PROJECT REPORT

Development and Validation of Web-Based Auditory and Auditory-Cognitive Training Program in Kannada for Children with Central Auditory Processing Disorder

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Abstract

Objective: This project focused on the development and validation of an interactive, web-based auditory-cognitive training application for children aged 7 to 12 years with Central Auditory Processing Disorder (CAPD) who are native speakers of the Kannada language.

Design: An expert-driven modified Delphi process was used for content creation and module refinement to ensure clinical content validity and age appropriateness. The web-based application was developed and loaded with training materials prepared for the Auditory and Auditory-Cognitive modules. The web-based application was evaluated for usability and engagement using the User Mobile Application Rating Scale (uMARS) among Audiologists. Training was given to 15 children diagnosed as having CAPD. They were divided into three groups: auditory training alone, auditory and auditory-cognitive training, and a waiting group. Before the initiation of training, a pre-training evaluation was conducted to assess frequency discrimination, temporal resolution, speech-in-noise perception, and responses to probe stimuli from the training material. Training was initiated, and the evaluations were repeated 1 month and 2 months post-training.

Results: The study's findings revealed that the auditory and auditory-cognitive training modules demonstrated strong content validity. The ratings of the uMARS received high scores for functionality, aesthetics, and overall quality. Both auditory-only training and combined auditory-cognitive training significantly improved frequency discrimination, speech perception in noise, and scores obtained for the different probe stimuli used in auditory training. Children who received additional auditory-cognitive training also showed improvement in the working memory tasks.

Conclusion: It can be concluded that the web platform provided accessible, home-based training, suggesting a technology-driven management tool for children with CAPD .

Chapter 1

Introduction

Central auditory processing disorder (CAPD) refers to a dysfunction of the central auditory nervous system that contributes to difficulties with the perceptual processing of auditory information (Weihing et al., 2015). This is reflected in the poor scores or development of skills such as sound localisation and lateralisation, auditory pattern recognition, auditory discrimination, temporal aspects of auditory processing and auditory performance in the presence of competing noise (Lotfi, Moosavi, et al., 2016). In addition, children with CAPD have a selective attention deficit and limited cognitive capacity (Stavrinos et al., 2018). These deficits have an impact on the speech perception abilities of children with CAPD (Lotfi, Moosavi, et al., 2016). Structured auditory intervention undergoes neuroplasticity, which induces reorganisation of the cortex and brainstem, thereby improving synaptic efficiency and neural density, and giving rise to associated cognitive and behavioural changes.(Voss et al., 2017).

Evidence from multiple studies indicates that traditional auditory training protocols improve specific auditory skills such as binaural integration, temporal processing, and dichotic listening, which are core components of CAPD (Carvalho et al., 2025; Mahdavi et al., 2021; Stephenson, 2008). These findings align with theoretical models positing that CAPD involves deficits in these discrete auditory domains. The observed correlation between improvements in auditory processing measures and functional listening abilities, including speech-in-noise perception and classroom listening, suggests that auditory training effects extend beyond laboratory tasks to real-world communication contexts (Loo et al., 2016).

Memory-focused cognitive training integrated into auditory interventions improves verbal memory, attention, and working memory, which are critical for auditory processing in noisy environments. Interventions combining auditory training with memory booster techniques show significant gains in auditory memory and functional listening skills, as indicated by behavioural and electrophysiological assessments (Cameron et al., 2015; Cameron & Dillon, 2011; Loo et al., 2016; Melo et al., 2016)Studies also note the interplay between auditory processing and higher-order cognitive functions in enhancing speech-in-noise comprehension (Barker et al., 2017; Loo et al., 2016).

The integration of bottom-up and top-down auditory training approaches, including cognitive auditory training, aligns with models that emphasise the interaction between sensory processing and higher-order cognitive functions such as attention and memory (Vendruscolo et al., 2023). Comparative studies show both bottom-up (sensory-driven) and top-down (cognitive-driven) auditory training methods can enhance auditory processing skills, with some evidence suggesting combined or tailored approaches yield better outcomes. Randomized controlled trials indicate that bottom-up training improves fundamental auditory discrimination, while top-down training enhances linguistic and memory aspects (Ahmadpour et al., 2018; Sharma et al., 2012).

Research efforts focus on developing and validating computerised auditory and auditory cognitive training programs targeting specific auditory and memory deficits, with positive preliminary efficacy demonstrated in pediatric populations (Aghaie et al., 2018; Cameron & Dillon, 2011; Luís et al., 2023)Aghaie et al., 2018, Cameron & Dillon, 2011, Luís et al., 2022). Computer-based programs with a guided approach offer accessibility and standardised delivery, provide tailored feedback and adaptability (Vendruscolo et al., 2023).

The linguistic resources used for therapy in the aforementioned studies are primarily in English, with no materials available in native languages such as Kannada. Kannada is the official language of Karnataka and is spoken by over 44 million people, according to the Census of India. Karnataka covers an area of approximately 191,791 square kilometres**,** comprising urban, semi-urban, and rural populations, with limited access to specialised auditory services in many regions. Globally, the prevalence of CAPD is reported to be 2% to 5% in school-aged children (Chermak & Musiek, 2002). In a study conducted in Mysuru by Muthuselvi (2009) and Muthuselvi and Yathiraj (2010), a prevalence of CAPD of 3% and 5.9% (Yathiraj & Vanaja, 2018) was observed in school-aged children. This implies that potentially many Kannada-speaking children in Karnataka may require CAPD evaluation and intervention. The need for linguistically and culturally relevant tools for this population is crucial, especially given the lack of Kannada-language CAPD training modules.

Need for auditory-cognitive training in children with CAPD

Auditory training facilitates bottom-up sensory processing of speech sounds, while auditory cognitive training modules enable top-down sensory processing, particularly in challenging listening situations (Henshaw & Ferguson, 2013; Pichora-Fuller & Levitt, 2012). Cognitive training refers to engagement with standardised, cognitively challenging tasks to improve different cognitive functions (Lampit et al., 2014). Both approaches aim to exploit neural plasticity to improve speech perception. Auditory cognitive training has a positive impact on speech perception. Speech perception in noise is a complex task that requires the optimum role of the cognitive system. Working memory capacity varies across individuals (Daneman & Carpenter, 1980). The involvement of working memory in speech perception varies depending on the difficulty of the listening conditions (Rudner et al., 2011). The situation becomes more cognitively demanding if the incoming signal is distorted or has limited information. In that case, rapid access to the phonological loop, working memory capacity, selective attention, and high-speed information processing become more critical to understanding spoken language. Conway et al. (2001) have reported that higher working memory capacity is required for selective attention. Selective listening skills appear to be one of the primary requisites for speech perception in noise.

An integrated framework by Magimairaj & Nagaraj (2018) explains that the combined impact of auditory processing deficits, working memory deficits, and language deficits leads to overall listening difficulty in individuals with CAPD. Additionally, the developmental overlap between auditory processing and working memory abilities highlights the connection between the two processes. In addition, an extensive population study by Moore et al. (2010)revealed that children with deficits in auditory processing scored low on both cognitive and communication measures. Additionally, a study by Ahmed et al. (2014) found that a cognitive factor associated with auditory processing issues affected the functional listening outcome. These studies indicate that individuals with CAPD not only have auditory deficits but also have cognitive deficits. Thus, providing only auditory training alone might not address the issues in the cognitive domain. Hence, to verify this notion, the study attempts to analyse whether providing additional training in the cognitive domain is effective. The combination of auditory and cognitive training yields greater benefits than auditory training alone in speech perception in noise. Thus, auditory cognitive training appears to be a helpful intervention strategy for re-adjusting auditory skills in subjects with CAPD. Auditory cognitive training will be instrumental in reorganising the neural substrate, providing appropriate experiences, shaping existing circuits in the CANS, and increasing the neural density, reflected by an improvement in behavioural evaluation. Moreover, to date, there is no auditory cognitive training module in the scheduled Indian language. As the first step, it is developed in the Kannada language, and later, the test stimuli in another official language of India can be recorded and loaded into the software.

Considering this viewpoint, the current study aims to address those lacunae and include cognition as a component in the management regime. Thus, intervention programs that combine listening and auditory working memory training may alleviate perceptual difficulties in children with CAPD.

Need for a web-based application for training of CAPD

Several studies in the literature have demonstrated that various computer-based programs, such as Fast Forward and the Earobics program, can improve the language, spelling, and reading skills of children (Tallal, 2013). There is some initial evidence to suggest that computer-based auditory training may be of benefit for children with APD (Loo et al., 2016). However, research is necessary to substantiate these preliminary findings. In addition, the barriers that lead to attrition in training for CAPD impact children with CAPD and may prevent them from receiving necessary intervention. Web-based applications provide an effective way to deliver training directly to clients in their homes. These tools offer flexibility, continuity of care, and overcome access barriers, particularly in under-resourced or geographically distant areas. A web-based intervention program can offer accessible training from the comfort of your own home. It also enables self-paced learning, accommodating varied schedules and minimising disruptions to daily routines or employment. Furthermore, digital delivery can significantly lower costs, making training more financially accessible (Pichora-Fuller & Levitt, 2012). Overall, such remote programs not only expand reach but also promote sustained engagement and reduce attrition, thereby enhancing the overall effectiveness and equity of the intervention (Rezaei-Hanjani et al., 2022).

Web-based training intervention software has become increasingly prominent due to its capacity to address specific client requirements. A series of instructions is provided in the software, along with options for interacting with the training program. The interactive training module involves client participation in decision-making, strategy development, and competition. These factors enhance intrinsic motivation to use it regularly and consistently.

Thus, in the present project, an attempt was made to develop interactive auditory cognitive software to aid in the management of children with CAPD.

Need for Quality Assessment

Assessing the usability and engagement of the web-based application becomes a crucial first step to ensure that the digital intervention meets user needs and maintains high standards. Moustakis et al., (2004) explain that the quality of website can be described as a function of its content, appearance and multimedia, navigation, structure and design, and uniqueness. The assessment of the quality of the app with respect to different features like engagement, functionality, aesthetics, information quality, subjective quality, and perceived impact helps in refining the app's interface and features (Stoyanov et al., 2015). Stoyanov et al., (2016) illustrated that capturing both quantitative ratings and qualitative user insights from target users and caregivers acts as a significant tool in enhancing mHealth app design. Hence, to obtain feedback on the working of the web-based application and to improve it, there is a need to assess the quality of the web-based application.

Aim

The study aimed to develop and validate a web-based application for the Auditory and Auditory-Cognitive Training Program for children with Central Auditory Processing Disorder. The study also aimed to compare the efficacy of auditory and auditory-cognitive training programs on psychoacoustic measures and speech perception in noise.

Objectives

1. To develop a web-based Kannada-language intervention module comprising Auditory Training (AT) and Auditory-Cognitive Training (ACT) for children aged 7–12 years with CAPD.

   [Auditory module: Auditory Closure, Auditory discrimination, Auditory figure-ground; Cognitive module: Running Span, Operation Span, Reading Span]

2. To assess the usability and engagement of the developed module using the User Version of the Mobile Application Rating Scale (uMARS).

3. To compare the performance in each task among children with (C)APD across three groups—AT, AT+ACT, and Control (no training)—at baseline, one month, and two months post-intervention.

   [Tasks: Psychoacoustic measures: Frequency Discrimination, Temporal Resolution, Speech in Noise, Auditory training: Auditory closure, Auditory discrimination, Auditory figure-ground. Auditory + cognition Training: Auditory Training + Running Span, Operation Span, Reading Span]

4. To evaluate within-group improvements across the training period on each task among children with CAPD served in training groups (Groups 1 and 2) and the waiting group (Group 3) to determine the short-term and sustained effects of auditory and auditory-cognitive training.

Chapter 2

Methods

The study aimed to develop and validate a web-based auditory and auditory-cognitive training program for children with CAPD. Auditory and auditory-cognitive training was given to children with CAPD using the web-based module. A multi-group pretest-posttest design was used in the study. The study was carried out in the following phases:

Phase I: Preparation of the training material

Phase II: Content validation of the training material

Phase III: Development of the web-based application

Phase IV: Verification of the web-based application

Phase V: Validation of the application - Training of the children with CAPD

Phase I: Preparation of training materials

This study employed a modified Delphi method to develop the materials required for the web-based application. The Delphi method involves structured, anonymous feedback from experts across multiple rounds, which minimises group bias and ensures that the materials are relevant, linguistically appropriate, and developmentally effective for the targeted population, while providing training for children with CAPD.

Conceptualisation and Construction of Training Materials

Initially, an expert panel was constituted to review the auditory and cognitive tasks related to speech perception that are particularly challenging for children with CAPD. Among the various problems faced by children with CAPD, speech perception in noise is the most prevalent issue commonly reported by experts involved in the Delphi Method. The panel included professionals with experience in audiology. Experts were selected based on their academic and clinical experience in assessing and managing children with CAPD. A total of four panel members participated in the present study, which employed the Delphi Method, comprising four rounds. One panel member had knowledge of developing web modules, two others were subject experts, and the other member had knowledge of the CAPD population, but not web-based modules. These judges were not the members who were involved in the development of the stimulus. This committee was formed to seek their suggestions on the development of the stimulus.

Round 1. Initially, the investigators involved in the present study identified the auditory and cognitive tasks required for effective speech processing. Each task was referred to as a chapter. The term 'chapter' was used, as the software is intended for use by children and parents, and a colloquial term was employed. Auditory tasks included auditory analysis, auditory attention, auditory association, auditory closure, auditory discrimination, temporal patterning, auditory synthesis, and auditory figure-ground. For the auditory-cognitive domain, the tasks included were operation span, reading span, and working memory span. The expert panel members were asked to provide qualitative feedback on the age appropriateness of the auditory tasks assigned for content validation. In Round 1, experts rated the importance, required level, and acquisition difficulty of each chapter. If three out of the four panel members (75%) agreed to include those chapters, they were included for the development of the material.

Round 2: The tasks involved in each chapter, as well as how these tasks were divided into sub-chapters, were discussed in Round 2. Further, for each of the sub-chapters, the levels and sub-levels were decided. The division of levels and sublevels was explicitly done for each task in the subchapters. The subdivision was also based on the level of difficulty. The instructions to be given and the scoring pattern for each task were discussed. Based on the task complexity, if it were to be considered for further steps, agree (1) was given; if not, disagree (0). The data were presented for discussion among the expert committee members. If three out of the four panel members (75%) agreed to include those sub-chapters, they were included for the development of the material. According to the panel members' suggestions, the inclusions and exclusions of the sub-chapters were made.

Round 3 Based on the comments received in the two rounds of Delphi, a collected list of chapters, sub-chapters, levels and sub-levels was prepared. The chapters, sub-chapters, levels, and sub-levels that the committee did not approve were removed. In the event of a discrepancy between experts' opinions, a consensus was obtained from another expert. The final revised list was prepared, and it is depicted in Table 2.1.

Table 2.1: Overview of the chapters and subchapters of the auditory and auditory cognitive module:

	Auditory Module			
Sl. no	**Chapter**	**Subchapter**	**Level**	**Sublevel**
1	Auditory Analysis	1.1 Vowels	-	-
		1.2 Number of Sounds	-	-
		1.3 Syllable number	1.3.1 Initial	-
			1.3.2 Medial	-
			1.3.3 Final	-
		1.4 Syllable recognition	-	-
2	Auditory attention	2.1 Single step commands	-	-
		2.2 2-step commands	-	-
		2.3 3-step commands	-	-
		2.4 Story Comprehension	-	-
3	Auditory Association	3.1 Vowels	-	Easy
			-	Difficult
			-	Hard
		3.2 Consonants	-	Easy
			-	Difficult
			-	Hard
		3.3 Syllables	-	-
		3.4 Words	-	-
		3.5 Sentences	-	Easy
			-	Difficult
			-	Hard
4	Auditory Closure	4.1 Missing words	4.1.1 Initial	Easy
				Difficult
				Hard
			4.1.2 Medial	Easy
				Difficult
				Hard
			4.1.3 Final	Easy
				Difficult
				Hard
		4.2 Missing Syllable	4.2.1 Initial	Easy
				Difficult
				Hard
			4.2.2 Medial	Easy
				Difficult
				Hard
			4.2.3 Final	Easy
				Difficult
				Hard

5	Auditory Discrimination	5.1 Vowel	-	Easy
			-	Difficult
			-	Hard
		5.2 Consonants	-	Easy
			-	Difficult
		5.3 Clusters	-	Easy Difficult
				Hard
		5.4 Phrases	-	Easy
			-	Difficult
			-	Hard
6	Temporal patterning	6.1 Auditory Pattern	2 pattern	-
			3 pattern	-
			4 pattern	-
		6.2 Humming	2 pattern	-
			3 pattern	-
			4 pattern	-
		6.3 Pattern Completion	-	Easy
			-	Difficult
			-	Hard
		6.4 Vowels	-	Easy
			-	Difficult
			-	Hard
		6.5 Consonants	-	-
		6.6 Clusters	-	Easy
			-	Difficult
			-	Hard
7	Auditory Synthesis	7.1 Compound Words	-	-
		7.2 Words	7.2.1 Familiar	Easy
				Difficult
				Hard
			7.2.2 Unfamiliar	Easy
				Difficult
				Hard
				Hardest
		7.3 Phrases	7.3.1 Familiar	-
			7.3.2 Unfamiliar	-
		7.4 Sentences	7.4.1 Familiar	-
			7.4.2 Unfamiliar	-
		7.5 Riddles	-	-
8	Auditory figure-ground	8.1 Following directions	Simple	Easy

			Intermediate	Difficult
			Complex	Hard
		8.2 Stories	-	Easiest
			-	Easy
			-	Moderate
			-	Hard
			-	Hardest
	Auditory Cognitive Module			
1	Operation span	-	-	-
2	Reading span	-	-	-
3	Running span	-	-	-

Construction of the training material

As per the expert panel's decision, stimuli for the training material were prepared for the various auditory and auditory-cognitive tasks. The training material was developed using the state syllabus Kannada textbooks of the 2^{nd}, 3^{rd}, 4^{th}, and 5th standards. The material for all the auditory and auditory cognitive tasks was prepared in the Kannada language. The training material consisted of two modules: the auditory module and the auditory-cognitive module. For each of the tasks in the auditory and auditory-cognitive domains, a set of three levels — easy, difficult, and hard — of stimuli was prepared. The chapters, sublevels, and levels under each module are listed in Table 2.1, and corresponding stimulus examples are provided in the Appendix. Of the tasks mentioned above, in the auditory module, only three chapters - auditory closure, auditory discrimination, and auditory figure-ground were considered for training. In the auditory cognitive training module, operation span, reading span, and working memory span were trained. Descriptions of these training tasks are provided in the appendix.

Phase II: Content validation of the developed material

This step involves expert judgment of the training material, indicating that it has content validity. For this purpose, the study included five experts. The judgment of the developed material was carried out with the cooperation of five experts. The content was validated by three Audiologists, one special educator, and one parent. They were given three months to assess and rate all the items in the training material. The experts were asked to write down their choice in the listed items of the training material, according to the factor they judged appropriate for them. The training material was rated on a 5-point rating scale for the following parameters: Familiarity, Stimulability, Trainability, and Comprehension, which are described below. The experts were asked to rate each of the items in the training material using a 5-point Likert scale, where 1 = Strongly disagree, 2 = Disagree, 3 = Neither agree nor disagree, 4 =

Agree, and 5 = Strongly agree, based on task familiarity and complexity. The rating was conducted based on the following parameters.

i. **Familiarity:** Are the word sentences, paragraphs or stories and/or pictures familiar to even young children?

ii. **Appearance** of the image: Are the picture stimuli appropriate in terms of appearance? (only for Chapter 3)

iii. **Stimulability:** Can the stimulus material elicit responses from the child?

iv. **Trainability:** Can the stimuli be used for intervention purposes?

v. **Comprehensive:** Are the words, sentences, paragraphs or stories and/or pictures comprehensive to even young children?

Phase III: Development of a web-based application:

The development of the software involved preparing materials for various auditory and cognitive tasks. The test was developed in Kannada only. The development involved the following steps:

1) ***Preparation of a requirements document***

This step involved preparing a requirements document that specified all essential details for web application development. The project team conducted several structured brainstorming sessions with the software engineer. Each task associated with the objectives in the activity sheets was examined thoroughly. The team documented clinician requirements and software specifications in a clear format to facilitate comprehension by the web application developers. Distinct documents were prepared for each training domain.

2) ***Preparation of the application screen designs***

In this step**,** the Figma application, an advanced online design tool, was used to model the necessary screen layouts and their interactions for the web application. This step was taken to reduce rework during the actual web application development process. The wireframes were first created to draft the structural layouts of the screens. Later, these designs were improvised with colour palettes and typography. Additionally, Figma's interactive features facilitated the creation of a navigation mock-up between the screens. The researchers reviewed the design for any issues and confirmed that the prototype interface was user-friendly and visually appealing.

*3) **Implementation of the web application***

In this step, both the front-end and back-end were developed, along with their integration. Front-end development entailed constructing the client-side of the web application. The team implemented approved designs using open-source technologies, including HTML, CSS, and JavaScript. The interface was designed to be responsive and optimised for multiple screen sizes and devices. Back-end development focused on the server-side, including the configuration of databases MySQL for data storage. Server-side logic and the application programming interface (API) were developed using Java. The process also involved implementing user authentication and authorisation. Security protocols such as encryption and data protection were established to safeguard the application. This systematic approach resulted in a fully functional back-end system that interacts efficiently with the front-end, manages requests, and processes data effectively.

*4) **Testing and Quality Assurance***

In this step, developers conducted both manual and automated testing to ensure the application operates efficiently and is free from bugs. They conducted unit testing, integration testing, and system testing to ensure the application performed as intended. Furthermore, load testing was executed to verify the application's ability to handle traffic effectively. Compatibility across different browsers and devices was reassessed, and security testing was conducted to identify and address any vulnerabilities.

5) Deployment and Hosting

This step involved deploying and hosting the web application. Initially, the application was deployed on a local server. Later, it was hosted on a cloud platform. Additionally, security measures such as firewalls were configured. Subsequently, an account was created with the cloud service provider, along with selecting a suitable hosting plan that met the requirements for bandwidth and storage. A virtual machine or container service was established, and the application files were deployed using CI/CD pipelines.

6) **Stimuli Recording**

Five stimuli for phonemes, syllables, words, phrases, sentences, and humming were recorded by three 27-year-old female native Kannada speakers. The speakers were instructed to maintain normal intonation, intensity, and pronunciation. The stimuli were recorded using Adobe Audition version 3.0 software, with a Behringer B-2 Pro microphone connected to a MOTU MicroBook IIc interface to ensure clear recordings. The microphone was positioned 6 inches from the mouth.

The samples recorded from the three speakers were presented to the expert committee. Based on the ratings given by the expert committee members, the speaker was selected to be loaded into the web-based software. The speaker recorded each stimulus (Table 3.2) of the auditory and auditory cognitive modules three times. Each stimulus recorded in the middle was considered due to reduced fluctuation in the intonation and vocal effort. All stimuli were RMS-normalised to 1.5 dB. Each stimulus saved in .wav was processed and renamed according to the corresponding modules, chapters, and subchapters.

7) **Final preparation of the web-based application**

The recorded stimuli were loaded into the web-based application. For each sublevel, a stimulus set of 30 items was uploaded. The developed web application included the following features:

i. User Registration: To access the web application, users must register.
ii. Menu Navigation: Upon clicking the menu, modules related to auditory and auditory-cognitive training were displayed on the screen. Users can select and navigate through different modules from the left-hand ribbon. The main page contains the actual training materials, and users can switch between modules using the next or previous buttons at the bottom. Appropriate messages are provided to facilitate ease of access.
iii. Interactive Activities: Each module contains sufficiently challenging activities to maintain interest, attention, and engagement.
iv. Feedback Mechanism: The application provides feedback to the patient by displaying the activity score or a message indicating level completion.
v. It would provide the patient with feedback on their progress or lack thereof.
vi. Language Adaptability**:** The existing program module is designed as a non-language-specific program. The web-based application is dynamically developed, allowing users to change the stimuli according to their language preferences. Currently, the training module is specifically designed for individuals with CAPD who have knowledge of the Kannada language.
vii. The link for the web-based application is https://capd.jssish.com/homepage

Phase IV: Verification of the Web-Based Application

The materials developed in Phase I were incorporated into the web-based application. The verification of the web-based application was carried out using the User Mobile Application Rating (uMARS) questionnaire (Stoyanov et al., 2016). 10 Audiologists rated the web-based application. The questionnaire was rated on a 5-point rating scale. It included the three subsections: App Quality Ratings, App Subjective Quality, and Perceived Impact. A rating of 3 or higher is considered a good response to an app.

i. **Engagement:** This subsection covers overall engagement, as well as specific aspects such as entertainment, interest, interactivity, and suitability for the target audience. It includes questions related to each of these components.

ii. **Functionality:** In this subsection, questions were based on the app's functioning, ease of learning, navigation, flow logic, and gestural design.

iii. **Aesthetics:** Information on graphic design, overall visual appeal, colour scheme, and stylistic consistency of the web-based application was gathered in this sub-section.

iv. **Information**: This sub-section contains high-quality information on text, feedback, measures, and references.

v. **Subjective quality of the app:** In this subsection, questions were designed to understand how people feel about an app and how likely they are to use or recommend it.

Phase V: Validation of the application- Training of children with CAPD

Participant selection criteria:

A total of 15 participants were included in the study. Participants in the age range of 8 to 12 years diagnosed as having CAPD were recruited for the study. Participants were native speakers of Kannada, and none of them reported any neurological, psychological, or cognitive problems. The opinions of the Neurologist and Psychologist were considered. Any child with problems related to IQ was excluded.

The participants were randomly assigned to three groups. Each group comprised five participants recruited for each training regime. The participants in Group I received auditory training (AT) alone, those in Group II received auditory cognitive training (ACT) along with AT, and the participants in Group III served as a waiting group, which did not receive any training. The Sample size was calculated based on the effect size of 0.71 observed in a previous preliminary study by Yathiraj & Vanaja (2018) where auditory training for CAPD was given. When alpha was set at 0.05 and power was kept at 0.95, a sample size of 5 per group was obtained. Group III received training after the evaluations were conducted at three points in time, with a one-month gap between each session. Details of demographic details and preliminary assessment of each participant are provided in Table 2.2.

Inclusion criteria:

i. Hearing thresholds are less than 15 dB in both ears.
ii. Children should have a normal middle ear status as indicated by an 'A' type tympanogram with the presence of reflexes at frequencies from 250 Hz to 4 kHz (in octaves)
iii. Children who failed the Screening Checklist for Auditory Processing (SCAP), developed by Yathiraj and Mascernhas (2003, 2004), were subjected to detailed diagnostic tests.

iv. Children who failed in at least one auditory processing test (2 SD criterion) or two tests (1 SD criterion) in the behavioural test battery used to assess auditory processing, with reference to the guidelines of Yathiraj & Vanaja (2018).

v. The intelligence quotient (IQ) score was greater than 90 on the Ravens Progressive Matrices

vi. Participants who were native speakers of the Kannada language.

Exclusion criteria

1. Children with active middle ear discharge during the time of testing.
2. Children with thresholds greater than 15 dB HL.
3. Participants who were not native speakers of Kannada.
4. Children who have passed the SCAP questionnaire.

Table 2.2: Details of demographic details and Preliminary assessment of each participant.

Unique ID	Age (years)	Grade	Gender	Handedness	STAP Refer domain	PTA_R	PTA_L
AT1	11	6	Male	Right	SPIN	1.25	12.5
AT2	11	6	Female	Right	DCV	2.5	10
AT3	9	4	Male	Right	DCV	11.25	8.75
AT4	9	4	Female	Right	DCV,SPIN	2.5	5
AT5	8	3	Male	Right	SPIN	18.75	20
ACT1	11	6	Male	Right	DCV,SPIN	13.75	12.5
ACT2	11	6	Female	Right	SPIN,GDT	8.75	5
ACT3	10	5	Male	Right	GDT	10	10
ACT4	8	4	Female	Right	GDT,AWM	16.25	12.5
ACT5	8	3	Female	Right	SPIN,GDT	16.25	12.5
Wt G1	11	5	Male	Right	DCV	16.25	11.25
Wt G2	10	5	Male	Right	DCV	15	15
Wt G3	11	6	Male	Right	DCV	20	15
Wt G4	10	6	Male	Left	DCV	12.5	10
Wt G5	12	6	Female	Right	DCV	17.5	18.7

2.7- Preliminary Assessment

Screening was performed using the SCAP questionnaire and the Screening Test for Auditory Processing (STAP) before recruiting participants for the intervention program. Among 206 children, 36 students could not be tested (CNT) due to the presence of impacted earwax. Out of the remaining students, 173 passed the screening for CAPD, and 33 were identified as "at risk" (referred) for CAPD. Following screening, a basic audiological evaluation and a central auditory processing assessment were conducted. Pure tone thresholds were obtained using the modified Hughson and Westlake procedure at 500 Hz, 1000 Hz, 2000 Hz, 4000 Hz, and 8000 Hz. Children were diagnosed as having CAPD based on the diagnostic criteria given by Yathiraj & Vanaja (2018). On performing diagnostic tests, 20 children were diagnosed as having CAPD. Out of the 20 children, 15 children who met the inclusion criteria and whose parents provided consent were recruited for the study. According to sample size calculation the 15 (5 in each group) children with CAPD were recruited randomly.

Test Environment

All psychophysical tests were conducted in a quiet room. The stimuli were presented using a personal laptop connected to headphones. The stimuli were calibrated as follows: tones were set at 62.5 dB SPL, and speech stimuli were set at 75 dB SPL. The web-based auditory and auditory cognitive training was provided in a quiet room with minimal distractions. Training stimuli were presented at the most comfortable level and delivered through speakers.

Assessment Procedure

The procedure involved a baseline assessment to evaluate central auditory processing abilities, including auditory closure, temporal resolution, and pitch perception. These tests were conducted before training, 1 month after training, and 2 months after training. The following tests were conducted to assess the corresponding auditory skills: SNR-50 (auditory closure), frequency discrimination, and Temporal Modulation Transfer Function (temporal resolution) in each time period.

1) Speech in noise test

The SNR-50 test was used to assess auditory closure abilities. Speech-shaped noise with a spectrum similar to that of a standardised sentence was prepared. The procedure for generating speech-shaped noise was described by Hemanth & Akshay (2015). Three lists of standardised Kannada sentences, given by Methi & Kumar (2009), were used. Each sentence in the list comprises five target words. For each sentence, the root mean square (RMS) was identified, and then noise was added at the desired SNR. The first list of seven sentences was mixed with four talker babble at different signal-to-noise ratios ranging from +8 dB to -10 dB SNR in 3 dB step size. Two lists were used in the evaluation, namely List 1 and List 2.

Analysis:

In ten sentences, noise embedded at different SNRs was randomised. Each sentence was presented through headphones binaurally at the most comfortable level. The SNR level at which testing started (L), the number of correctly recognised target words in each sentence, the total number of words per decrement (W), and the SNR decrement step size in each sentence (d) were noted. The total number of target words from all sentences (T) was added. The obtained values were substituted into the Spearman-Karber equation, given below, to determine SNR 50. We will use the equation below to calculate the SNR of 50.

$$\mathbf{50\ point = L + (0.5*d) - d\,(T)/\,W}$$

2. Frequency Discrimination

In this study, the minimum frequency difference necessary to discriminate between two closely spaced frequencies was assessed. The frequency difference limen (FDL) was measured at complex tones. Both the standard and variable stimuli were 250-ms-long pure tones with onset and offset of 10-ms raised cosine ramps. On each trial of three blocks, two blocks contained pure tones at a standard frequency, and the other block contained a pure tone of variable frequency, which was always higher than the standard frequency. The minimum and maximum frequency deviations of the variable stimulus were 0.1 Hz and 200 Hz, respectively. The participant's task was to identify the variable block. The frequency difference corresponding to the 79.4% point of the psychometric function was calculated using a staircase procedure.

Analysis*s:*

The responses given by the participant were scored. The participant's responses, either humming or verbally mentioning different frequencies, were documented. A score of 1 was given for the correct response. The total score obtained was documented. The participant was instructed to identify the variable frequency.

3. Temporal Modulation Transfer Function (Temporal Resolution)

The TMTF stimulus developed by Lorenzi et al. (2000) was adopted. A 1000-ms white noise signal was sinusoidally modulated at modulation frequencies of 8 Hz, 64 Hz, and 128 Hz. These frequencies were selected to include both low and high modulation frequencies. The modulation depth of each frequency-modulated (FM) signal ranges from 0 dB to -30 dB. The maximum amplitude modulation was 0 dB (100%), and the minimum was -30 dB (0%). A three-interval forced-choice method was used, with two intervals consisting of white noise, and the target stimulus being the amplitude-modulated sinusoidal signal. Each participant was instructed to indicate the target stimulus.

The modulation detection threshold (MDT) in dB was calculated using the following equation.

MDT = $20 \log_{10} m$, where m is the modulation detection threshold in %.

The method adopted by Zeng et al., (2005) was used to calculate peak modulation sensitivity. The peak modulation sensitivity is the lowest modulation depth (in dB) required to identify the modulation from unmodulated white noise. The peak modulation sensitivity for each frequency modulation was calculated.

4. Auditory processing assessment

This included the administration of 10 probe stimuli for each of the subchapters in the chapters Auditory closure, Auditory discrimination, and auditory figure-ground. Each correct response was awarded a score of one, and zero for an incorrect response**.** For the chapter on Auditory closure, the children had to fill in missing words or syllables in sentences. The subchapters included were the missing words and the missing syllables. In Auditory Discrimination chapter, children listened to the two presented stimuli and indicated whether they were the same or different. The sub-chapters included Vowels, Consonants, Clusters and Phrases. In the Auditory figure-ground, speech stimuli were embedded with noise. Following directions and stories were the sub-chapters of this chapter. In the following directions sub-chapter, the child was instructed to carry out action-based tasks which were presented with noise. In the stories sub-level, stories which were embedded with noise were played to the child. The child had to listen to the story, understand and then answer the questions asked related to the story. Each correct response was awarded a score of one, and zero for an incorrect response**.**

5. Auditory Working Memory Assessment

Children were assessed on the working memory, reading span and the running span tasks. In the Operation span task, a sequence of mathematical operations was presented, interspersed with word sets. The child had to judge whether the solved mathematical operation was correct (true/false). At the end of the task, the child had to recall all the words in the correct order. In the Reading span task, a sentence was presented, followed by a word set. The child had to judge whether the sentence was semantically correct (true/false). Finally, the child had to recall all the words in the correct order. The string of number of words that were correctly recalled by the child was documented for both operation span and reading span. For the running span task, a series of random numbers was presented in increasing sets (ranging from two to eight digits). The child had to listen to the set of numbers and respond to the N digits as given in the criteria in the same order. The N digit which the child could correctly repeat in the correct order was documented.

Training

The developed web-based application was used to provide auditory training for children diagnosed with CAPD.

Group 1: Auditory training

Participants in this group received auditory training through a web-based auditory training module. The training focused on enhancing auditory discrimination skills and auditory closure abilities. The program contained three main chapters, Auditory closure, Auditory discrimination and Auditory figure-ground. The details of the chapters, along with the examples, are provided in the Appendix.

Group 2: Auditory and auditory cognitive training

Participants in this group received a combination of auditory training and auditory cognitive training. The auditory training component was identical to that of Group 1. In addition to auditory training, Auditory-cognitive training was also given, where the participants were trained with operation span, reading span and running span tasks. The details of the chapters with examples are given in Appendix 2.

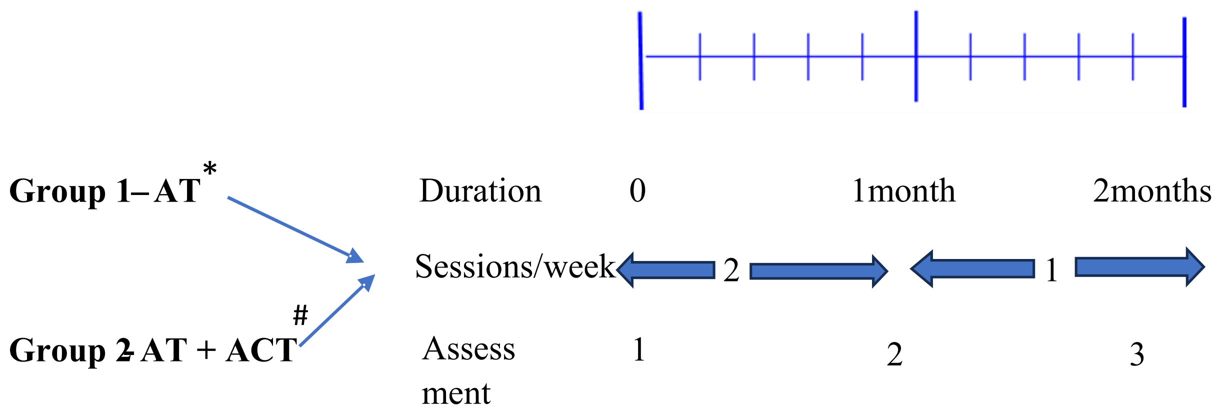
Therapy Framework

Each therapy session was structured to include both direct interaction with the child and collaborative involvement of the caregiver. The session began with initial instructions lasting about five minutes, during which the functioning of the web-based application was checked, and the activities from the previous session were reviewed. This was followed by five minutes of therapy led by the caregiver, focusing on reinforcing the activities taught in the previous session. A five-minute discussion was then held with the caregiver to review the child's performance and clarify any difficulties encountered during the earlier activities.

The main therapy segment lasted approximately 20 minutes, during which new activities for the current session were introduced and practiced. Following this, another five-minute discussion was conducted with the caregiver to address any queries related to the newly taught activities. The session concluded with a final five-minute discussion to plan the activities and goals for the upcoming session.

Training Regime

In the initial phase, a baseline assessment was conducted for all 15 participants. Following the assessment, participants were randomly assigned to either the auditory training group or the auditory cognitive training group. Both training programs were provided over eight sessions, followed by the first follow-up assessment. After this, home training was introduced, where parents or caretakers were guided to continue the training at home. Training sessions were then conducted once a week, followed by the second follow-up assessment. The training was conducted in a quiet room, with each session lasting 45 minutes. During each session, three activities were carried out, depending on the child's response. In each sublevel, 10 stimuli were presented, and the child's responses were documented to track progress. Once the child achieved 75% accuracy, they progressed to the next level. Verbal reinforcement was provided by the audiologist when the child met the target outcome or completed a level. The web-based application also provided feedback on task scores and level completion. Additionally, the audiologist offered personalised feedback on the child's participation and provided correct models for any incorrect responses.



AT- Auditory Training, # ACT- Auditory-cognitive training

Figure 2.1. Training timeline and assessment time points

The training regime and assessment points are provided in Figure 2.1. The speech perception and central auditory processing skills were assessed as a baseline. The training was a hybrid mode, involving both offline and online components. The participants and their parents/caregivers were thoroughly oriented on the usage of the web-based application through an offline mode.

In the first month, 45-minute sessions were provided twice a week under the supervision of an audiologist, using the developed web application. All the therapy session was provided in the silent room in the school setting. The therapy was divided into two phases. In Phase 1, the investigator provided training using a web-based application. The investigator provided training for a period of 1 month, a total of 8 sessions (2 sessions per week), 45 minutes per session, In the second phase, home training material was provided to the caretaker along with the web application, care taker was oriented to provide train the child according to designed plan schedule for 4 weeks i.e to work on the specific subchapter in each session. The investigator monitored and guided the parents online during one of the sessions once a week. The children were evaluated at three intervals: baseline, 1 month post-training, and 2 months post-training. The baseline assessment was conducted for all three groups. Training was initiated for groups 1 and 2. The assessments were conducted one month post-training, that is, after eight sessions of training, and were repeated after four weeks of home training for groups 1 and 2. Group 3 did not receive training until evaluations were carried out three times, with a one-month gap between each evaluation. After the assessment was done for the third time, training was initiated for them.

Chapter 3

Results

The study aimed to evaluate the efficacy of a web-based application designed to improve auditory and cognitive processing in children with CAPD. The study's findings, specifically regarding the development of the web-based application, evaluations, and the effect of the intervention on psychoacoustic, speech perception, auditory processing, and auditory memory tasks, are explained below.

3.1. Development of the web-based application

The web-based application was developed with valuable input from an expert panel. Three rounds of Delphi were conducted to identify the various components of the software.

3.1.1. Literature review and Delphi method

The literature review and comments from the expert committee determined the tasks for the auditory and auditory-cognitive domains. Auditory tasks included auditory analysis, auditory attention, auditory association, auditory closure, auditory discrimination, temporal patterning, auditory synthesis, and auditory figure-ground. For the auditory-memory domain, the tasks included were operation span, reading span, and running span. The levels and sublevels for each of these chapters were determined based on discussions with the authors and expert committee panel members. Table 3.1 summarises the chapters, subchapters, levels, and sublevels within the auditory module and the chapters of the auditory-cognitive module.

Table 3.1

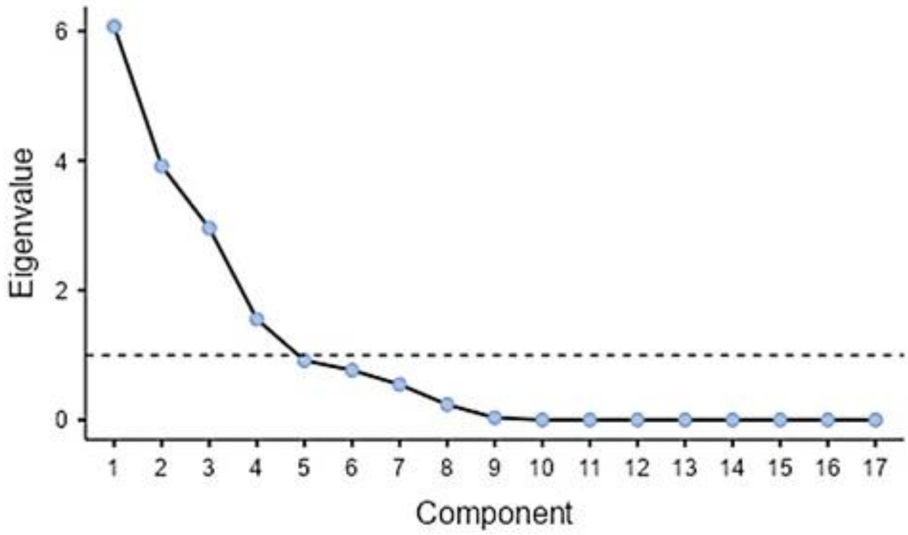
Details of the chapters, subchapters, levels, and sublevels under the auditory module and chapters of the auditory-cognitive module

Module	Chapters	Sub-chapters	Levels
Auditory module	Auditory attention	Two-step commands, Three-step commands, Story comprehension	-
	Auditory association	Vowels Consonants, Syllables, Sentences	Except for syllables, each sub-chapter comprises easy, difficult and hard levels.
	Auditory closure	Missing words, Missing syllables	In initial, medial, and final positions, the target words/syllables are missed.
	Auditory discrimination	Vowels Consonants Phrases	Each sub-chapter has easy, difficult and hard levels.
	Auditory synthesis	Compound words, Phrases Sentences Riddles	Except for Compound words and Riddles, the Phrases and Sentences have two sublevels, i.e familiar and unfamiliar.
	Auditory Figure Ground	Following directions. Stories.	Following directions has easy, difficult and hard levels Five SNRs (+18 to +2 in steps of 4) in stories
Auditory-memory module	Operation Span		
	Reading Span		
	Running Span		

3.1.2. Content Validity:

Data Reduction and Feedforward for content validation were initially conducted using Principal Component Analysis (PCA) to identify which levels required content validation. Bartlett's Test of Sphericity ($p < 0.01$) confirmed data suitability, and five components with eigenvalues >1 were extracted, explaining 98% of the variance (Figure 3.1). Oblimin rotation was used, and the Kaiser-Meyer-Olkin value was 0.7, indicating sampling adequacy. Internal consistency (Cronbach's alpha = 0.8) confirmed reliability for each factor. Based on the PCA, 12 out of 17 levels were retained, and five were eliminated.

Figure 3.1: Representations of the scree plot of each level of the auditory and auditory-cognitive module



Content validation was performed on a total of 17 components (one chapter, eight subchapters, and eight levels) by five experts. Items were rated on a 5-point scale across four parameters: Familiarity, Stimulability, Trainability, and Comprehension. The Content Validity Index (CVI) was calculated at both item (I-CVI) and scale levels (S-CVI/Ave and S-CVI/UA). S-CVI/Ave ranged from 0.9 to 1, and S-CVI/UA from 0.59 to 1, except for missing syllables and words. Items with I-CVI < 0.75 were excluded (83 out of 1322). Kappa values for chapters, subchapters, and levels were all 1, confirming perfect agreement. Expert suggestions led to further refinement of the material. After examining the expert suggestions for items, some were modified, and corrections were incorporated, except for the excluded items. Overall, the auditory and cognitive training modules demonstrated strong content validity.

Table 3.2

Summary of content validated auditory and auditory-cognitive training stimuli

Sublevel	Total no of items	No of the items eliminated
2.2.2-step commands	100	5
2.3. 3-step commands	100	21
2.4.Story Comprehension	5	0
3.5 Sentences	100	7
4.1.Missing words 4.1.1Initial	56	9
4.1.2Medial	49	2
4.1.3Final	50	0
4.2.Missing Syllable 4.2.1Initial	49	4
4.2.2Medial	94	1
4.2.3Final	86	8
5.4 Phrases	100	3
7.3.1 Phrases	100	18
7.4.1 Sentences	100	1
7.5 Riddles	100	1
8.1.Following directions	100	0
8.2 stories	33	3
Reading span	100	0
Total	**1322**	**83**

3.1.3. Revision of web application

During the development of the CAPD training, several issues were identified by participants, and each theme was refined with appropriate solutions.

Software Layout and Design: The initial layout dimensions were too small for comfortable mobile phone use. To improve visualisation, the dimensions of the home and test screens were modified, with the menu display adjusted to a width of 260–320 pixels and a height of 120–150 pixels.

Test Page: The instructions displayed on the test page were unclear, poorly aligned, and sometimes difficult to read. Additionally, the auditory stimuli were not always audible, prompting participants to request repeats. To address this, the display size, font, and colour alignment were improved. A repeat button was also introduced, but its use was restricted to three times to avoid excessive trials.

Time Window: The inter-stimulus interval was initially fixed at 1000 milliseconds, which was too short and caused difficulties. To overcome this, the response time was made dependent on the input given by the participant. As soon as the response button was clicked, the next stimulus appeared with a short delay of 100 milliseconds, ensuring smoother progression and minimising technical glitches.

Stimuli and Instructions: Several issues emerged with stimulus presentation and instruction clarity. The training audio began abruptly, the instructions were unclear, and font size and colour choices made the text difficult to follow. Additionally, stimuli repeated across consecutive sessions made the tasks monotonous, and the difficulty ratio was uneven in discrimination tasks (for example, 10 easy and 20 difficult items). Noise levels were also inconsistently balanced with speech in auditory figure-ground tasks. These issues were resolved by adding 500 ms of silence before stimuli, providing more explicit instructions with examples, and improving the visual format through larger fonts (title: 24 px, instructions: 20 px, examples: 18 px) and better colour contrast. Four randomised stimulus lists were introduced for each subchapter to prevent repetition, and difficulty levels were standardised into three categories: easy, difficult, and hard. The stimulus ratio was balanced to 40% same and 60% different items for the discrimination task. Further, all auditory materials were RMS-normalised and mixed at constant or varied SNR levels before being loaded into the software to ensure consistency.

Response: The placement and size of the response buttons were initially too small and narrow, making it difficult for participants to select the correct option. This was corrected by resizing and repositioning the buttons to improve accessibility and accuracy.

Scoring: Problems were also noted in the scoring system. Scores did not appear immediately after pressing the exit button, and incomplete attempts led to inaccurate calculations. To correct this, scores were programmed to display instantly when exiting, with correct responses awarded a score of 1 and incorrect ones a score of 0. If a participant exited without responding, the attempt was marked wrong and included in the total score. For cognitive tasks, a minimum accuracy of 75% was required to progress to the next level, ensuring that participants advanced only after demonstrating sufficient mastery.

Through these modifications, the CAPD training software was refined to enhance usability, clarity, and accuracy, addressing both technical and user-experience challenges.

3.1.4. Users Mobile Application Rating Scale

The app was evaluated by 10 experts using the User Mobile App Rating Scale (UMARS) across four key domains: Engagement**,** Functionality**,** Aesthetics**,** and Information. The domain-wise mean scores were calculated and used to compute the overall app quality rating. The Engagement domain had a mean score of 17.3 out of a maximum of 25, indicating that the app was perceived as fairly engaging, offering features such as interactivity, customisation, and user-targeted design. The Functionality domain received the highest mean score of 17.7 out of 20, suggesting that the app was consistently rated as easy to use, with smooth navigation, responsive performance, and intuitive gestural design. The Aesthetics domain had a mean score of 12.4 out of 15, reflecting a positive perception of the visual design, layout, and overall appearance of the web-based application. The Information domain scored the lowest, with a mean of 4.0 out of 5, still indicating that the content was considered to be of high quality, accurate, visually precise, and from a credible source. The mean total app quality rating (calculated as the average of the four domain scores for each expert) was 12.85 out of 15, suggesting that the app was overall rated highly in terms of its quality, usability, and effectiveness by the panel of experts.

The subjective quality of the web-based application was evaluated by four key indicators: recommendation likelihood**,** anticipated future use**,** willingness to pay**,** and overall star rating**.** The item "Would you recommend this app to people who might benefit from it**?"** received a mean score of 4.2 out of 5. This suggests that most experts would be willing to recommend the app to others, indicating strong perceived value and potential usefulness. On the question "How many times do you think you would use this app in the next 12 months if it were relevant to you?"**,** the average score was 3.6 out of 5, indicating a moderate to high likelihood of continued usage over time. All 10 experts rated the item "Would you pay for this app?" with a score of 5, showing the agreement on the perceived worth and value proposition of the application. The overall star rating assigned by the experts was consistent, with all experts giving it a 4 out of 5, reflecting a generally positive perception of the app's overall quality and usability. The average subjective quality score across the four items was 4.2 out of 5**,** indicating a high level of user satisfaction and acceptance of the app.

3.2. Group and training time period differences in each task

3.2.1 Psychoacoustic Measures

A Kruskal-Wallis test was used to compare the groups on frequency discrimination and temporal modulation transfer function, as assessed in children with Central Auditory Processing Disorder (CAPD) who were in three intervention groups: Group 1, Auditory training only; Group 2, Auditory and cognitive training; and Group 3, a waiting period. The psychoacoustic measures were captured at three different time periods: baseline, 1 month post-training, and 2 months post-training (Appendix 3, Table A1). Furthermore, the Mann-Whitney test was performed to see groups in which a significant difference occurred. Additionally, within-group comparisons were conducted using the Friedman Test (Appendix 3, Table A2). If a significant difference was found, the Wilcoxon signed-rank test was used to identify the time point at which the difference became significant.

Table 3.3

Frequency discrimination scores across groups at three time points

Frequency Discrimination	**Group 1**		**Group 2**		**Group 3**		**Kruskal Wallis Test**	
	Median	IQR	Median	IQR	Median	IQR	$\chi 2$	P
Base line	44.30	40.02	45.02	446.38	95.35	268.01	3.92	0.14
1 PT	10.10	25.50	31.01	352.69	72.88	297.79	5.36	0.07
2 PT	7.73	7.07	8.01	248.09	52.28	185.37	2.48	0.29

Note: PT- Post Training, IQR- Interquartile range.

The frequency discrimination scores across groups at three time points are provided in Table 3.3. At the baseline and at the 2-month post-intervention, there was no significant difference between groups in frequency discrimination. However, at 1 month after intervention, Group 1 (Median = 10.10, IQR = 25.50) demonstrated a lower median indicating better frequency discrimination followed by Group 2 (Median = 31.01, IQR = 352.69) and then Group 3 (Median = 72.88, IQR = 297.79) and this difference did not reach significance [χ^2 (2) = 5.36, p = 0.07].

Furthermore, a Friedman Test was performed for the within-group comparison. A statistically significant improvement over time was observed in Group 1 and Group 2. Group 1 (χ^2 = 8.40, p = 0.02), Group 2 (χ^2 = 10.00, p = 0.01), and Group 3 (χ^2 = 8.40, p = 0.06) demonstrated consistent improvement in frequency discrimination abilities. Wilcoxon signed-rank test revealed that in Group 1, there was a significant improvement from Baseline to 1 month (Z = -2.02, p = 0.04) and from Baseline to 2 months (Z = -2.02, p = 0.04), but no significant change between 1 and 2 months (p = 0.35). Group 2 showed a similar pattern of improvement from Baseline to both 1 month and 2 months (p = 0.04), with further significant improvement between 1 and 2 months (p = 0.04), indicating continued progress. In Group 3, no significant difference was observed between the Baseline and subsequent evaluations.

The TMTF threshold obtained for all the groups at three time points is represented in Table 3.4. At 8 Hz, baseline median TMTF thresholds were similar across groups, with values of –16.60 dB (Group 1), –13.60 dB (Group 2), and –15.40 dB (Group 3), showing no significant group differences (χ^2 = 1.21, p = 0.55). After 1 month, Group 2 showed a notable improvement, with a median of –21.63 dB, compared to –16.40 dB and –13.60 dB in Groups 1 and 3, respectively (χ^2 = 0.56, p = 0.76). By 2 months, further improvements were observed, with Group 2 reaching –23.13 dB and Group 1 reaching –20.80 dB, while Group 3 showed lesser change (–16.70 dB). The group difference approached no statistical significance (χ^2 = 4.34, p = 0.11), suggesting a trend towards better outcomes in Groups 1 and 2.

At 64 Hz, median values were similar at baseline (–16.00 dB for Group 1, –15.60 dB for Group 2, and –13.00 dB for Group 3), with no significant group difference (χ^2 =0.07, p = 0.97). After 1 month, median values improved more in Group 1 (–19.40 dB), followed by Group 2 (–17.40 dB) and Group 3 (–15.00 dB); however, the difference remained statistically non-significant (χ^2 = 2.57, p = 0.28). After 2 months, both Group 1 (–19.20 dB) and Group 2 (–19.60 dB) maintained greater improvement compared to Group 3 (–15.00 dB), with the difference again approaching no significance (χ^2 = 4.34, p = 0.11).

At 128 Hz, baseline medians were –16.40 dB (Group 1), –13.20 dB (Group 2), and –14.60 dB (Group 3), with no significant group differences (χ^2 = 2.18, p = 0.34). At 1 month, medians remained close across groups (–15.60 dB, –14.80 dB, and –15.80 dB), and the difference was not significant (χ^2 = 1.09, p = 0.58). At 2 months, Group 1 showed further improvement (–17.20 dB), compared to –14.80 dB in Group 2 and –12.80 dB in Group 3, though the difference remained non-significant (χ^2 = 1.21, p = 0.55).

Overall, the findings indicate that children in Groups 1 and 2 demonstrated greater improvement in TMTF thresholds over time, particularly at 8 Hz and 64 Hz, compared to those in Group 3. Although statistical significance was not achieved, a clear trend emerged suggesting that auditory training alone or in combination with cognitive training may yield better outcomes in temporal processing for children with CAPD.

Within-group comparison of the Friedman Test revealed no significant changes were observed across the three time points in any group for the TMTF tasks at 8 Hz, 64 Hz, or 128 Hz. It suggests that the TMTF skills remained relatively stable over the training period, regardless of the training received.

Table 3.4

Temporal Modulation Transfer Function Thresholds Across Groups at Three Time Points

TMTF	Group 1		Group 2		Group 3		Kruskal-Wallis Test	
	Median	IQR	Median	IQR	Median	IQR	χ2	p
8Hz B	-16.60	7.54	-13.60	8.40	-15.40	5.80	1.21	0.55
8Hz 1 PT	-16.40	5.50	-21.63	19.59	-13.60	7.10	0.56	0.76
8Hz 2 PT	-20.80	6.78	-23.13	5.50	-16.70	8.39	4.34	0.11
64Hz B	-16.00	10.20	-15.60	9.65	-13.00	7.60	0.07	0.97
64Hz 1 PT	-19.40	5.50	-17.40	10.90	-15.00	3.85	2.57	0.28
64Hz 2 PT	-19.20	4.80	-19.60	8.10	-15.00	6.15	4.34	0.11
128Hz B	-16.40	5.70	-13.20	7.20	-14.60	5.35	2.18	0.34
128Hz 1 PT	-15.60	3.60	-14.80	8.94	-15.80	5.80	1.09	0.58
128Hz 2 PT	-17.20	6.75	-14.80	8.40	-12.80	6.20	1.21	0.55

TMTF- Temporal Modulation Transfer Function; B- Baseline; PT – Post-training, IQR- Inter-quartile range

Table-3.5

Speech perception in noise Scores Across Groups at Three Time Points

SNR 50	Group 1		Group 2		Group 3		Kruskal-Wallis Test	
	Median	IQR	Median	IQR	Median	IQR	χ2	P
Baseline	2.60	2.00	2.20	2.70	3.00	2.10	0.95	0.62
1 PT	1.20	2.92	0.80	3.00	1.00	6.84	1.54	0.46
2 PT	-3.40	4.85	-1.90	4.18	-1.90	4.25	2.93	0.23

SNR 50 - Signal-to-Noise Ratio at 50% threshold; PT– Post-training, IQR- Inter-quartile range

The details of Signal-to-Noise Ratio at 50% threshold (SNR-50) was assessed across three groups of children with CAPD at three time points. At baseline, the median SNR-50 values were 2.60 dB (Group 1), 2.20 dB (Group 2), and 3.00 dB (Group 3). The interquartile ranges (IQR) were 2.00, 2.70, and 2.10 dB, respectively. The Kruskal-Wallis test indicated no statistically significant difference between groups (χ^2 = 0.95, p = 0.62). At 1 month post-training, median SNR-50 values decreased to 1.20 dB (Group 1), 0.80 dB (Group 2), and 1.00 dB (Group 3), indicating improvement in all groups. The IQRs were 2.92, 3.00, and 6.84 dB, respectively. However, no significant difference was found between the groups (χ^2 = 1.54, p = 0.46). At 2 months post-training, groups demonstrated further improvement, with median SNR-50 values of –3.40 dB (Group 1), –1.90 dB (Group 2), and –1.90 dB (Group 3). The interquartile ranges were 4.85, 4.18, and 4.25 dB, respectively. Although Group 1 showed the greatest improvement, the difference between groups was not statistically significant (χ^2 = 2.93, p = 0.23). In summary, while all three groups showed improvement in SNR-50 over time, especially by 2 months post-training, no statistically significant differences were observed between the intervention types at any time point. Group 1 (auditory training) appeared to benefit the most in terms of SNR-50 reduction, followed by Group 2 and then Group 3.

Furthermore, a within-group comparison of the Friedman test revealed significant improvements were seen in Group 1 (χ^2 = 7.60, p = 0.02) and Group 2 (χ^2 = 10.00, p = 0.01), but not in Group 3 (χ^2 = 0.74, p = 0.67). This suggests a general enhancement in speech-in-noise perception over time, with stronger gains expected in the intervention groups. The Wilcoxon signed-rank test revealed that in Group 1**,** a significant change was observed only from Baseline to 2 months (p = 0.04), with no significant differences from Baseline to 1 month or between 1 and 2 months.
Group 2 showed significant improvement at all time points (Baseline to 1 month, Baseline to 2 months, and 1 to 2 months; all $p \leq 0.04$), reflecting robust effects of combined training.

3.2.2. Auditory processing tasks

A Kruskal-Wallis test was used to compare the groups on direct remediation tasks (Auditory: closure, discrimination, and figure-ground) assessed in children with CAPD who are in three intervention groups: Group 1, auditory training only; Group 2, auditory and cognitive training; and Group 3, a waiting period. The direct remediation tasks were captured at three different time periods: baseline, 1 month post-training, and 2 months post-training. Furthermore, the Mann-Whitney test was performed to determine whether a significant difference occurred between the groups. Additionally, within-group comparisons were conducted using the Friedman Test. If a significant difference was found, the Wilcoxon signed-rank test was used to identify the time point at which the difference became significant.

3.2.2.1 Auditory Closure The tasks in Auditory closure included Missing words and Missing syllables. The results of missing words and missing syllables are represented in Table 3.6 and Table 3.7, respectively.

3.2.2.1.1. Missing words

Table 3.6

Auditory closure (Missing words) Scores Across Groups at Three Time Points.

Auditory Closure - Missing words	**Group 1**		**Group 2**		**Group 3**		**Kruskal Wallis test**	
	Median	IQR	Median	IQR	Median	IQR	$\chi2$	p
Baseline	5.00	3.00	5.00	3.00	5.00	3.50	0.54	0.76
1 PT	7.00	0.50	7.00	2.00	6.00	3.00	4.26	0.12
2 PT	9.00	2.00	8.00	1.50	7.00	2.50	6.98	**0.03**

Note: PT – Post Training, Bold values indicate statistical significance (p < .05), IQR-Interquartile range

At baseline, the median scores for missing word identification were equal across all three groups at 5.00, with IQRs of 3.00 for Groups 1 and 2, and 3.50 for Group 3. The Kruskal-Wallis test indicated no statistically significant differences between groups ($\chi^2 = 0.54$, $p = 0.76$). At 1 month post-training, improvements were observed across groups. The median score increased to 7.00 in both Group 1 and Group 2, while Group 3 had a median of 6.00. The IQR was lowest in Group 1 (0.50), followed by Group 2 (2.00) and Group 3 (3.00), suggesting more consistent performance in the training groups. Despite these differences, the Kruskal-Wallis test did not show statistical significance ($\chi^2 = 4.26$, $p = 0.12$). At 2 months post-training, the median scores were highest for Groups 1 (9.00) and 2 (8.00), while Group 3 had a median score of 7.00. The IQRs were 2.00, 1.50, and 2.50 for Groups 1, 2, and 3, respectively. A statistically significant difference was observed between the groups at this time point ($\chi^2 = 6.98$, $p = 0.03$). Furthermore, the Mann-Whitney U test was performed to determine which group showed a statistically significant difference in the number of missing words. Significant differences were observed between Group 1 (auditory training) and Group 3 (waiting group) ($U = –2.13$, $p = 0.03$), and between Group 2 (auditory + cognitive training) and Group 3 ($U = –2.38$, $p = 0.02$). However, no significant difference was found between Group 1 and Group 2 ($U = 0.00$, $p = 1.00$). This indicates that auditory and cognitive training, especially auditory-only training, resulted in greater improvements in auditory closure performance over time compared to the waiting period group.

Furthermore, the Friedman Test was performed for the within-group comparison. In the task of missing words (AT 4.1), Groups 1 ($\chi^2 = 9.58$, $p = 0.01$) and 2 ($\chi^2 = 9.00$, $p = 0.01$) demonstrated statistically significant improvement, while Group 3 did not show any significant change ($\chi^2 = 1.64$, $p = 0.44$). The Wilcoxon Rank test results revealed significant improvements in Group 1 and Group 2 between the baseline and 2 months ($p = 0.04$) and between 1 and 2 months ($p \leq 0.05$). However, the scores on missing words between the Baseline and 1-month follow-up revealed no significant difference (p = 0.07). Group 3 did not show any significant differences across time points in scores of missing words.

3.2.2.1.2. Missing Syllables

Table 3.7

Auditory closure (Missing Syllables) Scores Across Groups at Three Time Points.

Auditory closure - Missing Syllable	**Group 1**		**Group 2**		**Group 3**		**Kruskal-Wallis Test**	
	Median	IQR	Median	IQR	Median	IQR	$\chi2$	P
Baseline	5.00	2.00	4.00	6.50	6.00	4.00	2.03	0.36
1 PT	9.00	2.00	9.00	3.00	6.00	6.00	1.48	0.48
2 PT	9.00	0.50	9.00	1.00	6.00	5.50	2.47	0.29

Note: PT – Post Training, IQR- Interquartile range

At baseline, the median score for missing syllables was 5.00 in Group 1, 4.00 in Group 2, and 6.00 in Group 3. The IQRs were 2.00, 6.50, and 4.00, respectively, reflecting high variability in Group 2. The Kruskal-Wallis test revealed no significant differences between groups at this stage (χ^2 = 2.03, p = 0.36). At 1 month post-training, median scores for missing syllables improved to 9.00 in both Group 1 and Group 2, while Group 3 had a median of 6.00. The IQR was smallest in Group 1 (2.00), moderate in Group 2 (3.00), and largest in Group 3 (6.00), suggesting more consistent improvement in the training groups. However, the group difference was not statistically significant (χ^2 = 1.48, p = 0.48). At 2 months post-training, the median score for missing syllables remained at 9.00 for both Group 1 and Group 2, while Group 3 had a median of 6.00. The IQRs were 0.50 (Group 1), 1.00 (Group 2), and 5.50 (Group 3), indicating higher consistency of performance in Groups 1 and 2. Although the auditory training groups showed better performance, the Kruskal-Wallis test still did not indicate statistically significant differences across the groups (χ^2 = 2.47, p = 0.29).

In addition, the Friedman Test was performed for the within-group comparison. In the missing syllables task (AT 4.2), both Group 1 (χ^2 = 9.29, p = 0.01) and Group 2 (χ^2 = 7.43, p = 0.02) showed significant improvements, indicating that training enhanced auditory closure skills, whereas Group 3 showed no significant change (p = 0.67). Furthermore, the Wilcoxon Rank test results revealed that Group 1 showed significant improvement from Baseline to 1 month and 2 months (p = 0.04), although the difference between 1 and 2 months was not significant. Group 2 trended toward significance (Baseline to 1 month, p = 0.06), but was not statistically significant across time points. Group 3 showed no significant changes.

3.2.2.2. Auditory Discrimination

The performance of the children of different groups for Auditory Discrimination for the different sub-chapters, Phrases, Vowels, Consonants, and Clusters are explained beow.

3.2.2.2.1. Phrases: The Auditory Discrimination Scores for Phrases across groups at three time points are depicted in Table 3.7.

Table 3.8

Auditory Discrimination (Phrase) Scores Across Groups at Three Time Points.

Auditory Discrimination – Phrases	**Group 1**		**Group 2**		**Group 3**		**Kruskal-Wallis test**	
	Median	IQR	Median	IQR	Median	IQR	$\chi2$	P
Baseline	8.00	4.00	8.00	3.00	10.00	1.00	3.02	0.22
1 PT	10.00	0.50	10.00	0.50	9.00	1.00	5.12	0.08
2 PT	10.00	0.00	10.00	0.00	9.00	2.00	6.92	**0.03**

Note: PT – Post-training, Bold values indicate statistical significance (p < .05), IQR-Interquartile range.

In the discrimination of phrases, at baseline, Groups 1 and 2 had identical median scores of 8.00, with IQRs of 4.00 and 3.00, respectively, while Group 3 had a higher median of 10.00

with a narrower IQR of 1.00. However, these differences were not statistically significant (χ^2 = 3.02, p = 0.22). At 1 month post-training, Groups 1 and 2 improved a phrase discrimination median score of 10.00 with minimal variability (IQR = 0.50 for both), whereas Group 3 had a median of 9.00 (IQR = 1.00), but this difference did not show a statistically significant difference (χ^2 = 5.12, p = 0.08). At 2 months post-training, Groups 1 and 2 maintained perfect median scores of 10.00, with no variability (IQR = 0.00), while Group 3 remained at a lower median of 9.00, with a higher IQR of 2.00. The difference between groups at this stage reached statistical significance (χ^2 = 6.92, p = 0.03). Further, a Mann-Whitney result revealed a significant difference was observed between Group 1 and Group 3 (U = –1.94, p = 0.05), and similarly between Group 2 and Group 3 (U = –1.94, p = 0.05), but not between Group 1 and Group 2 (U = 0.00, p = 1.00). It indicates that auditory and cognitive training, as well as auditory-only training, yielded greater improvements in phrase-level auditory discrimination compared to conventional training. In addition, the within-group comparison of the Friedman Test revealed no difference in phrase discrimination in any group.

3.2.2.2.2. Vowels: The Auditory Discrimination Scores for Vowels across groups at three time points are depicted in Table 3.8.

Table 3.9

Auditory Discrimination (Vowels) Scores Across Groups at Three Time Points.

Auditory Discrimination – Vowels	**Group 1**		**Group 2**		**Group 3**		**Kruskal-Wallis Test**	
	Median	IQR	Median	IQR	Median	IQR	χ2	P
Baseline	9.00	2.50	7.00	3.50	8.00	3.00	0.76	0.68
1 PT	10.00	1.50	10.00	2.50	8.00	2.00	1.91	0.38
2 PT	10.00	0.50	10.00	0.50	8.00	2.00	6.94	**0.03**

Note: PT – Post Training, Bold values indicate statistical significance (p < .05), IQR-Interquartile range.

At baseline, the median scores for vowel discrimination were 9.00 (Group 1), 7.00 (Group 2), and 8.00 (Group 3), with IQRs of 2.5, 3.5, and 3.0, respectively. The Kruskal-Wallis test showed no significant group difference ($\chi^2 = 0.76$, $p = 0.68$). At 1 month post-training**,** the median score for vowel discrimination was 10.00 (Groups 1 and 2) and 8.00 (Group 3). The IQRs were 1.5 (Group 1), 2.5 (Group 2), and 2.0 (Group 3), showing more consistent improvement in Groups 1 and 2. However, the group difference remained statistically non-significant ($\chi^2 = 1.91$, $p = 0.38$). At 2 months post-training, the median scores for vowel discrimination remained at 10.00 in Groups 1 and 2, while Group 3 maintained a median of 8.00. The IQRs were 0.5 (Group 1), 0.5 (Group 2), and 2.0 (Group 3), indicating greater consistency and improvement in the training groups. The Kruskal-Wallis test revealed a significant difference between the groups at this stage ($\chi^2 = 6.94$, $p = 0.03$). Furthermore, the Mann-Whitney U test was conducted to determine which group might have caused significant differences in vowel discrimination. Group 1 vs Group 3 ($U = –2.13$, $p = 0.03$) and Group 2 vs Group 3 ($U = –2.13$, $p = 0.03$) showed significant differences, while Group 1 vs Group 2 showed no significant difference ($U = 0.00$, $p = 1.00$). It indicates that vowel discrimination improved significantly in children who received auditory or combined auditory and cognitive training compared to the group of children in the waiting period.

In addition, the Friedman Test was performed for the within-group comparison on vowel discrimination (Vowel). Only Group 1 showed a significant change over time ($\chi^2 = 8.38$, $p = 0.02$), while Group 2 ($\chi^2 = 0.56$, $p = 0.07$) and Group 3 showed no change ($\chi^2 = 0.78$, $p = 0.37$). Furthermore, the Wilcoxon Rank test results revealed that in Group 1, there was a significant improvement from Baseline to 2 months ($p = 0.04$), but not at other intervals.

3.2.2.2.3. Consonants: The Auditory Discrimination Scores for Consonants across groups at three time points are depicted in Table 3.9.

Table 3.10

Auditory Discrimination (Consonants) Scores Across Groups at Three Time Points

Auditory Discrimination	**Group 1**		**Group 2**		**Group 3**		**Kruskal-Wallis test**	
(Consonants)	Median	IQR	Median	IQR	Median	IQR	$\chi 2$	P
Baseline	9.00	1.00	9.00	3.00	9.00	2.00	0.69	0.71
1 PT	9.00	1.50	10.00	1.00	9.00	2.00	1.21	0.55
2 PT	10.00	0.00	10.00	0.00	10.00	0.50	2.00	0.37

Note: PT Post-training, Bold values indicate statistical significance (p < .05), IQR-Interquartile range.

At baseline, the median score for consonant discrimination for all groups was 9.00, with IQRs of 1.00 (Group 1), 3.00 (Group 2), and 2.00 (Group 3). The Kruskal-Wallis test showed no significant differences among the groups ($\chi^2 = 0.69$, $p = 0.71$). At 1 month post-training, the median scores for consonant discrimination remained stable at 9.00 (Group 1 and 3) and increased to 10.00 in Group 2. The IQRs were 1.50 (Group 1), 1.00 (Group 2), and 2.00 (Group 3). However, the Kruskal-Wallis test continued to show no significant group difference ($\chi^2 = 1.21$, $p = 0.55$). At 2 months post-training, both Group 1 and Group 2 achieved perfect median scores of 10.00 with no variability (IQR = 0.00), while Group 3 also reached a median of 10.00 with slightly more variability (IQR = 0.50) on consonant discrimination. Despite the observable improvement across all groups, the Kruskal-Wallis test indicated no statistically significant difference among the groups ($\chi^2 = 2.00$, $p = 0.37$), suggesting that all training approaches were similarly effective in enhancing consonant discrimination over time. In addition, within-group comparison of the Friedman Test revealed no difference in consonant discrimination in any group.

3.2.2.2.4. Clusters The Auditory Discrimination Scores for Clusters across groups at three time points are depicted in Table 3.10.

Table 3.11

Auditory Discrimination (Clusters) Scores Across Groups at Three Time Points.

	Group 1		**Group 2**		**Group 3**		**Kruskal-Wallis test**	
Auditory Discrimination - Clusters	Median	IQR	Median	IQR	Median	IQR	$\chi 2$	P
Baseline	9.00	5.00	8.00	4.00	10.00	1.00	1.52	0.47
1 PT	10.00	0.50	10.00	0.00	10.00	0.50	1.08	0.58
2 PT	10.00	0.00	10.00	0.00	10.00	0.50	2.00	0.37

Note: PT – Post Training, IQR- Inter quartile range.

At baseline, the median auditory discrimination cluster scores were 9.00 (IQR = 5.00) in Group 1, 8.00 (IQR = 4.00) in Group 2, and 10.00 (IQR = 1.00) in Group 3. Although Group 3 initially appeared to perform better, the Kruskal-Wallis test revealed no significant group differences (χ^2 = 1.52, p = 0.47). At 1 month post-training, all three groups demonstrated improvements, reaching a median of 10.00, with low variability, as indicated by IQRs of 0.50 (Groups 1 and 3) and 0.00 (Group 2). The Kruskal-Wallis test continued to show no significant differences between groups (χ^2 = 1.08, p = 0.58). At 2 months post-training, Groups 1 and 2 maintained perfect median scores of 10.00 with no variability (IQR = 0.00), while Group 3 also had a median of 10.00 with minimal variability (IQR = 0.50). The Kruskal-Wallis test showed no statistically significant difference among the groups (χ^2 = 2.00, p = 0.37), indicating that all intervention types were similarly effective in enhancing cluster discrimination skills over time.

In addition, the Friedman Test was performed for the within-group comparison on cluster discrimination, reaching statistical significance only in Group 2 (χ^2 = 6.00, p = 0.05), suggesting a benefit from combined auditory and cognitive training. The Wilcoxon Rank test results revealed that in Group 2, there was no significant improvement across time points.

3.2.2.3. Auditory Figure Ground

This chapter included the sub-chapters Following Directions and Stories. The results of the performance of children for those sub-chapters are explained below

3.2.2.3.1.Following Direction: The details of the scores across groups at three time points for this sub-chapter is given in Table 3.12

Table 3.12

Auditory figure ground (Following direction) Scores Across Groups at Three Time Points.

Auditory Figure Ground - Following Direction	**Group 1**		**Group 2**		**Group 3**		**Kruskal -Wallis test**	
	Median	IQR	Median	IQR	Median	IQR	$\chi 2$	P
Baseline	7.00	3.00	6.00	4.00	8.00	2.50	2.64	0.27
1 PT	10.00	2.50	8.00	1.50	8.00	2.00	2.82	0.24
2 PT	10.00	0.50	10.00	1.50	8.00	2.00	7.32	**0.03**

Note: PT – post-training, Bold values indicate statistical significance (p < .05), IQR-Interquartile range.

At baseline, Group 1 showed a median score of 7.00 on the Auditory Figure Ground (IQR = 3.00), Group 2 had a slightly lower median of 6.00 (IQR = 4.00), and Group 3 had a higher median of 8.00 (IQR = 2.50). The between-group differences were not statistically significant (χ^2 = 2.64, p = 0.27). At 1 month post-training, Group 1 demonstrated improvement, with a median score of 10.00 (IQR = 2.50). Group 2 had a median score of 8.00 (IQR = 1.50), and Group 3 remained at 8.00 (IQR = 2.00). Although the medians suggested a trend toward better outcomes in Group 1, the differences were not statistically significant (χ^2 = 2.82, p = 0.24). At

2 months post-training, both Group 1 and Group 2 attained a median score of 10.00, with relatively low variability (IQRs of 0.50 and 1.50, respectively). In contrast, Group 3 remained lower, with a median score of 8.00 and a broader IQR of 2.00. The Kruskal-Wallis test revealed a statistically significant difference at this time point ($\chi^2 = 7.32$, $p = 0.03$), indicating that auditory training—either alone or combined with cognitive training—was more effective in improving auditory figure-ground abilities related to following directions than children in Group 3 of the waiting period. In the following directions task, a significant difference was found between Group 1 and Group 3 ($U = –2.52$, $p = 0.01$), with a trend toward significance between Group 2 and Group 3 ($U = –1.84$, $p = 0.07$), but no difference between Groups 1 and 2 ($U = 1.80$, $p = 0.50$).

In addition, the Friedman Test was performed for the within-group comparison in the following direction, reaching statistical significance in Group 1 ($\chi^2 = 8.38$, $p = 0.02$) and Group 2 ($\chi^2 = 9.58$, $p = 0.01$). The Wilcoxon Rank test results revealed a significant improvement in Group 1 and Group 2 from Baseline to 2 months ($p = 0.04$). Group 2 showed improvement even from Baseline to 1 month ($p = 0.04$), with a trend toward significance in the 1- to 2-month comparison, suggesting a benefit from combined auditory and cognitive training.

3.2.2.3.2. Stories The details of the scores across groups at three time points for this sub-chapter are given in Table 3.13

Table 3.13

Auditory figure ground (Stories) Scores Across Groups at Three Time Points.

Auditory Figure Ground - Stories	**Group 1**		**Group 2**		**Group 3**		**Kruskal-Wallis test**	
	Median	IQR	Median	IQR	Median	IQR	χ2	P
Baseline	2.00	0.75	1.50	2.25	1.50	1.75	2.63	0.45
1 PT	3.50	1.25	3.50	1.50	3.50	1.75	0.43	0.81
2 PT	4.50	1.00	5.00	1.50	3.50	1.25	2.59	0.27

Note: PT - Post-training, IQR- Interquartile range.

At baseline, Group 1 had a median score of 2.00 (IQR = 0.75) on the Auditory figure ground – stories. Group 2 scored slightly lower, with a median of 1.50 (IQR = 2.25), while Group 3 scored higher, with a median of 1.50 (IQR = 1.75). The between-group difference approached no statistical significance ($\chi^2 = 2.63$, $p = 0.45$), suggesting no pre-existing difference in story comprehension across groups. At 1 month post-training, all three groups demonstrated improvement and converged in performance, with each group having a median of 3.50. Group 1 had an IQR of 1.25, Group 2 had an IQR of 1.50, and Group 3 had an IQR of 1.75. The Kruskal-Wallis test indicated no significant difference among groups at this stage ($\chi^2 = 0.43$, $p = 0.81$). At 2 months post-training, Group 1 and Group 2 maintained strong performance with medians of 4.50 and 5.00, and IQRs of 1.00 and 1.50, respectively. Group 3 showed slightly lower scores with a median of 3.50 and an IQR of 1.25. These findings suggest that although the auditory and combined training groups showed greater improvement over time, the differences in Auditory Figure Ground – Stories performance did not reach statistical significance across the three groups ($\chi^2 = 2.59$, p = 0.27).

In addition, the Friedman Test was performed for the within-group comparison on the comprehension of stories, reaching statistical significance in Group 1 ($\chi^2 = 9.58$, $p = 0.01$) and Group 2 ($\chi^2 = 9.58$, $p = 0.01$). The Wilcoxon Rank test results revealed that both Group 1 and Group 2 showed significant improvements from Baseline to 2 months ($p = 0.04$), with Group 2 also improving from Baseline to 1 month, suggesting a benefit from combined auditory and cognitive training on comprehension of stories.

3.3. Auditory working memory tasks

3.3.1. Operation Span The details of the scores across groups at three time points for this sub-chapter are given in Table 3.14.

Table 3.14

Cognition (Operation span) Scores Across Groups at Three Time Points.

	Group 1		**Group 2**		**Group 3**		**Kruskal-Wallis test**	
Operation Span	Median	IQR	Median	IQR	Median	IQR	χ2	P
Baseline	2.00	1.00	2.00	0.50	2.00	2.00	2.34	0.31
1 PT	3.00	1.50	2.00	1.00	2.00	2.00	2.29	0.32
2 PT	2.00	1.50	4.00	1.00	3.00	2.50	2.54	0.28

Note: PT - Post-training, IQR- Interquartile range.

At baseline, comparable performance was observed with median operation span scores of 2.00 across all three groups. The IQRs were 1.00 for Group 1, 0.50 for Group 2, and 2.00 for Group 3. The Kruskal-Wallis test indicated no significant difference among groups ($\chi^2 = 2.34$, $p = 0.31$). At 1 month post-training, Group 1 showed a median of 3.00 (IQR = 1.50), Group 2 had a median of 2.00 (IQR = 1.00), and Group 3 remained at 2.00 (IQR = 2.00). The differences were again not statistically significant ($\chi^2 = 2.29$, $p = 0.32$). At 2 months post-training, Group

2 showed a notable improvement with a median of 4.00 (IQR = 1.00), while Group 1 had a median of 2.00 (IQR = 1.50) and Group 3 had a median of 3.00 (IQR = 2.50). Despite this upward trend in Group 2, the Kruskal-Wallis test did not reveal a statistically significant difference among groups (χ^2 = 2.54, p = 0.28). These findings suggest potential gains in working memory span over time, especially in the combined auditory and cognitive training group, though between-group differences were not statistically significant.

In addition, the Friedman Test was performed for the within-group comparison on operation span, reaching statistical significance in Group 2 (χ^2 = 8.38, p = 0.02) and Group 3 (χ^2 = 6.00, p = 0.05). The Wilcoxon Rank test results revealed a significant improvement in Group 2 between the baseline and 2-month follow-up (p = 0.04), suggesting a benefit from combined auditory and cognitive training. However, no improvement was seen in Group 3 between time periods on the operation span.

3.3.2. Reading Span The details of the scores across groups at three time points for this sub-chapter are given in Table 3.14.

Table 3.15

Cognition (Reading span) Scores Across Groups at Three Time Points.

Reading Span	**Group 1**		**Group 2**		**Group 3**		**Kruskal-Wallis test**	
	Median	IQR	Median	IQR	Median	IQR	χ2	P
Baseline	2.00	2.00	1.00	2.00	2.00	2.00	0.82	0.66
1 PT	3.00	3.00	3.00	2.50	2.00	2.50	0.12	0.94
2 PT	3.00	1.50	3.00	1.00	2.00	2.00	4.90	0.09

Note: PT - Post-training, IQR- Interquartile range.

At baseline, all groups demonstrated similar reading span scores with a median of 2.00. The IQRs were also identical at 2.00 across all groups. The Kruskal-Wallis test showed no statistically significant difference between the groups ($\chi^2 = 0.82$, $p = 0.66$). At 1 month post-training, Group 1 and Group 2 both showed a median score of 3.00, with IQRs of 3.00 and 2.50, respectively, whereas Group 3 had a median of 2.00 (IQR = 2.50). Despite slight increases in performance for Group 1 and Group 2, no statistically significant difference was found between the groups ($\chi^2 = 0.12$, $p = 0.94$). By 2 months post-training, Group 2 showed the highest median reading span of 3.00 (IQR = 1.00), followed by Group 1 with a median of 3.00 (IQR = 1.50), while Group 3 remained at a median of 2.00 (IQR = 2.00). Although there appeared to be a trend toward improvement, particularly in Group 2, the Kruskal-Wallis test revealed that the difference among groups was not statistically significant ($\chi^2 = 4.90$, $p = 0.09$). These results suggest potential post-training gains in reading span for the groups receiving targeted interventions, particularly those that included cognitive training, although statistical significance was not reached.

In addition, the Friedman Test was performed for the within-group comparison on reading span, reaching statistical significance only in Group 2 ($\chi^2 = 7.60$, $p = 0.02$). The Wilcoxon Rank test results revealed a significant improvement in Group 2 between the baseline and 2-month follow-up ($p = 0.04$), suggesting a benefit from combined auditory and cognitive training.

3.3.3. Running Span The details of the scores across groups at three time points for this sub-chapter are given in Table 3.16

Table 3.16

Cognition (Running span) Scores Across Groups at Three Time Points.

Running span	**Group 1**		**Group 2**		**Group 3**		**Kruskal-Wallis test**	
	Median	IQR	Median	IQR	Median	IQR	$\chi 2$	P
Baseline	2.00	0.50	2.00	0.50	2.00	1.00	4.20	0.12
1 PT	3.00	1.50	3.00	2.00	2.00	0.00	4.40	0.11
2 PT	3.00	1.50	4.00	1.00	2.00	1.50	8.34	**0.02**

Note: PT - Post-training, Bold values indicate statistical significance (p < .05), IQR-Interquartile range.

At baseline, all three groups had a consistent median running span score of 2.00. The IQRs were narrow (0.50 for Groups 1 and 2; 1.00 for Group 3), indicating low variability. The Kruskal-Wallis test showed no statistically significant difference between the groups ($\chi^2 = 4.20$, $p = 0.12$). At 1 month post-training, both Group 1 and Group 2 showed improvement, with medians of 3.00 (IQR = 1.50 and 2.00, respectively), whereas Group 3 remained at a median of 2.00 with no variability (IQR = 0.00). Although the groups receiving training showed better performance, the difference was not statistically significant ($\chi^2 = 4.40$, $p = 0.11$). By 2 months post-training, Group 2 demonstrated the highest performance with a median of 4.00 (IQR = 1.00), followed by Group 1 with a median of 3.00 (IQR = 1.50), and Group 3 with a median of 2.00 (IQR = 1.50) on running span. The Kruskal-Wallis test indicated a statistically significant difference between the groups on running span at this time point ($\chi^2 = 8.34$, $p = 0.02$). Furthermore, a Mann-Whitney test was conducted, and the results revealed a significant difference between Group 2 and Group 3 ($U = –2.58$, $p = 0.01$). The comparisons between Group 1 and Group 2 ($U = –4.40$, $p = 0.11$) and between Group 1 and Group 3 ($U = 3.50$, $p = 0.20$) were not statistically significant. It suggests that combined auditory and cognitive training led to greater improvements in working memory capacity as measured by the running span task.

In addition, the Friedman Test was performed for the within-group comparison on reading span, reaching statistical significance only in Group 2 ($\chi^2 = 8.00$, $p = 0.02$). The Wilcoxon Rank test results revealed a significant improvement in Group 2 between the baseline and 2-month follow-up ($p = 0.03$), suggesting a benefit from combined auditory and cognitive training.

Overall, statistically significant improvements were noted from the baseline assessments and post-training evaluations with respect to frequency discrimination, speech perception in noise, and for a few of the probe stimuli, for children who received auditory training alone and also for those who received both auditory and auditory cognitive training. However, children who received auditory cognitive training in addition performed significantly better after training in the performance of the probe stimulus in the cognitive tasks.

Chapter 4

Discussion

The study aimed to evaluate the efficacy of a web-based application designed to improve auditory and cognitive processing in children with CAPD. The study's findings are discussed below in relation to evaluations and the impact of the intervention on psychoacoustic, speech perception, auditory processing, and cognitive tasks.

Expert evaluation during content validation ensured that the materials selected were both age-appropriate and familiar to children with CAPD. The high level of agreement among experts, as indicated by the ICVI, Kappa coefficient, SCVI/Ave, and SCVI/UA ratio, confirms the suitability and effectiveness of the speech stimuli in facilitating auditory skill enhancement and communication development in children aged 8–12 years with CAPD. The verification of the web-based application using the uMARS aligns with best practices in digital health interventions, where user-friendliness is critical to adherence and outcome efficacy. The engagement domain scored highly, suggesting that the application successfully captured attention and provided meaningful interactivity—an important component, particularly when working with children, as engagement directly influences motivation and learning. The information domain reflected strong agreement on the accuracy, clarity, and reliability of content. Overall, the app is highly rated by the Audiologist team and suggests its usefulness for managing CAPD.

The results of the present study indicate that children with CAPD demonstrated improvement in the frequency discrimination task following training. This was observed in the groups which underwent Auditory training alone and those that obtained cognitive training along with auditory training. This affirmed the impact of auditory and combined training. These results align with a study by Mustek & Schochat (199), where intensive auditory training on intensity and frequency discrimination, gap detection, and speech-based tasks, such as dichotic listening, showed a significant improvement in frequency discrimination ina child with CAPD.

Speech-in-noise perception, measured using SNR-50, improved notably across Groups 1 and 2, with Group 1 showing the greatest gains. This aligns with the study by Loo et al. (2016), who found that a 12-week computer-based auditory training (AT) program significantly enhanced speech-in-noise performance in children with APD. The improvement in speech perception in noise was sustained after three months, and these improvements correlated with teacher-rated functional listening, highlighting real-world benefits and confirming that speech-based Auditory Training can be generalised to everyday listening scenarios (Loo et al., 2016). The study is also in consonance with the findings of similar studies. Similarly, the current study's findings revealed a statistically significant improvement in the speech perception skills of children who underwent Auditory and Auditory cognitive training. Specifically, Group 1 (Auditory training) showed a significant difference between the baseline and the 2-month interval, while Group 2 (Auditory + Auditory cognitive training) exhibited consistent progress across all time points. This finding suggests that providing auditory cognitive training along with auditory training helped children with APD show an improvement in the speech-in-noise test more quickly than those who received only auditory training. Children who underwent only auditory training required 2 months to show a significant difference in scores of SNR 50 between the baseline and follow-up evaluation. However, children who underwent both auditory and auditory-cognitive training showed a significant difference between the baseline and follow-up evaluations within one month. These findings underscore the importance of auditory cognitive training along with auditory training.

The training provided led to an improvement in the auditory closure skills (Missing Words and Missing Syllables) of the children with CAPD, as assessed using the probe stimuli. Statistically significant between-group differences were observed at 2 months in the Missing

Words task, where the performance of Groups 1 and 2 was significantly better compared to that of Group 3. Within-group analyses further confirmed that both intervention groups showed steady improvement across sessions. These findings suggest that both auditory and combined training strategies are effective in enhancing auditory closure, a crucial skill for filling in missing auditory information during degraded listening conditions. These results align with the study by Weihing et al. (2015), who highlight that auditory training (AT) is a critical intervention for children with CAPD, particularly in improving auditory closure. Programs like Earobics and Fast ForWord specifically target auditory closure by presenting degraded or incomplete speech stimuli and training children to interpret them. These structured, adaptive exercises enhance auditory processes, such as discrimination and phonological awareness. These findings suggest that using process-specific, computer-based Auditory Training tools with graduated difficulty and motivational strategies improves listening and speech understanding.

In the current study, TMTF, which assesses temporal resolution, did not show comparable improvements. The training had no impact on the temporal processing. This outcome may be attributed to the predominantly speech-focused nature of the web-based training material. The intervention primarily targeted speech-related processing, with improvements being more apparent in speech-based measures.

In auditory discrimination tasks, improvement was observed in the groups which received training for vowel identification. At 2 months, both Groups 1 and 2 showed significantly better performance compared to Group 3. Click or tap here to enter text.Ferre (2016) highlight auditory discrimination as a fundamental skill impaired in CAPD, which often affects speech perception due to difficulty in distinguishing subtle acoustic cues. The improvement in auditory discrimination helps improve speech perception. Mustek & Schocha (1998) have also reported improvement in auditory discrimination skills after an intensive 6-week auditory training program.

Tasks measuring auditory figure-ground abilities (Following Directions and Stories) revealed significant between-group differences at the 2-month mark in the Following Directions task. Both groups 1 and 2 showed superior performance relative to Group 3. These tasks are critical for daily communication, particularly in multi-speaker environments or classrooms, where children must distinguish important speech from background noise. Improvement in story comprehension was also notable in Groups 1 and 2. This demonstrated that targeted auditory training improves not only basic auditory discrimination but also higher-order linguistic processing within noise contexts.

Group 2 (auditory + cognitive training) performed better in the cognitive tasks (Operation Span, Reading Span, and Running Span tasks) across all evaluations carried out. This was demonstrated within Group 2, particularly between the baseline and the 2-month follow-up. These findings are consistent with research suggesting that working memory can be enhanced through structured cognitive training, especially when paired with auditory rehabilitation.

In the current study, the group that received both auditory and cognitive training showed consistent improvement in cognitive skills, unlike a study in the literature (Kumar et al., 2021), which investigated the impact of speech-in-noise (SIN) training on auditory and cognitive functions in children with CAPD. Working memory was improved after speech-in-noise training was given to children with CAPD. However, in the current study, the group which received only auditory training did not show an improvement in cognitive skills. The probable reason could be that the current study assessed a complex form of working memory, whereas the study by Kumar et al. (2021) assessed simple working memory tasks. Vendruscolo et al.

(2023) evaluated the effectiveness of cognitive auditory training in CAPD through both tele-rehabilitation and in-person methods. Using the Online Cognitive Auditory Training Program, which integrates both bottom-up (auditory skills) and top-down (cognitive and linguistic) strategies, children showed significant improvements in auditory figure-ground skills, selective attention, memory, and listening comprehension. Performance gains were observed in Pediatric Speech Intelligibility and Dichotic Digit tests. Importantly, telerehabilitation was as effective as traditional in-person training, enhancing accessibility. These findings confirm that cognitive training, particularly through digital platforms, can effectively enhance auditory and cognitive processing in children with CAPD, thereby supporting communication and academic success.

Overall, the study's findings reveal the efficacy of web-based auditory and cognitive training in managing children with CAPD. The study also highlights the applicability of a web-based application in managing their environment, enabling them to access training.

Clinical implications

This study supports that structured auditory training, whether implemented alone or in combination with cognitive training, leads to improvements in multiple auditory and cognitive areas. The use of a web-based application enabled consistent and accessible delivery, overcoming common barriers associated with in-clinic training, such as scheduling, engagement, and compliance. The findings also highlight the integration of web-based technology into routine CAPD therapy. The adaptability of app-based tools can enhance service delivery in underserved populations and provide engaging, evidence-based content tailored to individual needs. Furthermore, the study validates that auditory skills such as frequency discrimination, speech-in-noise perception, and figure-ground comprehension are trainable through web-based platforms. When combined with cognitive modules, additional benefits in executive functioning can be realised.

Future Directions

As a future direction from the current study, Further studies can be carried out with a large sample size. Additionally, feedback from the child and the parent can be obtained. Future studies should incorporate real-world usability and acceptability from the target population to ensure relevance and effectiveness. Additionally, the intervention in the current study lasted for two months; more extended follow-up periods would help establish the durability of the observed improvements. Furthermore, exploring generalisation to academic outcomes can also be a valuable area of study.

Summary

This study demonstrated that both auditory and combined auditory-cognitive training offer significant benefits for children with CAPD. Improvements were observed for frequency discrimination, speech-in-noise perception, auditory closure, and figure-ground processing. Moreover, cognitive enhancements, especially in working memory tasks, were achieved predominantly through combined training. The control group, for which no training was provided, did not show any improvements in the different auditory processes tested. The validated web-based application served not only as a delivery tool but also proved to be an effective and well-received medium for intervention, combining usability with clinical relevance. The findings from this study provide evidence for the effectiveness of a web-based intervention program in improving auditory and cognitive processing in children with CAPD. Auditory training alone led to significant gains across frequency discrimination, speech-in-noise perception, and auditory closure, while combined training enhanced working memory outcomes. The web-based application was positively rated by experts across all domains, demonstrating feasibility, acceptability, and potential for clinical impact.

1

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Appendix 1

Details of Auditory training:

AUDITORY CLOSURE- The ability to fill in missing or distorted auditory information is auditory closure. This chapter includes 2 Subchapters, namely ‘Missing words’ and ‘Missing syllables’. Each of these subchapters is further divided into 3 different levels –‘Initial’, ‘Medial’ and ‘Final’ positions. These levels are further divided into 3 sublevels- ‘Easy’, ‘Difficult’ and ‘Hard’.

In **Missing words,** in the **Initial level**, the first word of the sentence would be replaced by a pure tone signal. The child is expected to say the word which was replaced by a pure tone signal.

Easy - /…………t̪a:gadina thuthuri/ /bannadha/

Difficult- /……. ni:ʋu d̪ʱarisiruva ʋastu, id̪u ‘ʧiʈʈe’jond̪ige pra:sabad̪d̪iva:gide/ /baʈʈe/

Hard- /……..ilige: bale bi:lisʊʋa matu saŋkaʈa ni:duʋa pra:ɳi, na:nu jeradu akʂarada pra:ɳi/ bekku/

Similarly, at the Medial level, the task is to find the words in the middle part of the sentence. It follows the 3 sublevels- Easy, difficult and hard.

Easy- /dinavu ……….maɖa:beku/ /sna:na/

Difficult- /suman ………..naɭ̂i ma:rketige ho:danu/ / mo:ʈarsaɪkəl/

Hard- /na:nu hasidiruʋa:ga na:nu ……..ma:dut̪e:ne/ / uʈa/

In **Final level**, the task is to find the ending/last part of the sentence. It follows the 3 sublevels- Easy, difficult and hard.

Easy- /niːvu hallu ………………./ /udʒ͡aːbeku/

Difficult- /nanna beːku kaleːdu hoːgide, nanageː tumba ……/ / bedʒaraːgide/

Hard- /naːnu dʒamiːninal̂i ʋaːsisutit̪ʰeːne , naːnu hul̂u t̪in̂alu iʃt̪a pad̪ut̪eːne , naːnu haːlan̂u kod̪ut̪eːne , naːnu ……… / hasu/

In **Missing Syllable**, there are 3 levels- Initial, Medial and Final. It is further divided into 3 Sublevels- Easy, difficult and hard.

In the **Initial level**, task is to find the initial segment of the word which will be missing.

Finish this word for me. The first part is missing /…maːna/ /vImaːna/

Easy- /nɑːnu ….sid̪ʱid̪ʱɑrinda nanna hoʈːe guruguttitu/ /hasid̪ʱid̪ʱɑrinda/

Difficult- /namːa kotad̪ijannu nɑːʋu …t͡ʃagolisabeku/ /swat͡ʃagolisabeku/

Hard- /kit̪akigalu sund̪arɑʋɑd̪a …t̂egalannu hond̪id̪ʱaʋu /bat̂egalannu/

In the **Medial level**, the task is to find the middle part of the word in which both ends are present.

Fill in the middle of this word. For example: /ki….ki/ /kitaki/

Easy- / nɑːnu hɑlɑd̪id̪ʱi ba…han̂aɳ̪an̂u sulid̪id̪ʱene / /bɑɭehannaɳ̪ɳ̪annu/

Difficult- / mrugɑlɑjɑd̪ʱalli nɑːnu ɑː …ge j kɑd̪ale kɑːijɑn̂u t̪ʰin̂isid̪ʱeʋu/ /ɑːnege/

Hard- / mɑle surid̪ʱa kɑːrɑnɑ maid̪ʱɑnɑ ʋa ….jɑgit̪ʰu/ /ʋad̪̂ejɑgit̪ʰu/

In the Final level, the task is to find the last syllable of the word which is missing.

Finish this word for me. For example: the last part is missing. “pusta…”

/pustaka/

Easy- /ɑʋanu pusṯɑ…. oːd̪uṯʰɑne / /pustaka/

Difficult- /miːnɑ hannugɑlannu karid̪isɑlu mɑːrukaʈʈe..… hoːd̪ɑlu/ /mɑːrukaʈʈege/

Hard- / nɑːnu nam̂a prɑʋɑːsad̪a nanṯʰarɑ jellɑrigu t͡ʃɑːjɑt͡ʃiṯrɑʋɑ….. ṯʰorisid̪ʱeʋe/

/ tʃɑːjɑtʃiṯrɑʋɑn̂u/

AUDITORY DISCRIMINATION- This chapter has been divided it into 4 subchapters- Phrases, Vowels, Consonants, and Clusters. Each subchapter has three levels- Easy, Difficult and Hard except for the consonants subchapter, which has only Easy and Difficult.

In the Phrases task, participants listen to two presented phrases and indicate whether the phrases are the same or different.

Easy- /ṯale ṯuːgu/ /ṯale ṯuːgu/= same

Difficult- /ban̂i mara/ /ban̂i ʋara/= different

Hard- /anitha kɑːrinind̪ʱɐ jed̪ɐlu/ /anitha kɑːrinind̪ʱɐ bid̪ɐlu/= different.

In the Vowels task, participants listen to two presented vowels and indicate whether they are the same or different.

Easy- /ɑ/ /ɑ/ = Same /ɑ/ /iː/ = different

Difficult- /iː/ /iː/ =same /oː/ /iː/ = different

Hard- /au̯/ /au̯/= same /o/ /oː/ = different

In the Consonants task, participants listen to two presented consonants and indicate whether the phrases are the same or different.

Easy - /gɑ /- /mɑ/= different /kɑ/-/kɑ/= same

Difficult- /ki/-/ki/= same /ku/- /kʰu/ = different

In the Clusters task, participants listen to two presented clusters and indicate whether they are the same or different.

Easy- /t̪ru/ – /t̪la/= different /st̪ri/ /st̪ri/= same

Difficult- /ɡja/ – /ɡʊa/= different /kvɑ/- /kvɑ/= same

Hard- /skɹuː/– /skluː/= different /bʱruː/ /bʱruː/= same

Auditory Figure Ground- This task has **2 Sub-chapters** – Following direction and Stories.

In the following direction, the stimuli are embedded with speech noise, it is divided into 3 levels- Simple, Intermediate and Complex. In each level, it is further divided into 3 Sublevels- Easy, Difficult and Hard.

In simple level, the action-based sentences will be presented with noise, and the child has to follow.

Easy- /ni:vu ed̪̂u nilli/

Difficult- /nimm̂a mukʱa t̪oɭejuvɑnt̪ʰe natisi/

Hard- /gɐɖijɑːrɐd̪ɐlli eruva sɐŋkjɐgalann̂u e:ɳisi/

In intermediate,

Easy- /ni:vu ed̪̂u nilli mat̪̂u ba:gilɑ bali o:ɖi/

Difficult- /bɑːgilu t̪erejiri mɑt̪̂u horɑge nodi/

Hard- / nimm̂a hesarannu pisugut̂i mat̪̂u pust̪akadaÎI bareyiri /

In complex,

Easy- / nim̂a pennu illi kod̪i mɑt̪ʰe pust̪ʰaka jet̪ʰukoɭi /

Difficult- /mod̪alu pust̪akaʋan̂u nant̪ara pen̂u t̪erejiri mat̪̂u nim̂a hes̪aran̂u barejiri/

Hard- /hasiru bɐɳad̪a ʋast̪uvond̪ara hesaran̂u ka:gad̪a meːle bidisi mat̪̂u ad̪u eːnu end̪u nange t̪iɭisi/

In **stories**, stories are embedded with muti-talker babble. Participants are instructed to listen to the stories carefully and answer the questions which is asked by the clinician/mother. There are 5 sublevels —Easiest, Easy, Moderate, Hard, and Hardest —and the background noise was presented at varying signal-to-noise ratios (SNRs) of +18, +14, +10, +6, and +2 dB, respectively. Each sub-level contains 3 stories followed by 5 questions that are related to the story.

Story: /nan̂a hesaru raːma nan̂a t̪and̪e nanɑge hosa saːku prɑːɳijannu khariːd̪isid̪aru. avanu mud̪̂ɑːd̪ə puṭṭa nɑːji. avanu iːga tʃik̂avanɑːgiruvud̪arind̪a avanu nid̪risut̪̂ɑːne. nɑːjiyannu sʋətʃ̂ʋɑːgiḍal̪u nan̂a t̪and̪e mat̪̂u t̪ɑːji nanage sahaːja maːḍut̪̂ɑːre. avanu uḷid̪ukoḷ̂uʋa nɑːjimane nam̂al̪̂id̪e. nɑːnu ʃɑːl̪ejind̪ə sɑndʒe manege avanond̪ige ɑːḍut̪̂eːne. avanu ʋeːgaʋɑːgi bel̪eyut̪̂id̪̂ɑːne. nɑːnu nan̂a hosa saːkuprɑːɳijannu priːt̪isut̪̂eːne./

Question: /raːmana hosa saːkuprɑːɳi jɑːvud̪u/?

Answer: /raːmana hosa saːku praɳi puṭṭə nɑːji/

Appendix 2

Details of Auditory-cognitive training

Operation Span

The primary task of the child is to listen to the word presented carefully and remember all the words presented. The secondary task is to say whether the mathematical operations are correct or wrong. The following sequence is followed:

Word1: /sara/

2+2=5, Wrong

Word 2: /baḷe/,

3-1=2, Correct

Word 3: /huḷi/

9+2=11, Correct

Word 4:/ ha:vu/

40-5=35, Wrong

The child had to recall the words: /sara/, /baḷe/, /huḷi/, /ha:vu/

Reading Span

The primary task of the child is to listen carefully to the word presented and remember all the words presented. The secondary task is to say whether the sentences presented are semantically correct or wrong. The following sequence is followed:

Word 1: /mane/,

/a:ka:ʃa nil̪ijagid̪e/- Correct

Word 2: / va:sa/,

/na:vu nee:rannu t̪̪in̂ut̪̪̂e:ve/- Wrong

Word 3: /u:ṭa/

/rat̪ri hot̪t̪u su:rja barut̪t̪a:ne/- Wrong

The child had to recall the words: /mane /, /va:sa/, /u:ṭa/

Running Span

The child is made to listen to a string of numbers carefully.

2, 9, 4,3,1

The child is instructed to recall the last 2 digits and say it back.

The child is expected to say 3,1

Appendix 3

Table A1

Comparison of tests between time periods in each group

	Group 1		Group 2		Group 3	
	Z	P	Z	P	Z	P
Frequency discrimination						
B- E1	-2.02	**0.04**	-2.02	**0.04**	-	-
B- E2	-2.02	**0.04**	-2.02	**0.04**	-2.02	**0.04**
E1- E2	-	-	-2.02	**0.04**	-2.02	**0.04**
SNR 50						
B- E1	-	-	-2.02	**0.04**	-	-
B- E2	-2.02	**0.04**	-2.02	**0.04**	-2.02	**0.04**
E1- E2	-2.02	**0.04**	-2.02	**0.04**	-	-
Probe: Auditory closure-Missing words						
B- E1	-	-	-	-	-	-
B- E2	-2.07	**0.04**	-2.03	**0.04**	-	-
E1- E2	-2.04	**0.04**	-2.00	**0.05**	-	-
Probe: Auditory closure-Missing Syllable						
B- E1	-2.03	**0.04**	-	-	-	-
B- E2	-2.03	**0.04**	-	-	-	-
E1- E2	-	-	-	-	-	-
Probe: Auditory Discrimination- Vowels						
B- E1	-	-	-	-	-	-
B- E2	-2.07	**0.04**	-	-	-	-
E1- E2	-	-	-	-	-	-
Probe: Auditory Figure Ground- Following direction						
B- E1	-	-	-2.03	**0.04**	-	-
B- E2	-2.06	**0.04**	-2.04	**0.04**	-	-
E1- E2	-	-	-	-	-	-
Probe: Auditory Figure Ground- Stories						
B- E1	-	-	-2.04	**0.04**	-	-
B- E2	-2.03	**0.04**	-2.02	**0.04**	-	-
E1- E2	-2.04	**0.04**	-	-	-	-
Probe: Operation span						
B- E1	-	-	-	-	-	-
B- E2	-	-	-2.04	**0.04**	-	-
E1- E2	-	-	-	-	-	-
Probe: Reading span						
B- E1	-	-	-	-	-	-
B- E2	-	-	-2.07	**0.04**	-	-
E1- E2	-	-	-	-	-	-

Probe: Running span						
B- E1	-	-	-	-	-	-
B- E2	-	-	-2.12	**0.03**	-	-
E1- E2	-	-	-	-	-	-

B- Baseline, E1- Evaluation 1, E2- Evaluation 2.

Bold values indicate statistical significance ($p < 0.05$).

Table A2:

Friedman Test (within-group comparison) results for all three groups

Friedman Test - within group comparison						
	Group 1		Group 2		Group 3	
	χ^2	P	χ^2	p	χ^2	P
Frequency_discrimination	8.40	0.02	10.00	0.01	8.40	**0.02**
TMTF_8Hz	1.20	0.55	3.60	0.17	2.00	0.37
TMTF_64Hz	0.40	0.82	2.80	0.25	0.40	0.82
TMTF_128Hz	2.80	0.25	1.20	0.55	0.40	0.82
SNR50_B	7.60	0.02	10.00	0.01	6.00	**0.05**
Probe: Auditory closure						
Missing words	9.58	0.01	9.00	0.01	1.64	0.44
Missing Syllable	9.29	0.01	7.43	0.02	0.80	0.67
Probe: Auditory discrimination						
Phrases	5.60	0.06	5.20	0.07	2.60	0.27
Vowels	8.38	0.02	5.38	0.07	2.00	0.37
Consonants	5.60	0.06	3.50	0.17	3.80	0.15
Clusters	3.50	0.17	6.00	0.05	2.00	0.37
Probe:Auditory figure ground						
Following directions	8.38	0.02	9.58	0.01	3.00	0.22
Stories	9.58	0.01	9.58	0.01	2.00	0.37
Probe: Operation span	0.67	0.72	8.38	0.02	6.00	**0.05**
Probe: Reading span	2.60	0.27	7.60	0.02	2.00	0.37
Probe: Running span	3.50	0.17	8.00	0.02	1.40	0.50

Note: Bold values indicate statistical significance ($p < .05$).