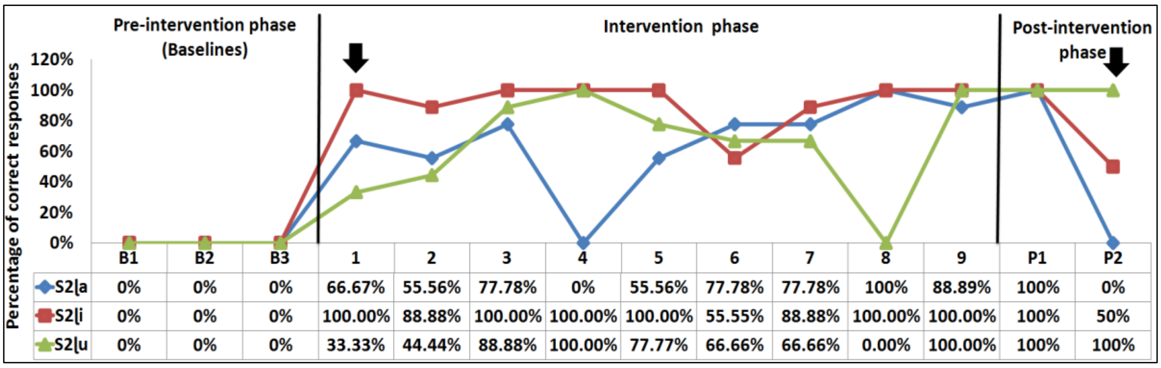
All three participants had differences in performance. For S2, vowel /i/ was facilitating with higher percentage correct response scores and minimum variability (Figure 4 and Table 2). In contrast, PCC scores at P2 were high in the context of vowel /u/ followed by /i/ and then /a/. S1 had stable performance in the context of vowel /u/ during intervention phase (Figure 13; Appendix V), but production of lateral retroflex was retained only in the context of /a/ at P2 (Table 2). During the intervention phase, percentage correct response score in the context of the vowel /a/ were relatively higher compared to /i/ for S3 (Figure 14; Appendix V). In contrast to S1 and S2, the PCC-R scores were retained in the context of /i/ only for S3 during both P1 and P2 (Table 2). P1-PCC-R scores were high in the context of vowel /u/ for S1, whereas it was the same in all three vowel contexts for S2. In sum, according to graphical analysis, the order of facilitating vowel contexts for voiceless /ʈ/ and voiced /ɖ/ retroflexes was /u/>/a/>/i/; for nasal retroflex /ɳ/, /u/>/i/≥/a/. For lateral retroflex /ɭ/, the order of facilitating vowels was inconclusive.



	B1	B2	B3	1	2	3	4	5	6	P1	P2
S2ɳa	0%	0%	0%	100%	100%	100%	100%	100%	100%	100%	50%
S2ɳi	0%	0%	0%	33.33%	77.77%	100.00%	100.00%	100.00%	100.00%	100%	50.00%
S2ɳu	0%	0%	0%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100%	100%

(S2ɳa: Subject 2, /ɳ/ in the Context of Vowel /a/; S2ɳi: Subject 2, /ɳ/ in Context of Vowel /i/; S2ɳu: Subject 2, /ɳ/ in the Context of Vowel /u/; ⬇: Indicates the Session Number at Which Vowel has Shown the Effect on the Target Sounds /ɳ/).

***Fig. 3:** Percentage Correct Response of Retroflex /ɳ/ Production in the Context of Vowels /a/, /i/, and /u/ by Subject 2(S2).*



	B1	B2	B3	1	2	3	4	5	6	7	8	9	P1	P2
S2ɭa	0%	0%	0%	66.67%	55.56%	77.78%	0%	55.56%	77.78%	77.78%	100%	88.89%	100%	0%
S2ɭi	0%	0%	0%	100.00%	88.88%	100.00%	100.00%	100.00%	55.55%	88.88%	100.00%	100.00%	100%	50%
S2ɭu	0%	0%	0%	33.33%	44.44%	88.88%	100.00%	77.77%	66.66%	66.66%	0.00%	100.00%	100%	100%

(S2ɭa: Subject 2, /ɭ/ in the Context of Vowel /a/; S1ɭi: Subject 2, /ɭ/ in Context of Vowel /i/; S2ɭu: Subject 2, /ɭ/ in the Context of Vowel /u/; ⬇: Indicates the Session Number at Which Vowel has Shown the Effect on the Target Sounds /ɭ/).

***Fig. 4:** Percentage Correct Response of Retroflex /ɭ/ Production in the Context of Vowels /a/, /i/, and /u/ by Subject 2(S2).*

Table 3: *The Effect Size for Nasal Retroflex /ɳ/ in All the Three Vowel Contexts.*

Phonemes	**Baseline-Post Evaluation 1**	**|z|**	**Effect Size-r**	**Baseline-Post Evaluation 2**	**|z|**	**Effect Size-R**
/ɳ/	/a/B-/a/P1	2.070	0.93	/a/B-/a/P2	1.633	0.71
	/i/B-/i/P1	2.121	0.95*	/i/B-/i/P2	1.857	0.83
	/u/B-/u/P1	1.890	0.85	/u/B-/u/P2	2.000	0.89*

**Highest Effect size; B: Baseline; P1: Post Evaluation 1; P2: Post Evaluation 2.*

The subjective graphical inference generally leads to bias and is inconclusive. Hence, the Wilcoxon signed rank test was run using SPSS version 17 for percentage raw score during B3 and P1 across the three vowel contexts. Significant differences in scores were present in all three vowel contexts for target nasal retroflex /ɳ/ only as the sample size was relatively high (n=5) compared to other target phonemes (n=3). Hence, the effect size was calculated only for nasal retroflex using the formula: |z|÷√n, to determine the order of facilitating vowels [49]. An effect size of ≥0.8 is considered to show a larger effect, and Table 3 depicts the results.

It is evident from Table 3, vowel /i/ (r=0.95) is facilitating the production of nasal retroflex at P1, whereas vowel /u/ (r=0.89) at P2. This result agrees with the results of the graphical analysis as well. Hence, vowels /u/ and /i/ are the highly facilitating contexts for the correct production of nasal retroflex compared to vowel /a/.

DISCUSSION

The current study examined the facilitatory effects of vowels /a/, /i/, and /u/ on the correct production of retroflex sounds /ʈ/, /ɖ/, /ɳ/, and /ɭ/ in children with SSD who received a structured word level intervention. Although all participants showed similar performance in acquiring the target speech sounds, there were differences across the participants regarding performance during the intervention, maintenance of the learned behavior during the post-intervention phase, and PCC-R scores between P1 and P2 which attributes to the individual variations and gender differences.

The graphical analysis revealed vowel /u/ facilitating the production of three retroflex sounds /ʈ/, /ɖ/, and /ɳ/, whereas it was inconclusive for lateral retroflex /ɭ/. In addition, the effect size for the correct production of nasal retroflex reflected vowel /u/ to be most facilitating. These results are attributable to the physiological basis underlying the production of target phonemes and the vowel contexts. The ultrasound analysis of the tongue contours revealed that the production of Kannada retroflex /ʈ/, /ɖ/, and /ɳ/ involves tongue tip elevation with a narrow stretch of constriction of the tongue blade at the palate [50]. Another supporting ultrasound imaging study reported retroflex sounds in Kannada to be highly co-articulating in the context of following vowel /u/ compared to other vowels [51]. On the other hand, the lateral-retroflex /ɭ/ is produced as sub-apical palatal with a concave tongue shape with a back curl of the tongue tip and a larger area constriction of the underside tongue at the hard-palate [52]. Proctor *et al.* reported retroflex stops and nasal to be more susceptible to vowel coarticulation as the back-cavity volume is more compared to lateral retroflex [53].

In association with Swisher's physiological reasoning [25], the context minimally interfering or competing with the error sound is facilitating and accordingly, the back vowel /u/ is minimally competing with the tongue tip movement required for retroflex (/ʈ/, /ɖ/, and /ɳ/) production and thus, facilitating. The literature also reports that the presence of similarity between the error sound and the phonetic neighbor is also a facilitating condition. This condition is observed during typical speech development in toddlers of the first fifty-word stage by Shishira and Sreedevi in Kannada [8]. Vowel /i/ was found to facilitate the production of coronal sounds (subapical retroflex of Kannada). This result is not in consonance with the present study results; perhaps because school-aged children have higher efficiency in using different regions of the tongue as separate articulators compared to toddlers in speech. This is attributable to the improved neural control over speech articulators in school-aged children [54–56].

The results of the current study are not in agreement with the report of Krishna and Manjula that vowels /a/ and /i/ are facilitating the production of unvoiced retroflex /ʈ/ [26]. These differences attribute to the age of the participants. Also, the second facilitating context for /ʈ/ was vowel /i/; attributes to the similarity in place of articulation. In the present study, vowel /a/ was the least facilitating context for all the retroflexes considered because the transition distance and duration of the tongue movement seems to be more in the context of the mid-low vowel /a/ compared to other two high vowels. In addition to the age factor, another significant contributing reason could be the sample size. Despite both being case studies, the former study had a single participant, and the current study included three participants for the target voiceless retroflex /ʈ/. Another contributing factor can be the difference in the measurements used. Krishna and Manjula considered acoustic measures, whereas the present study included behavioral measurements [26]. Even intervention procedural variations in both the studies could have caused disagreement in results. In the present study, the target phonemes were taught at word level using phonetic placement approach whereas in Krishna and Manjula's study [26], intervention involved a hierarchy of steps: auditory training and discrimination tasks followed by multisensory with phonetic placement approach in isolation followed by production of target in various contexts at non-word and then word level.

From the discussion, it is apparent that age and neuronal control may be related to the differences in facilitating vowel context for phonemes in a particular language. The FCT may be age dependent [2]. As the frames develop, the contextual effects possibly differ leading to such variations in results. These findings need further in-depth research.

CONCLUSIONS

Children in the developmental age are at risk for speech sound disorder. Clinical observations report that 90% of frequently erred sounds in Kannada are retroflex and hence, this study confined to it. The results revealed that the production of /ʈ/, /ɖ/, and /ɳ/ are highly facilitated in the context of /u/ followed by /i/ and then /a/; the facilitating vowel context for lateral retroflex /ɭ/ is unclear.

IMPLICATIONS AND FUTURE DIRECTIONS

Replication of such studies is warranted to validate the present findings as the sample size considered in the current study was small. However, logical generality is applicable. Such facilitating context based studies are essential to guide speech-language pathologists for effective intervention program ensuring faster speech correction. Future investigations should deal with the effect of other contextual factors such as word position, neighboring phonemes, and clusters, as these also act in combination with vowel contexts in facilitating phoneme production. Also, similar studies should be replicated in different languages as coarticulation is language specific.

ACKNOWLEDGEMENTS

The present study is a part of an ongoing doctoral thesis on "Effect of vowel contexts and phoneme positions on the articulation of phonemes in children with speech sound disorder: Pre-post therapy comparison." The authors would like to thank the Director of the Institute for permitting to carry out the study and the children and their parents for their participation in the study.

Declaration of Interest

The authors report no declarations of interest.

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Cite this Article
Rao Amulya P, Sreedevi N. The Contextual Effect of Vowels on Correct Production of Retroflex in Kannada Speaking Children with Speech Sound Disorder: A Case Study. *Research & Reviews: Journal of Computational Biology*. 2018; 7(2): 46–66p.

Appendix 1: *Kannada Vowel and Consonant Inventory (Irene Thompson, 2016).*

Vowels

The Mysore dialect of Kannada has 15 vowel phonemes, i.e., sounds that make a difference in word meaning. All but one vowel (/ə/) can be short or long. Vowel length makes a difference in word meaning. In addition, there are two diphthongs: /ai/ and /au/.

	Front	**Central**	**Back**
Close	i, ī		u, ū
Close-mid	e, ē		o, ō
Mid		ə	
Open-mid	ɛ, ɛ̄		ɔ, ɔ̄
Open		a, ā	

- /ɛ/=*e* in *bed*
- /ə/= *a* in *about*
- /ɔ/= *o* in *bog*

Consonants

Mysore Kannada has a large number of consonant phonemes, i.e., sounds that make a difference in word meaning. The consonant system is characterized by the fact that besides a Dravidian inventory, it includes a number of features typical of Indo-Aryan languages. Below are some of the typical features:

- A contrast between apical and retroflex consonants, e.g., /t̪/–/ʈ/. Apical consonants are produced with the tip of the tongue touching the roof of the mouth, whereas retroflex consonants are produced with the tongue curled, so that its underside comes in contact with the roof of the mouth.
- A contrast between plain and aspirated stops.
- Limited occurrence of consonant clusters in final position.
- Gemination, or doubling, of consonants (doubled).

		Bilabial	Labiodental	Apicodental	Alveolar	Retroflex	Palato-alveolar	Velar	Glottal
Stops	voiceless plain/aspirated	p p^h		t̪ t̪ ʈ		ʈ ʈ^h		k k^h	
	voiced plain/aspirated	b b^h		d̪ d̪^{h}		ɖ ɖ^h		g g^h	
Fricatives	voiceless		F		s (z)*	ʂ	ʃ		h
Affricates	voiceless/voiced					Xx	tʃdʒ		
Nasals		M		n̪		ɳ	ɲ	ŋ	
Trill					r				
Laterals				l̪		ɭ			
Approximants			ʋ	.xx			j		

The Encircled Phonemes were Considered as Targets (Dependent Variables) in the Present Study.

- /ʈ, ɖ, ɳ, ʂ, ɭ, ɻ/ are retroflex consonants with no equivalents in English.
- /t̪, d̪, n̪, l̪/ are pronounced with the tip of the tongue touching the back of the front teeth.
- ʃ=*sh* in *shop.*
- /tʃ/=*ch* in *chop.*
- *z occurs only in borrowed words.
- /dʒ/=*j* in *job.*
- /ɲ/=first *n* in *canyon.*
- /ŋ/=*ng* in *song.*
- /ʋ/ has no equivalent in English.
- /j/=*y* in *yet.*

Reference

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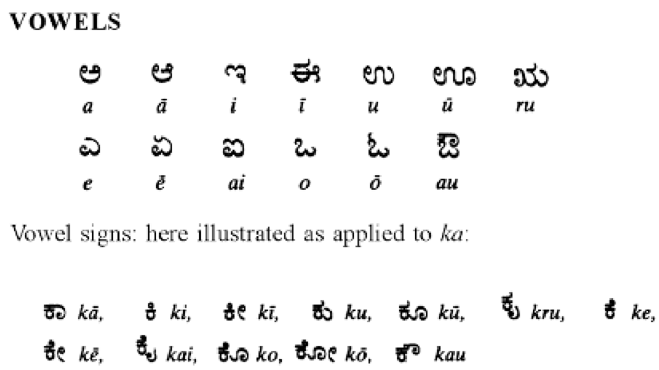
Modern Kannada Inventory of Consonants and Vowels (Campbell & Moseley, 2012)

CONSONANTS

ಕ *ka*	ಖ *kha*	ಗ *ga*	ಘ *gha*	ಙ *nga*
ಚ *ca*	ಛ *cha*	ಜ *ja*	ಝ *jha*	ಞ *nya*
ಟ *ṭa*	ಠ *ṭha*	ಡ *ḍa*	ಢ *ḍha*	ಣ *ṇa*
ತ *ta*	ಥ *tha*	ದ *da*	ಧ *dha*	ನ *na*
ಪ *pa*	ಫ *pha*	ಬ *ba*	ಭ *bha*	ಮ *ma*
ಯ *ya*	ರ *ra*	ಲ *la*	ವ *va*	
ಶ *śa*	ಷ *ṣa*	ಸ *sa*	ಹ *ha*	ಳ *ḷa*



Reference

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Appendix II: *Examples of Words in Which the Errors are Made with a Gloss.*

Target Sound	Target Word	Glossary	Erred Production*
/ʈ/	/ʈapa:lu/	Rack to keep books	/tapa:lu/
	/gaʈʈi/	Strong	/gatti/
/ɖ/	/ɖabbi/	Box	/dabbi/
	/baɖava/	Poor man	/badava/
/ɳ/	/kaɳɳu/	Eye	/kannu/
	/gaɳapa/	A Hindu God name	/ganapa/
/ɭ/	/keɭage/	Down	/kelage/
	/biɭi/	White	/bili/

***All these retroflexes are substituted by dental sounds.*

Appendix III: *Examples of Stimuli Words.*

Target Sound	Target Word	Glossary
/ʈ/	/ʈagaru/	Goat
	/buʈʈi/	Basket
	/uppiʈʈu/	A breakfast dish
/ɖ/	/ɖabbi/	Box
	/manɖi/	Knee
	/laɖɖu/	A sweet
/ɳ/	/baɳɳa/	Color
	/maɳi/	Pearl
	/kaɳɳu/	Eye
/ɭ/	/kaɭɭa/	Thief
	/baɭɭi/	Creeper
	/muɭɭu/	Thorn

Appendix IV: *Number of Intervention Stimuli per Target.*

Target Sound	/a/	/i/	/u/
/ʈ/	6	6	6
/ɖ/	6	6	4
/ɳ/	3	3	3
/ɭ/	3	3	3

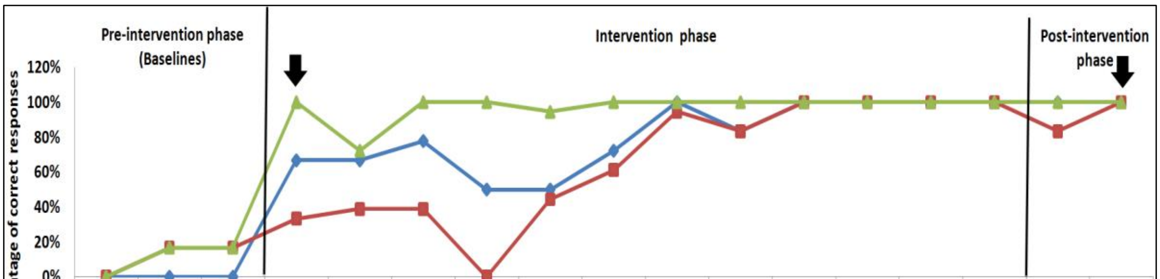
**A score of "1" given for each correctly produced target word.*

- There are only three targets in each context for /ɳ/ and /ɭ/ as they are present only in the medial position of words in Kannada.
- This wordlist was prepared as a part of PhD study.

Maximum Score Chart (3 Order Random Presentations)

Target Sound	/a/	/i/	/u/
/ʈ/	6×3=18	6×3=18	6×3=18
/ɖ/	6×3=18	6×3=18	4×3=18
/ɳ/	3×3=9	3×3=9	3×3=9
/ɭ/	3×3=9	3×3=9	3×3=9

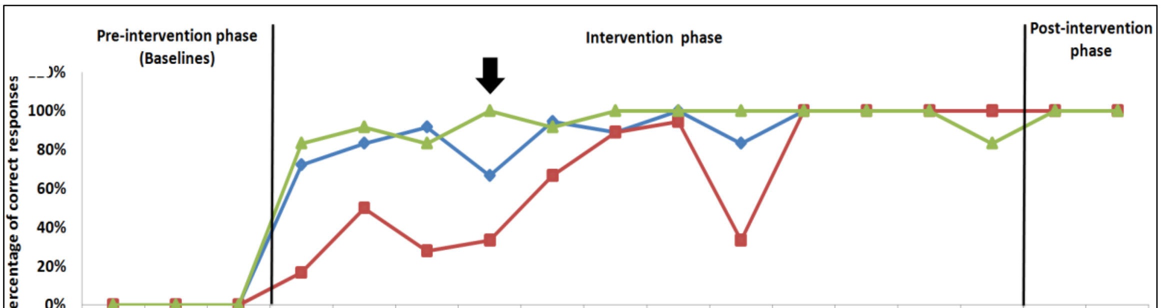
Appendix V: Figures



	B1	B2	B3	1	2	3	4	5	6	7	8	9	10	11	12	P1	P2
S2ʈa	0%	0%	0%	66.67%	66.67%	77.78%	50%	50%	72.22%	100%	83.33%	100%	100%	100%	100%	100%	100.00%
S2ʈi	0%	16.67%	16.67%	33.33%	38.89%	38.89%	0%	44.44%	61.11%	94.44%	83.33%	100%	100%	100%	100%	83.33%	100%
S2ʈu	0%	16.67%	16.67%	100%	72.22%	100%	100%	94.44%	100%	100%	100%	100%	100%	100%	100%	100%	100.00%

(S2ʈa: Subject 2, /ʈ/ in the Context of Vowel /a/; S2ʈi: Subject 2, /ʈ/ in Context of Vowel /i/; S2ʈu: Subject 2, /ʈ/ in the Context of Vowel /u/; ⬇: Indicates the Session Number at Which Vowel has Shown the Effect on the Target Sounds /ʈ/.)

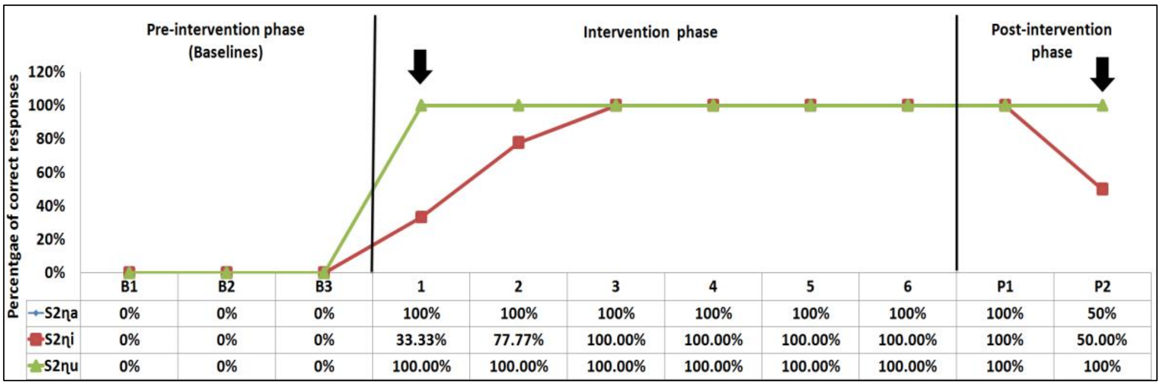
***Fig. 1:** Percentage Correct Response of Retroflex /ʈ/ Production in the Context of Vowels /a/, /i/, and /u/ by Subject 2(S2).*



	B1	B2	B3	1	2	3	4	5	6	7	8	9	10	11	12	P1	P2
S2ɖa	0%	0%	0%	72.22%	83.33%	91.67%	66.67%	94.44%	88.89%	100%	83.33%	100%	100%	100%	100%	100%	100%
S2ɖi	0%	0%	0%	16.67%	50%	27.78%	33.33%	66.67%	89%	94.44%	33.33%	100%	100%	100%	100%	100%	100%
S2ɖu	0%	0%	0%	83.33%	91.67%	83.33%	100%	91.67%	100%	100%	100%	100%	100%	100%	83.33%	100%	100%

(S2ɖa: Subject 2, /ɖ/ in the Context of Vowel /a/; S2ɖi: Subject 2, /ɖ/ in Context of Vowel /i/; S2ɖu: Subject 2, /ɖ/ in the Context of Vowel /u/; ⬇: Indicates the Session Number at Which Vowel has Shown the Effect on the Target Sounds /ɖ/.)

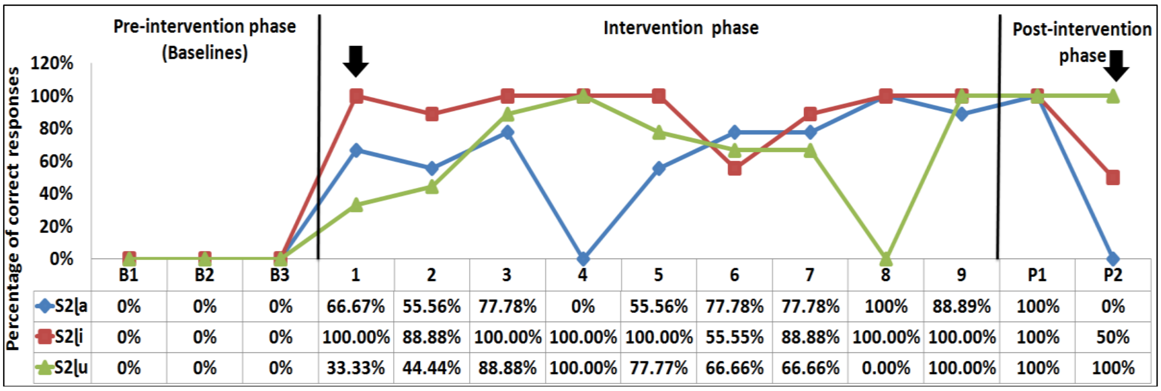
***Fig. 2:** Percentage Correct Response of Retroflex /ɖ/ Production in the Context of Vowels /a/, /i/, and /u/ by Subject 2(S2).*



	B1	B2	B3	1	2	3	4	5	6	P1	P2
S2ɳa	0%	0%	0%	100%	100%	100%	100%	100%	100%	100%	50%
S2ɳi	0%	0%	0%	33.33%	77.77%	100.00%	100.00%	100.00%	100.00%	100%	50.00%
S2ɳu	0%	0%	0%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100%	100%

(S2ɳa: Subject 2, /ɳ/ in the Context of Vowel /a/; S2ɳi: Subject 2, /ɳ/ in Context of Vowel /i/; S2ɳu: Subject 2, /ɳ/ in the Context of Vowel /u/; ⬇: Indicates the Session Number at Which Vowel has Shown the Effect on the Target Sounds /ɳ/.)

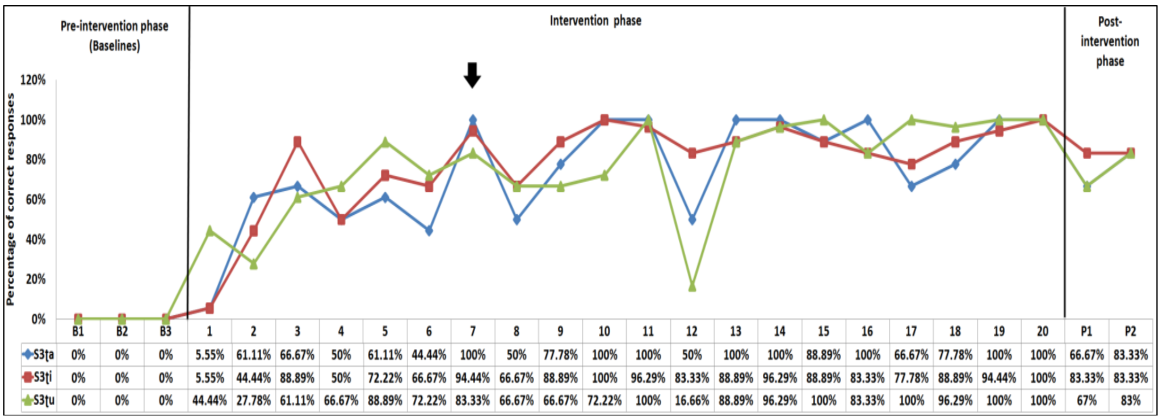
Fig. 3: *Percentage Correct Response of Retroflex /ɳ/ Production in the Context of Vowels /a/, /i/, and /u/ by Subject 2(S2).*



	B1	B2	B3	1	2	3	4	5	6	7	8	9	P1	P2
S2ɭa	0%	0%	0%	66.67%	55.56%	77.78%	0%	55.56%	77.78%	77.78%	100%	88.89%	100%	0%
S2ɭi	0%	0%	0%	100.00%	88.88%	100.00%	100.00%	100.00%	55.55%	88.88%	100.00%	100.00%	100%	50%
S2ɭu	0%	0%	0%	33.33%	44.44%	88.88%	100.00%	77.77%	66.66%	66.66%	0.00%	100.00%	100%	100%

(S2ɭa: Subject 2, /ɭ/ in the Context of Vowel /a/; S1ɭi: Subject 2, /ɭ/ in Context of Vowel /i/; S2ɭu: Subject 2, /ɭ/ in the Context of Vowel /u/; ⬇: Indicates the Session Number at Which Vowel has Shown the Effect on the Target Sounds /ɭ/.)

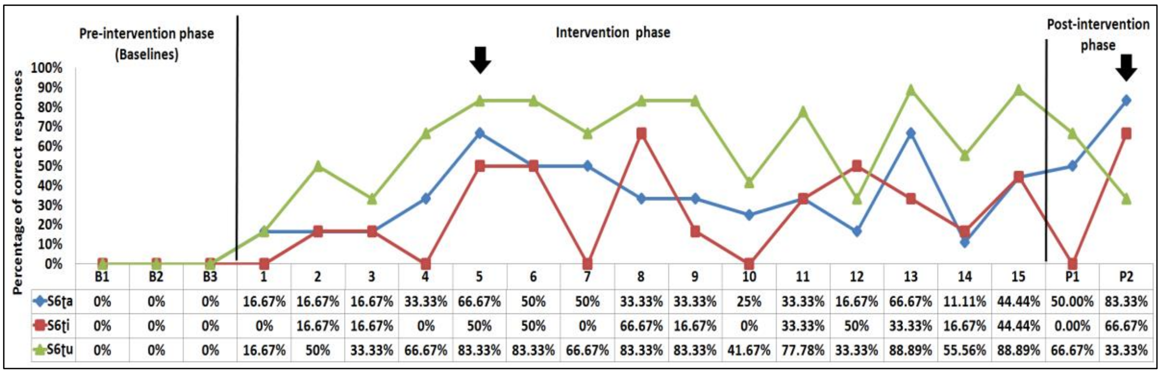
Fig. 4: *Percentage Correct Response of Retroflex /ɭ/ Production in the Context of Vowels /a/, /i/, and /u/ by Subject 2(S2).*



	B1	B2	B3	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	P1	P2
S3ʈa	0%	0%	0%	5.55%	61.11%	66.67%	50%	61.11%	44.44%	100%	50%	77.78%	100%	100%	50%	100%	100%	88.89%	100%	66.67%	77.78%	100%	100%	66.67%	83.33%
S3ʈi	0%	0%	0%	5.55%	44.44%	88.89%	50%	72.22%	66.67%	94.44%	66.67%	88.89%	100%	96.29%	83.33%	88.89%	96.29%	88.89%	83.33%	77.78%	88.89%	94.44%	100%	83.33%	83.33%
S3ʈu	0%	0%	0%	44.44%	27.78%	61.11%	66.67%	88.89%	72.22%	83.33%	66.67%	66.67%	72.22%	100%	16.66%	88.89%	96.29%	100%	83.33%	100%	96.29%	100%	100%	67%	83%

(S3ʈa: Subject 3, /ʈ/ in the Context of Vowel /a/; S3ʈi: Subject 3, /ʈ/ in Context of Vowel /i/; S3ʈu: Subject 3, /ʈ/ in the Context of Vowel /u/; ⬇: Indicates the Session Number at Which Vowel has Shown the Effect on the Target Sounds /ʈ/.)

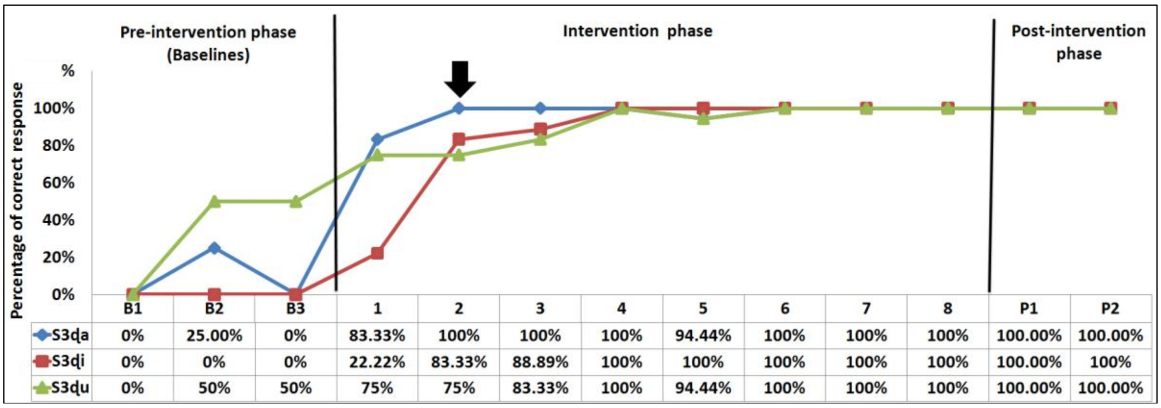
Fig. 5: *Percentage Correct Response of Retroflex /ʈ/ Production in the Context of Vowels /a/, /i/, and /u/ by Subject 3(S3).*



	B1	B2	B3	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	P1	P2
S6ʈa	0%	0%	0%	16.67%	16.67%	16.67%	33.33%	66.67%	50%	50%	33.33%	33.33%	25%	33.33%	16.67%	66.67%	11.11%	44.44%	50.00%	83.33%
S6ʈi	0%	0%	0%	0%	16.67%	16.67%	0%	50%	50%	0%	66.67%	16.67%	0%	33.33%	50%	33.33%	16.67%	44.44%	0.00%	66.67%
S6ʈu	0%	0%	0%	16.67%	50%	33.33%	66.67%	83.33%	83.33%	66.67%	83.33%	83.33%	41.67%	77.78%	33.33%	88.89%	55.56%	88.89%	66.67%	33.33%

(S6ʈa: Subject 6, /ʈ/ in the Context of Vowel /a/; S6ʈi: Subject 6, /ʈ/ in Context of Vowel /i/; S6ʈu: Subject 6, /ʈ/ in the Context of Vowel /u/; ⬇: Indicates the Session Number at Which Vowel has Shown the Effect on the Target Sounds /ʈ/.)

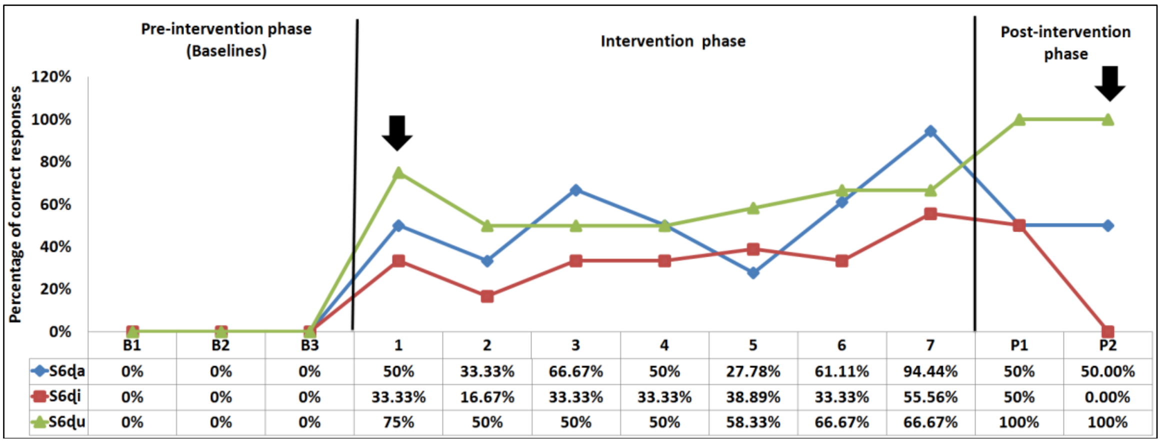
Fig. 6: *Percentage Correct Response of Retroflex /ʈ/ Production in the Context of Vowels /a/, /i/, and /u/ by Subject 6(S6).*



	B1	B2	B3	1	2	3	4	5	6	7	8	P1	P2
S3ɖa	0%	25.00%	0%	83.33%	100%	100%	100%	94.44%	100%	100%	100%	100.00%	100.00%
S3ɖi	0%	0%	0%	22.22%	83.33%	88.89%	100%	100%	100%	100%	100%	100.00%	100%
S3ɖu	0%	50%	50%	75%	75%	83.33%	100%	94.44%	100%	100%	100%	100.00%	100.00%

(S3ɖa: Subject 3, /ɖ/ in the Context of Vowel /a/; S3ɖi: Subject 3, /ɖ/ in Context of Vowel /i/; S3ɖu: Subject 3, /ɖ/ in the Context of Vowel /u/; ⬇: Indicates Point at Which Vowel has Shown the Effect on the Target Sounds /ɖ/.)

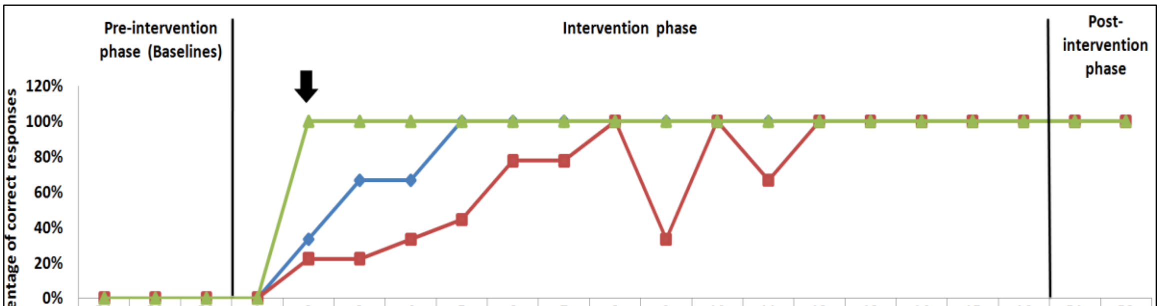
Fig. 7: *Percentage Correct Response of Retroflex /ɖ/ Production in the Context of Vowels /a/, /i/, and /u/ by Subject 3(S3).*



	B1	B2	B3	1	2	3	4	5	6	7	P1	P2
S6ɖa	0%	0%	0%	50%	33.33%	66.67%	50%	27.78%	61.11%	94.44%	50%	50.00%
S6ɖi	0%	0%	0%	33.33%	16.67%	33.33%	33.33%	38.89%	33.33%	55.56%	50%	0.00%
S6ɖu	0%	0%	0%	75%	50%	50%	50%	58.33%	66.67%	66.67%	100%	100%

(S6ɖa: Subject 6, /ɖ/ in the Context of Vowel /a/; S6ɖi: Subject 6, /ɖ/ in Context of Vowel /i/; S6ɖu: Subject 6, /ɖ/ in the Context of Vowel /u/; ⬇: Indicates the Session Number at Which Vowel has Shown the Effect on the Target Sounds /ɖ/.)

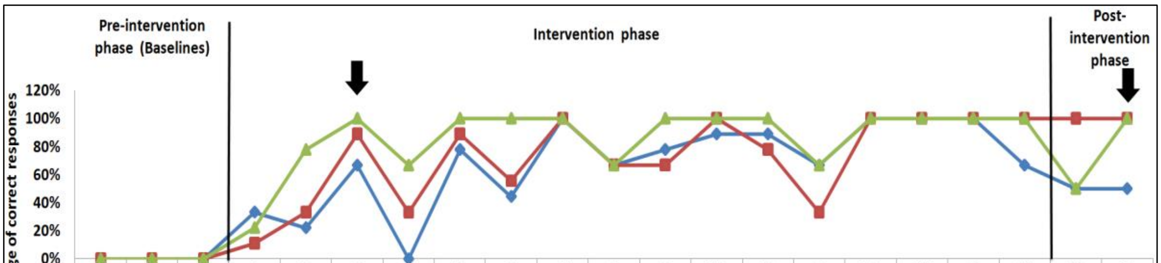
Fig. 8: *Percentage Correct Response of Retroflex /ɖ/ Production in the Context of Vowels /a/, /i/, and /u/ by Subject 6 (S6).*



	B1	B2	B3	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	P1	P2
S1ɳa	0%	0%	0%	0%	33.33%	66.67%	66.67%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
S1ɳi	0%	0%	0%	0.00%	22.22%	22.22%	33.33%	44.44%	77.77%	77.77%	100.00	33.33%	100.00	66.66%	100.00	100.00	100.00	100.00	100.00	100%	100%
S1ɳu	0%	0%	0%	0.00%	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100%	100%

(S1ɳa: Subject 1, /ɳ/ in the Context of Vowel /a/; S1ɳi: Subject 1, /ɳ/ in Context of Vowel /i/; S1ɳu: Subject 1, /ɳ/ in the Context of Vowel /u/; ⬇: Indicates the Session Number at Which Vowel has Shown the Effect on the Target Sounds /ɳ/.)

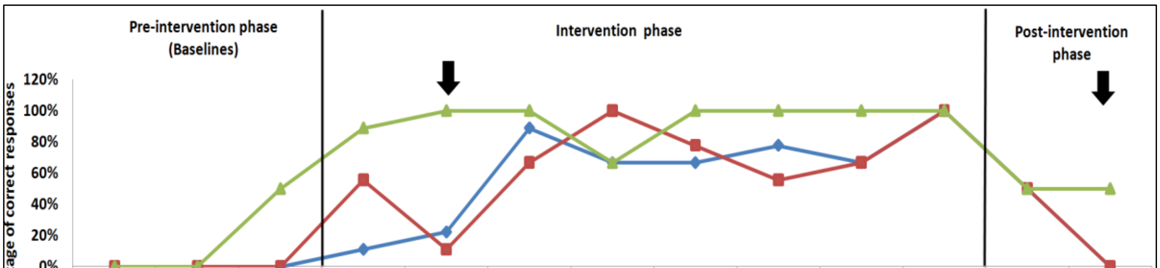
Fig. 9: *Percentage Correct Response of Retroflex /ɳ/ Production in the Context of Vowels /a/, /i/, and /u/ by Subject 1(S1).*



	B1	B2	B3	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	P1	P2
S3ɳa	0%	0%	0%	33%	22.22%	66.67%	0%	77.78%	44.44%	100%	66.67%	77.78%	88.89%	88.89%	66.67%	100%	100%	100%	66.67%	50%	50%
S3ɳi	0%	0%	0%	11.11%	33.33%	88.88%	33.33%	88.88%	55.55%	100.00	66.66%	66.66%	100.00	77.77%	33.33%	100.00	100.00	100.00	100.00	100%	100%
S3ɳu	0%	0%	0%	22.22%	77.77%	100.00	66.66%	100.00	100.00	100.00	66.66%	100.00	100.00	100.00	66.66%	100.00	100.00	100.00	100.00	50%	100%

(S31ɳa: Subject 3, /ɳ/ in the Context of Vowel /a/; S3ɳi: Subject 3, /ɳ/ in Context of Vowel /i/; S3ɳu: Subject 3, /ɳ/ in the Context of Vowel /u/; ⬇: Indicates the Session Number at Which Vowel has Shown the Effect on the Target Sounds /ɳ/.)

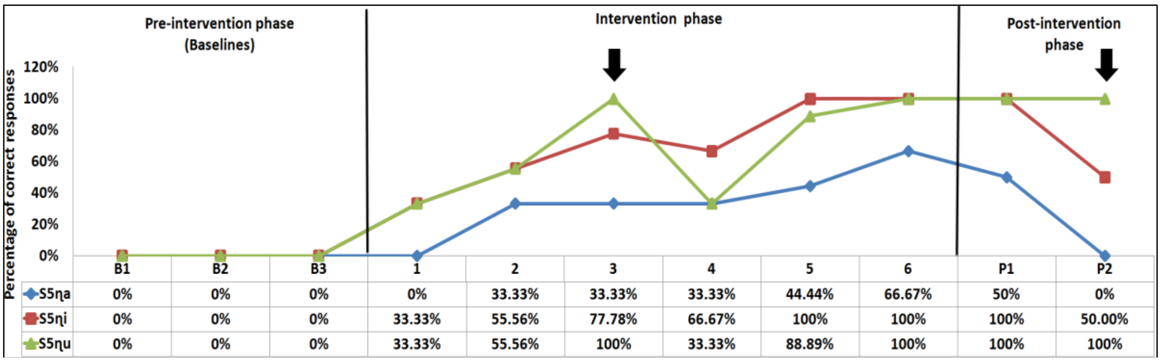
Fig. 10: *Percentage Correct Response of Retroflex /ɳ/ Production in the Context of Vowels /a/, /i/, and /u/ by Subject 3(S3).*



	B1	B2	B3	1	2	3	4	5	6	7	8	P1	P2
S4ɳa	0%	0%	0%	11.11%	22.22%	88.89%	66.66%	66.67%	77.78%	66.67%	100%	50%	0%
S4ɳi	0%	0%	0%	55.56%	11.11%	66.67%	100%	77.78%	55.56%	66.67%	100%	50%	0%
S4ɳu	0%	0%	50%	88.89%	100%	100%	67%	100%	100%	100%	100%	50%	50%

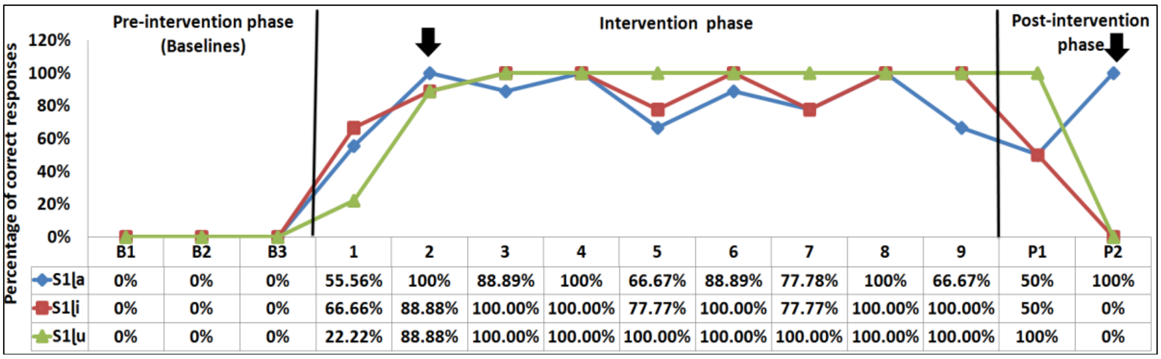
(S4ɳa: Subject 4, /ɳ/ in the Context of Vowel /a/; S4ɳi: Subject 4, /ɳ/ in Context of Vowel /i/; S4ɳu: Subject 4, /ɳ/ in the Context of Vowel /u/; ⬇: Indicates the Session Number at Which Vowel has Shown the Effect on the Target Sounds /ɳ/.)

Fig. 11: *Percentage Correct Response of Retroflex /ɳ/ Production in the Context of Vowels /a/, /i/, and /u/ by Subject 4(S4).*



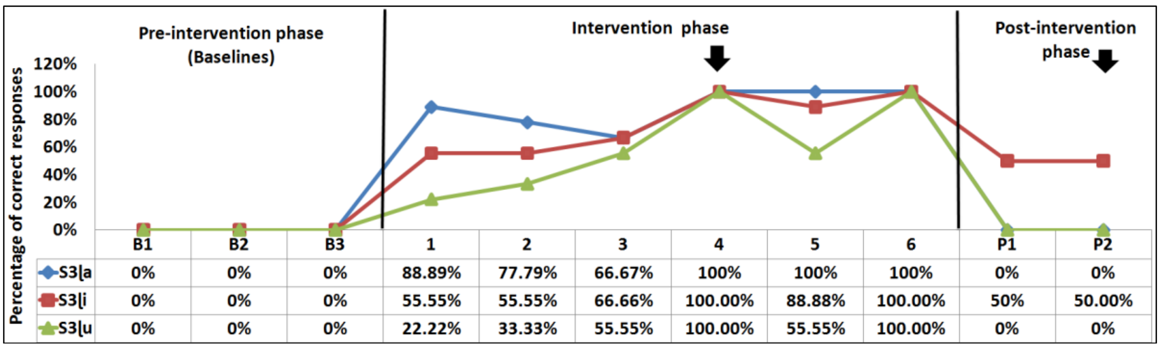
(S5ɳa: Subject 5, /ɳ/ in the Context of Vowel /a/; S5ɳi: Subject 5, /ɳ/ in Context of Vowel /i/; S5ɳu: Subject 5, /ɳ/ in the Context of Vowel /u/; ⬇: Indicates the Session Number at Which Vowel has Shown the Effect on the Target Sounds /ɳ/.)

Fig. 12: *Percentage Correct Response of Retroflex /ɳ/ Production in the Context of Vowels /a/, /i/, and /u/ by Subject 5(S5).*



(S1ɭa: Subject 1, /ɭ/ in the Context of Vowel /a/; S1ɭi: Subject 1, /ɭ/ in Context of Vowel /i/; S1ɭu: Subject 1, /ɭ/ in the Context of Vowel /u/; ⬇: Indicates the Session Number at Which Vowel has Shown the Effect on the Target Sounds /ɭ/.)

Fig. 13: *Percentage Correct Response of Retroflex /ɭ/ Production in the Context of Vowels /a/, /i/, and /u/ by Subject 1(S1).*



(S3ɭa: Subject 3, /ɭ/ in the Context of Vowel /a/; S3ɭi: Subject 3, /ɭ/ in Context of Vowel /i/; S3ɭu: Subject 3, /ɭ/ in the Context of Vowel /u/; ⬇: Indicates the Session Number at Which Vowel has Shown the Effect on the Target Sounds /ɭ/.)

Fig. 14: *Percentage Correct Response of Retroflex /ɭ/ Production in the Context of Vowels /a/, /i/, and /u/ by Subject 3(S3).*