LISTENING TRAINING STRATEGIES FOR AUDITORY PROCESSING DISORDER – A SYSTEMATIC REVIEW

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This Dissertation is submitted as part

fulfilment for the Degree of Master of Science in Audiology

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CERTIFICATE

This is to certify that this dissertation entitled **'Listening training strategies for auditory processing disorder – A systematic review'** is a bonafide work submitted as a part for the fulfilment for the degree of Master of Science (Audiology) of the student Registration Number: 19AUD027. This has been carried out under the guidance of the faculty of this institute and has not been submitted earlier to any other University for the award of any other Diploma or Degree.

Mysuru

September 2021

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DECLARATION

This is to certify that this dissertation entitled **'Listening training strategies for auditory processing disorder – A systematic review'** is the result of my own study under the guidance of Dr. N Devi, Assistant Professor, Department of Audiology, All India Institute of Speech and Hearing, Mysore and has not been submitted earlier to any other University for the award of any other Diploma or Degree.

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This Dissertation is dedicated to

My parents and My sister

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ABSTRACT

In recent years, clinical intervention for central auditory processing disorder (CAPD) has become a fascinating and challenging field of research for audiologists and speech-language pathologists. Due to the heterogeneous nature of CAPD, treatment approaches mainly focus on individualized intervention programs. This present study systematically reviews the articles published in the past fifteen years (2005-2020) regarding various strategies available to rehabilitate individuals with auditory processing disorders. This article gives an overview of the various intervention options that address certain specific auditory deficits. This study also highlights direct skill remediation and its importance when combined with other training techniques like compensatory strategies, signal enhancement techniques, and informal training.

With technological advancements, computer-based auditory training has become a prominent study interest in recent years. This study also gives an overview of recently developed computer-based auditory training software and interactive games for individuals with an auditory processing disorder. The studies explored in this research have also shown positive outcomes for therapy provided for auditory processes such as binaural integration, binaural separation, auditory closure training, temporal resolution, and temporal patterning. Besides providing direct remediation training, certain signal enhancement techniques (like FM systems and remote microphone hearing aid (RMHA) to cut off the noise and reverberations) and some compensatory approaches are also recommended. The present systematic review provides an overview of the studies on the efficacy of certain deficit-specific auditory training approaches in children with an auditory processing disorder.

Chapter 1

INTRODUCTION

The perceptual processing of auditory information in the central auditory nervous system (CANS) and the neurological activity underlined in this processing giving rise to auditory potential is referred to as auditory processing or (central) auditory processing (ASHA, 2005). Central auditory processing disorder (C)APD affects a wide range of people, including children and adults. It can be caused by various etiologies, including problems with the CANS. Neurological involvement ranging from degenerative diseases to exposure to neurotoxic substances can result in (C)APD. Furthermore, developmental, communication, learning difficulties, peripheral hearing loss, and aging processes can impact central auditory processing (American Academy of Audiology, 2010)

Several auditory abilities or skills are essential for processing the auditory information, such as auditory discrimination, temporal aspects of audition (temporal integration, resolution, ordering, and masking) and temporal processing (auditory pattern recognition), binaural processing such as sound localization and lateralization, and auditory performance with competing or degraded acoustic signals A deficit in any of these processes results in APD. A valid and reliable test battery helps identify and diagnose APD. APD can occur as an isolated disability or associated with other disorders (most commonly with a learning disability and others like language disorders, developmental disorders, etc.), so a multidisciplinary assessment is of paramount importance for differential diagnosis and to plan the management strategies (American Speech-Language Hearing Association, 2005)

The ultimate goal of screening and diagnostic assessment for auditory processing disorders (APD) is to describe the nature and extent of the disorder to determine effective management strategies and intervention programs for affected individuals (American Academy of Audiology, 2010). Speech-language pathologists (SLPs) and audiologists have been focusing primarily on intervention for (central) auditory processing disorder, or (C) APD, in recent years (Bellis & Anzalone, 2008). Rehabilitation for auditory processing problems is essential to lead a life as fulfilling as possible despite auditory processing difficulties (Yathiraj, 2015).

Management for (C)APD has received much attention from the mid-90s, with advancements in neuroscience demonstrating the pivotal role of neural plasticity in producing changes behaviourally through intensive training and enhancing auditory abilities by stimulating the deviant auditory process (American Academy of Audiology, 2010). The recent past trend in APD management is towards the evidence-based individualized or customized therapy perspective according to the client's profile (age, cognition, language, co-morbid conditions, auditory abilities, etc.) and deficit-specific therapy (Wertz et al., 2002).

A significant trend in deficit-based intervention or direct remediation therapy for APD comprises two main approaches: bottom-up and top-down (Yathiraj, 2015). The bottom-up therapy program involves auditory training to tap the deviant auditory processes and improve signal-to-noise ratio through environmental modifications, which are primarily targeted at increasing individual's access to auditory information by enhancing the signal clarity and the ease of learning and listening in various settings such as the home, classroom, work and social environment. It employs bottom-up (for example, listening environment and signal enhancement with assistive devices or by reducing noise and reverberation, improved room acoustics) and top-down approaches (e.g., home, leisure, classroom, and workplace) techniques. Furthermore, direct skill training, often known as auditory training, is a bottom-up therapy strategy for CAPD. They aid in the processing of information and sound by the brain. In both a formal (in an acoustically treated room) and informal (at home or school setting) setting, these activities promote brain neuroplasticity (Taneja, 2017).

Conversely, the top-down therapy program, often known as compensatory approaches, focuses on improving the individual's abilities to utilize rules of language (metalinguistic & language strategies) and cognition abilities (cognitive & metacognitive strategies), interventions in the educational field (i.e., modifications in instructional & learning strategies) (American Academy of Audiology, 2010). These approaches improve the auditory skills and deficit-specific therapy strategies, efficiently stimulate the allocation of perceptual and higher-order resources (e.g., language, memory, and attention), and provide compensatory skills to minimize functional auditory deficits (Taneja, 2017).

With advancements in technology, auditory training and bottom-up therapy approaches include several computer-based auditory training (CBAT) programs that address auditory and language components and taps different auditory processing skills. Over the years, many evidence-based CBAT software's are for both children and adults with (C)APD, such as Sound Storm7 software program (previously LiSN & Learn), LACE (Listening and Communication Enhancement), Fast For Word (FFW), Earobics, Dichotic inter-aural intensity difference (DIID), Sound Auditory Training (SAT), clEAR™ (customized learning: Exercises for Aural Rehabilitation) (Keith et al., 2019; Weihing et al., 2015). The treatment plans developed over the years suggest using ARIA (Auditory Rehabilitation for Inter-aural Asymmetry) procedure focusing on dichotic auditory training has shown significant improvements in Amblyaudia cases (Moncrieff & Wertz, 2008)

A recommended evidence-based treatment for APD involves amplification with remote microphone hearing aid systems (RMHAs), providing immediate assistance and long-term therapeutic effects. Studies on RMHA treatment for children with APD have shown consistent therapeutic and assistive benefits, as RMHA assists hearing ability and learning. It also improves psychosocial adjustment, which results in positive changes in neuroplasticity, which leads to improvement in listening skills, whereas hearing aids for adults with APD will be fitted with accessory RM systems (Keith & Purdy, 2014; Keith et al.,2019). Besides providing direct remedial training, recommendations regarding environment modification, enhancing auditory perception is also essential, along with compensatory and coping strategies. These strategies can be utilized to help individuals with APD deal with difficulties faced in day-to-day situations.

It is critical to distinguish between studies where interventions have been validated for other populations, e.g., language, specific language impairment, dyslexia, and studies investigating the benefit of these interventions for the APD population. Several APD therapies have been derived from other populations rather than directly validated (Campbell et al., 2011). With improving technologies and research in (C)APD, there is a need to closely monitor and systematically evaluate rehabilitation strategies available for individuals with (C)APD.

The therapeutic plans for individuals with APD should be modified if a good process is not observed or when the patient's context changes. So, there is an at most need for the Audiologist to keep abreast of changes in the rehabilitation strategies or the modifications available for individuals with an auditory processing disorder.

1.1 Need For The Study

There is a dearth of data to support the efficacy of certain treatment techniques for APD. Significant progress has been made in the field of rehabilitation for auditory processing disorders over the years. A vast amount of literature is available regarding the same, and an update on the current rehabilitation strategies or techniques has become the day's need.

Research in terms of treatment efficacy emphasizing the selection of deficit-specific rehabilitation approaches and guided recommendations regarding necessary and adequate frequency, duration, intensiveness, and termination of treatment programs has gained a great deal of importance in the recent past. There is a necessity for a systematic comparative review on the treatment options available for individuals with an auditory processing disorder.

1.2 Aim of the study

The present study aims to review the significant studies conducted in the past fifteen years (2005-2020) regarding the strategies established to rehabilitate individuals with auditory processing disorders.

1.3 Objectives of the study

The specific research questions for the study include:

1. What are the rehabilitation techniques or strategies developed for different types and severity of APD?

2. What is the efficiency of the newly developed remediation strategies for APD over the past 15 years?

3. What rehabilitation techniques or strategies are developed in the recent past for children and adults with APD?

Chapter 2

METHODS

The systemic review was conducted based on the Preferred Reporting Items for Systematic Review and Meta-analyses statement (PRISMA statement) (Page et al., 2021). A systematic literature search was carried out for peer-reviewed articles published from 2005 to 2020.

2.1 Information sources

The following databases were extensively searched for studies on APD rehabilitation treatments or strategies: PubMed/Medline, Google Scholar, Science Direct, and Com-Disdome (ProQuest) and PsyNet. Lists of references and citations were searched manually for further relevant studies.

2.2 Search strategy

The search was carried out using the following key terms, related search phrases, derivatives, and MeSH words relevant to the study combined with Boolean operators such as 'AND,' 'OR,' 'NOT.

"Central auditory processing disorder" OR "auditory processing disorder" AND "auditory perceptual disorder" OR "intervention" OR "management" OR "training" OR "therapy" OR "direct remediation" OR "computer-based auditory training" OR "listening strategies" OR "bottom-up approach" OR "top-down approach" OR "compensatory strategies" NOT "auditory spectrum disorder" NOT "learning disability" NOT "ADHA" were used as the key terms for searching studies.

2.3 Study selection

The specific inclusion and exclusion criteria for the selection of studies were as follows:

2.3.1 Inclusion Criteria:

- Original articles containing human subjects with appropriate samples, practical treatment approaches, and relevant Statistics.
- Articles that are published in peer-reviewed journals over the past fifteen years.
- Studies focusing on computer-based management strategies.
- Case series studies emphasizing the management of APD.

2.3.2 Exclusion Criteria:

- Articles with low methodological quality and language apart from English.
- Articles that were focusing mainly on the assessment or diagnosis of APD.
- Studies focusing on mixed treatment regimens for associated disorders, vestibular interventions, and pharmacological interventions.
- Case reports, letters to editors, and editorials.
- Management for individuals with co-morbid conditions like language impairment, reading disorder, learning disability, and attention deficit.

2.4 Data extraction

The search results were combined using the Rayyan QCRI (Qatar Computing Research Institute) and Mendeley desktop reference manager system, and the duplicate studies were eliminated. The studies that met the inclusion criteria were identified by screening the titles and abstracts retrieved from the search strategies. Thereafter, the full text of the potential studies was retrieved and matched to see if they were eligible. The extracted data included: article title, author details with their affiliation, year of publication, research design, study population, sample size, age group, comparison group, method of outcome measures and keywords specific to management strategies of auditory processing disorder.

2.5 Quality assessment:

The Critical Appraisals Skills Programme (CASP) was used to conduct a methodological quality assessment of the included studies. The finding has been shown in the result section in detail.

Chapter 3

RESULTS

A total of 15106 articles were identified using database searches, with 320 duplicates eliminated. A total of 14796 articles were included in the title/abstract screening. Following titles and abstracts review, 70 articles were selected for the full-length article screening. Twenty-three articles matched the inclusion criteria in the study. The remaining 46 articles were excluded mainly because of the study design (pilot study, systematic review, letter to the editor, case reports) and irrelevant study population (study population had comorbidity like ADHD, learning disability, etc.). A detailed Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flow chart for the selection of the study is shown in Figure 3.1

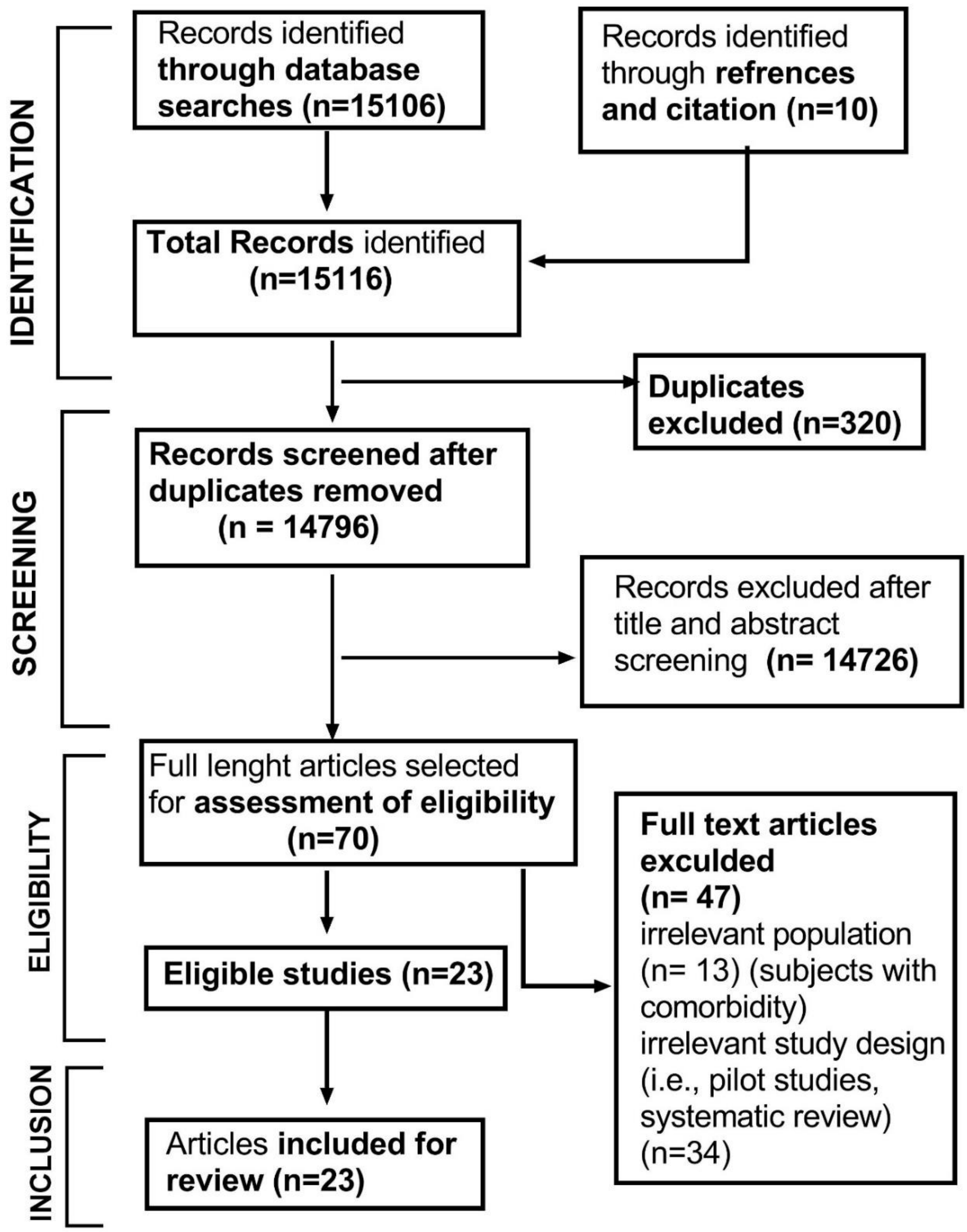

Figure 3.1: PRISMA flowchart for the selection process of articles included in the review

3.1 Study Characteristics

Out of the 23 articles finalized for review, 13 focused on the bottom-up training approach, seven focused on computer-based auditory training, and three focused on bottom-up and top-down training approaches. Amongst the 13 articles which focused on the bottom-up approach of training, three studies state the benefit of FM systems, and one study state the benefit of remote microphone hearing aid. Furthermore, three studies focused on dichotic listening training and three studies on formal and informal auditory training. The remaining three studies focused on noise desensitization, gap detection, and auditory lateralization training.

The study population in 20 studies were the pediatrics group (age ranging from 5-19 years) and in two studies were geriatric (age ranging from 60 to 85 years), and one study was performed in adults (age ranging from 17-38 years). To describe the changes after training, all of the studies used various outcome measures.

Table 3.1 summarizes the type of treatment evaluated, type of outcome measured, study design, study population details, assessment approaches, details of intervention intensity, and study outcomes.

Table 3.1 Study Characteristics of the selected articles

Author and year	**Study design**	**Research question**	**Population type**	**Testing parameters used**	**Treatment parameters used**	**Results**	**Discussion**
Putter-Katz et al. (2008)	Randomized control trial	Impact of speech in noise training and dichotic listening training in children diagnosed with CAPD	30 Hebrew speaking children with (C)APD divided into: *Treatment group:*20 children between the ages of 7.11 years and 14.4 (mean age 9.4 years) Who were further divided into Noise groups having poor performance SPIN (n=11) Noise+dichotic group: poor performance on SPIN and BS (n=9) Control group: 10 children aged 6.2 years months to	<u>**Assessment:**</u> • Binaural separation and Selective attention-competing sentence test • Monaural low redundancy speech task - SPIN GDT, MLD Outcome measures: auditory processing test.	**Management included:** *Bottom-up approach:* acoustic signal amplification and enhancing the listening environment using tasks like: a. Hearing and comprehension in noise and competing verbal stimuli. b. selective and divided attention tasks c. FM systems *Top-down approach:* auditory closure, speech reading, and metacognitive	<u>SPIN:</u> Significant improvement for the right ear in the noise+dichotic group and the left ear in the noise group was seen post-training. Short competing: improvement was seen for left ear in 'noise+ dichotic' group No difference seen for the Noise group and control group • <u>Long Competing sentences:</u> The 'noise+ dichotic' group showed	Significant increases in auditory function after the intervention, as well as no changes in the untreated group, show that (C)APD management has the potential to improve children's listening skills.

			11.11 years (mean age 8.3 years).		awareness enhancement, and classroom, instructional, and learning strategies, along with home accommodations. Treatment duration: A 45 min session per week for four months.	improvement in both ears. Marginal improvement was seen in the left ear for the 'noise group.' Ear difference: Right ear was better	
Johnston et al. (2009)	Quasi-experimental design	Potential benefits of a new personal FM system in terms of speech perception and psychosocial function.	Experimental group: 10 children aged from 8.2-15.7 years (mean age of 11 years, 8 months) with APD Control group: 13 children aged 8.2-13.2 years (mean age of 10 years, 6 months) without APD.	AFG, DDT, SSW auditory analysis skills and phonemic synthesis test (DPT and PPT). SIFTER LIFE HINT BASC-2	Subjects in the APD group were binaurally fitted with the FM system by Phonak (Phonak EduLink, non-occluded with ear level style receiver) and recommended use in classroom situations. Duration of usage: At least for 5 months.	*Academic performance:* On Post-fit evaluation, no significant difference in the academic domain between the control and APD groups. APD group yielded significant improvement (LIFE) in 3 conditions:	• The use of FM technology in schools can lessen the demand for ESE (exceptional student or special education) and other specialized programs, which results in reduced

						Other pupils creating noise, teacher talking from the front, teacher talking when turned back. *Speech perception:(post fitting measure)* On post fit evaluation, 11.9dB less SNR was required to achieve desired speech comprehension. Significant improvement in aided condition. *Psychosocial measures:* Parents rated lower risk of having issues with leadership quality and functional communication. • Children	costs and responsibilities for the school system and teachers. • Considering the possibility of lowering academic failure and enhancing psychosocial function in children with APD, implementing this type of intervention is cost-effective.

						rated lower risk of having issues on locus of control, mental factors (depression and anxiety), and interpersonal relationships.	
Alonso & Schochat (2009)	Pre-experimental study	Efficacy of formal auditory training in children with (C) APD using behavioral and electrophysiological evaluations	The participants were 29 individuals with APD (16 males and 13 females) aged between 8-16 years with normal hearing sensitivity.	**Behavioral test:** 1. Monotic test: SSI- ICM, Speech test with white noise Dichotic test: Nonverbal directed attention test, SSW test, **Electrophysiological test:** BAEP, P300	Formal training: ***Frequency training*:** Discrimination of two tones (low and high). Sequencing & labeling for frequency, intensity, and duration, DIID, sound localization, speech perception, and informal training *Training period*: 2 months Retested after 1 month of training.	No significant ear difference was observed. On electrophysiological test (prior training) 9 subjects had no detectable P300 wave (in the right ear for 4 subjects and the left ear for 1 subject), but only 1 subject had no detectable P300 wave in the right ear. Statistically lower mean P300 latency	• Auditory stimulation introduced changes to the CANS (changes in the neural plasticity) monitored in the P300 waves. • P300 latency is a more sensitive indicator of the potential for

					Training duration: 50 min session each once a week.	values were observed. Substantial differences in all behavioral measures were seen.	neurophysiologic change.
Schochat et al. (2010)	Quasi-experimental study	To investigate the MLR characteristics following auditory training for children with (C) APD.	Treatment group:30 children with APD Control group:22 individuals without APD All the children were in the age ranged from 8 years to 14 years.	**Behavioural test:** 2 monotic and 2 dichotic tests included: PSI, SPIN, SSW, DDT, DNVT **Electrophysiologic test:** MLR	**Formal auditory training:** *1. **Frequency training**:* discrimination of two tones (low and high). Step 1: identifying the two tones as same or different Step 2: assign a pitch to the two tones they hear, for example, high-low or low-high. Step 3: report the correct sequence of three tones that changed in pitch, such as high (H)-low (L)-low(L), HLH, HLL, and so on.	*Behavioral auditory processing tests:* A significant improvement observed on all the behavioral tests in the (C) APD group. *Electrophysiologic test:* A substantial difference was seen in the amplitudes of Na and Pa peaks observed in the APD group post-training, while latency was unchanged.	Children with (C)APD have reduced callosal input to the left hemisphere for dichotic hearing tests.

					2. ***Intensity training.*** A technique analogous to training with frequency, here the intensities of the tones were varied. 3. ***Temporal training***. GDT training**-** The noise gap's incidence was random, and the duration of the gap was modified systematically based on the subjects' performance. ***DIID:*** The better ear intensity level is reduced, while the poorer ear level is kept constant (at around 50 dB HL), till the poorer ear performance is approximated to normal.	C3 (left hemisphere) was the most impacted electrode site.	

					1. Localization and speech perception: participants should listen to speech and competing signals:1) speakers in towards both ears,2) in front of the head and back of the head,3) in front and back of the head in the opposite position of condition one, 4) in front of the head and back of the head but in the opposite direction of condition two. **Informal training:** (was done at home along with the parents 15 min a day) the training included: • Listening to a story and identifying the target words		

					• Sketch each paragraph after listening to the story (and recall the story based on the drawing after 4-5 paragraphs) • Adding a word to the topic (e.g.; if parent says apple the child should add another fruit name) • Listening to song and repeating the lyrics. • Motor task: 1-4 step direction commands.		

Hoen et al. (2010)	Quasi-experimental study	Does the EduLink device has an effect on speech understanding in classroom contexts?	20 children age from 8-10 years (mean: 9 years and 2 months) were divided into 2 groups: Test group: 9 children having APD (5 male and 4 female) Control group: 11 children without APD (5 male and 6 female)	Oldenburg Sentence Test (adapted in the German language) was used to assess speech comprehension in noise.	The test was carried out with or without EduLink. (In with EduLink condition- worn binaurally) ***Stimuli:*** 5 word sentences presented with 2 types of competing noise: ***Speech-in-noise condition*:** a stationary wideband noise with the same power spectrum as the test voice material but without any linguistic information. ***Speech-in-speech condition*:** Multitalker babble (female talker speech presented from left and male talker speech from right speaker)	• Marginally the significant difference in the speech in speech condition. • When using the EduLink in the speech in speech condition APD group performed similarly to the control group • Speech understanding improved significantly in both groups with EduLink, with an average EduLink SRT advantage of 17 dB (SRT) and no difference between groups	• EduLink allows for significant improvement in speech comprehension. For children with APD, an FM system like EduLink can be quite effective in addition to traditional therapy.

					Presentation of sentences: The target sentences were presented from the front, at a distance of 3 meters. The noise was presented from both sides, at 90° and 270° and a distance of 1 m at a level of 60dBA.		
Umat et al. (2011)	Quasi-experimental study	• Impact of use of FM systems on short term auditory memory in children with APD • Benefit of using bilateral vs unilateral FM system.	60 primary school children aged from 7-10 years with APD were divided into 3 groups, with 20 subjects each group: Group 1 - control group (n=15) (without the FM) Group 2 – fitted with unilateral (right Ear) FM group (n=19)	APD screening tests: DDDT PPT Assessment of short-term auditory memory: RAVLT	All the children used the FM system during school hours (4-5 hours per day), and the subjects wore the FM for 12 weeks of school.	***Working memory:*** Significant improvement was seen in the mean scores of WM ***Best learning:*** The mean BL scores improved over time in both the unilateral and bilateral groups post-fitting. ***ROI:*** No significant correlation No significant difference	• Improved WM scores indicates FM system may enhance attention and faster processing of auditory information in some subjects suspected of having APD. • Plasticity

			Group 3 – fitted with bilateral FM group (n=19)			between unilateral and bilateral fitting groups for all the 3 auditory memory measures.	and memory index were improved as a result of increased frequency representatio n of behaviorally relevant stimuli,
Maggu & Yathiraj (2011)	Randomiz ed control trial	Noise desensitization training's efficacy in children with low speech-in-noise scores.	Children aged from 8-11 years were divided into two groups: The experimental group (received training) – n=5 Control group (did not receive training) – n=5	**Screening for selection of participants:** • Screening Checklist for Auditory Processing • Monosyllable speech identification test in English for Indian children: Monosyllabic words using headphones Monosyllabic words and	**Noise desensitization training**: 15 English passages, with each passage having 80-100 words and 4 questions. Three types of noises (ambient noise, speech noise, and speech babble) presented with the passages, with 0,5,10 dB SNRs. The training was carried out in 6 stages:	• The experimental group obtained higher scores following training. • The scores improved for both the ear on monosyllable test performed with headphones. • In binaural listening condition, improvement was observed for words and	Noise desensitizatio n training may improve binaural hearing performance, which is a circumstance that is similar to real life.

				sentences through sound-field speakers.	Level 1 – Quiet condition Level 2 – with environmental noise (fan noise) at +15 dB SNR Level 3, 4, 5 - Speech noise at +10 dB SNR, + 5 dB SNR, 0 dB SNR respectively. Level 6 – with Multi-speaker babble at 0 dB SNR The number of sessions: 15 to 20, depending on the child's speech perception score. Session duration: 25 – 30 minutes each.	sentences at +10 dB SNR and 0 dB SNR condition.	
Kishon-Rabin et al. (2013)	Pre-experimental study	Improvement in GDT following auditory training in older and younger adults.	30 females divided into 4 groups: Two groups of older adults (age range 60-85 years (mean= 65.5 years) and younger adults	**GDT** **Stimulus:** narrow band signal centered at 1KHz with the duration of each stimulus varied from 200 to 300ms. The	The training was carried out for 10 sessions which consisted of 10 GDTs in each session. 3 GDTS were obtained 24hrs after the last training day and 1	The elder group's initial GDTs were substantially lower than the young adults'. However, by the fourth training day, both group had nearly	Some parts of auditory perceptual learning may be preserved with normal aging, as evidenced by

			(age range 18-30 years (mean= 26.3 years))	stimulus was gated with 20ms raise-fall time at first marker's onset and second marker's offset and 5ms rise fall time at onset and offset of the gap. Duration of the silent gaps varied between 1ms and 20ms at 1-ms steps.	month post training to evaluate learning retention.	identical GDTs, and both groups improved at the same rate in subsequent sessions. Retention of learning was present.	the performance and retention capacities achieved at the end of the training session.
Cruz et al. (2013)	Retrospective study	Effectiveness of auditory training in adults with APD	18 individuals with aged between 17 to 38 years (9 males and 9 females) with APD	**<u>Inclusion criteria:</u>** Normal peripheral hearing An abnormal result on at least one behavioral test for auditory processing assessment; no evident syndrome or other cognitive disorder; and completed formal auditory training.	**Formal auditory training** of eight sessions of 45-minute each held twice a week DPT, FPT training, auditory closure (speech+white noise) AFG for verbal and nonverbal sound on tasks of monotic and dichotic listening (SSI, DDT, NVD, DCV).	No statistical difference between right and left eras. Better results were observed on behavioral tests. Statistically significant differences were seen for DPT and FPT for both men and women.	In individuals with auditory processing impairments, formal auditory training improves figure-ground listening skills for verbal sounds and temporal processing as determined

				<u>Outcome measures:</u> DPT, FPT, SSW, and SSI test.	• Right, and left ears were trained separately.		by behavioral tests.
Cameron et al. (2015)	Longitudinal study.	An 18-month evaluation of diagnostic and remediation for patients with CAPD in a significant number of hearing centers in various socio-economic and regional locations.	Total of 408 subjects aged 6 to 18 having the following deficit in one of the three areas tested. Spatial processing disorder (SPD): n=130 aged from 6-13 years. The deficit in **TAPS-3:** n=174 aged from 6-18years. Binaural integration deficit: n=104 aged from 7-14 years. 29 subjects with binaural interaction deficit	**<u>LiSN-S:</u>** simple sentences presented in the background of two children's stories. *Baseline measure:* spatial, talker, and total advantage **<u>TAPS-3</u>** Subtest: NMF and NMR **DDT** **<u>Outcome measurement questionnaire:</u>** LIFE –Teacher Scale. COSI-C	**Remediation option:** ***LiSN & Learn:*** • 5 training games With distracting speech (2 children's stories) • 4 of the 5 training Games grammatically right but semantically meaningless target sentences are presented from 0^{o} azimuth. *Task*: choosing a picture corresponding to one word in the target sentence. • 5^{th} training game: target sentences presented in the form of directions are at 0^{o} azimuth.	*<u>Post-training results:</u>* • **LiSN-S**: Significant improvements were found for the low-cue SRT, high cue SRT, spatial advantage, total advantage. • *<u>Memory Booster:</u>* Post-training NMF and NMR scaled scores were considerably better compared to retraining performance. However, post-training NMF scores was still beyond the normal range.	Ratings of post-remediation client and instructor outcome assessments indicate that the remediation had a very good impact. The LiSN & Learn is the only training option for this form of CAPD treatment when it comes to SPD.

					Task: select the direction and number of gaps heard from a visual display. Training duration: 2 training games a day, five days a week, until completion of total of 100 games **Memory Booster:** • Begins with a short animated story followed by strategies rehearsal, chunking , story creation, and visual imagery. Training duration: 8 weeks, train for 15 to 20 minutes every day, five days per week. **FM Systems:** • iSense Classic FM receiver (body level worn bilaterally) by Phonak.	• *FM systems:* FM was fitted to 29 participants (19 with dichotic deficit, four having memory problems, three having SPD, and 3 who passed all tests but had difficulty listening in presence of noise). Significant changes were reported on LIFE and COSI-C on all three training programs.	

					• iSense Micro ear level receiver (unilateral or bilateral) • Amigo R5 (body The level receiver used with lightweight headphones or binaural earbuds, by Oticon.		
Morais et al. (2015)	Randomized control trial	Assessing the efficacy of acoustically controlled auditory training (ACAT) using behavioral measures and P300 in elderly individuals.	16 elderly individuals (14 female and 2 male) aged 60–78 years, APD Following *Evaluation 1*, the subjects were divided into: Active control group (n=8) who received placebo training (a weekly exercise which consisted of watching a series of 45-minute documentaries and	**Evaluation 1:** Electrophysiological test (P300) Behavioral assessment: SPIN,DDT, PPT,GDT 12 weeks after evaluation 1, all the subjects were revaluated (**evaluation 2**) and received ACAT for 8 weeks. 4 weeks later, the subjects underwent a final evaluation (**evaluation 3**).	**Acoustically controlled auditory training (ACAT):** Impaired skills detected at E2 were trained, which included: ***Perceptual activities:*** • Discrimination of monosyllabic words and compressed disyllabic words. • Sentence comprehension in the presence of various types of noise and	No significant difference was observed between the first 2 evaluations or between the 2 groups indicating the absence of placebo and test-retest effects. Behavioral assessment: Significant improvement was seen in all the auditory skills except the	The most difficult task for elderly subjects was temporal ordering (as reflected in PPS). This loss of temporal processing due to aging (decreased corpus callosum function) may contribute to

			answering questions about them) for 8 weeks. Control group (n=8) who did not receive any training for 12 weeks.		competitive speech. • Ordering and discrimination of pure tones. • Gaps perception ***Cognitive skills (working memory):*** Discrimination of five words in the presence of noise and repeating in reverse order. ***Sensory integration by visual tasks aggregation****:* written sentence identification. Motor tasks: pointing to figures based on the descriptions heard in the right ear using the left hand. **Training duration:** 8 weeks with a 50-min session per week.	temporal ordering skill. No significant difference was observed between P300 stimuli.	speech perception impairment. For all of the tested auditory skills, ACAT promotes changes in behavioral performance in older individuals.

Loo et al. (2016)	Randomized control trial	Effect of auditory training on listening skills in children with APD.	39 children with APD aged between 7 to13 years divided into 1. Control group who received only the current standard treatment using various listening/educational strategies at school (N = 19); 2. Intervention group who undertook a 3-month 5-day/week computer-based auditory training program at home, consisting of a wide range of speech-based listening tasks with environmental sounds, in addition to the current	**AP test battery:** FPT, DPT, DDT, RGDT, MLD. **Outcome measures :** LiSN-S,CELF-4 CHAPS	3-month **computer-based auditory training program**: 3 SPIN training games aimed at improving speech interpretation, fine phonetic detail discrimination, and keyword extraction in the presence of background noises. Dichotic speech listening training with directed attention to one ear, i.e., • Speech in noise for: words in sentences, isolated CVC monosyllabic words, words in phrases • Dichotic speech listening training: Stimulus: Digits, mono- and bi-syllabic words; sentences not	Only in the training group, significant improvements in speech-in-noise performance were linked to higher CHAPS questionnaire scores. The improvements in speech-in-noise performance lasted three months after the intervention.	Children with APD had better speech-in-noise perception, which was mirrored in enhanced active listening.

			standard treatment.		longer than eight words. Masker: Simultaneous presentation of competing speech stimuli identical to the target speech to the contralateral ear at varied SNRs for sounds across the two ears Response: Indicate the items displayed to one ear on a computer while ignoring the other. The game ends at 50% correct scores or 16 reversals.		
Kaul et al. (2016)	Retrospective study	Efficacy of auditory processing training based on Jack Katz's buffalo model for remediating	Twenty subjects aged 5 to 15 years (mean age of 8.4 years) diagnosed with APD were included in the study.	**<u>Speech Understanding in Quiet and Noise:</u>** word recognition measures in quiet and noise and quiet-noise	***Auditory processing training***: phonemic synthesis training; phonemic awareness and phonemic recognition training; whole body active participation	12 out of 17 measures showed significant differences post-training. *<u>The magnitude of treatment effect:</u>*	These findings show that training for auditory processing can increase children's

		children with APD.		difference for each ear. **SSW Test:** Non-competing and competing items scores of each ear and total error scores were considered. **Dichotic Listening Measures:** SIR based on the competing message scores (RC and LC) on the SSW and DOM **Phonemic Synthesis Test:** quantitative and qualitative scores**.** Phoneme Recognition Test Phoneme-Word Association Test ***Outcome measure:*** BMQ	and listening training; auditory listening endurance; short-term memory; auditory attention; working memory/organization training; selective ear listening training; dichotic and monaural listening training; speech in noise training for each ear (at +15 to +5 SNR), auditory ear lateralization; ear separation listening auditory processing integration training. ***Dichotic Offset Training*** (DOT), provided for 6 children to enhance their dichotic listening abilities further.	*Small effect size:* Speech in Quiet for both ears and Quiet/Noise difference (rt ear) *Medium effect size:* Speech in noise (rt ear), and SSW LNC, and DOM. *Large size effect:* was seen for phonemic synthesis measures, phoneme recognition, and word association. All the categories under BMQ showed significant improvement post-training.	auditory processing abilities with the greatest improvements found for auditory phonological processing and dichotic listening (SSW measures). Direct remediation can increase auditory processing skills.

Lotfi et al. (2016)	Randomized control trial	Effects of auditory lateralization training on speech perception in the presence of noise and competing signals in children with (C) APD.	60 children suspected to (C) APD were divided into control group (n=30) with mean age 9.07±1.25 years; training group (n=30) with mean age 9.00±1.28.	**<u>Pre-training evaluation:</u>** DDT, PPT and mSAAT The auditory lateralization training effects were measured using the SWRS and mSAAT.	**Auditory lateralization training:** *Stimulus:* A high pass and low pass noise with a 2 kHz cut-off point, a length of 250ms, and rise and fall periods of 20 milliseconds. Stimuli were delivered via headphones at 50 dB HL with ITDs of 880, 660, 220, zero, -220, -660, -880 µs. **Localization training:** Loudspeakers in free field condition and sound were given through headphones during lateralization training. *Task:* 7 images of loudspeakers arranged in a circle around children at	In the training group, mSAAT score and spatial WRS in noise improved substantially after the auditory lateralization training.	Auditory lateralization can considerably increase speech interpretation in noisy environments.

					angles of -90, -60, -30, 0, +30, +60, +90°.Children had to point to the location where they perceived the sound from. *Training duration:* 12 formal sessions (2 sessions in each week)		
Osisanya & Adewunmi (2017)	Randomized control trial	Effectiveness of dichotic listening training, compensatory methods, and integrated therapies in the treatment of children with APD	80 children aged between 7–11 years with APD randomly selected	Screening for APD was done for the selection of participants. 1. SCAN-3:C 2. Expanded RGDT	**Dichotic listening training:** ***(i) Binaural integration and separation training:*** the story was played in a free field training mode in the classroom or at home. The subjects wore earplugs in their poorer ear. They were asked to answer questions regarding what they heard on the poorer ear (separation) and on both the masked and	For the cocktail party effect, CS was more successful at improving listening, while DLT was more effective in improving sound localization. The CT, on the other hand, was more effective in both cases. Gender effect: on following sound localization	• As CS outperformed DLT for the cocktail party effect suggests that language helps children with APD focus on a specific discussion and pay attention to the speaker. The recorded messages in DLT, on the

					unmasked ear (integration). ***(ii) speech-in-noise training:*** A story was narrated using a multitalker system to introduce competing background noise (movies), and questions were asked. ***(iii) sound localization training*****:** locating the source of noise (a metal item dropped intermittently when the story was played) Task: locate the sound source and report back what they heard about the story. **Compensatory strategies (CS):** ***1. improving auditory attention:***	training, males had better scores.	other hand, sounded quite similar to the interrupted messages, making it more difficult to tell them apart. Since the therapies were integrated and the flaws associated with one treatment were eroded in the other, the CT's effects were overtaken, ensuring that best clinical practice was applied.

					stage 1: whole body listening (a story presented at a distance of 2 meters along with gestures and body language to emphasize the story) stage 2: story presented at a distance of 2 meters and few words were highlighted and intoned and a distracting story was presented at a distance of 2.5 meters Stage 3: a story was read at a distance of 1 metre. For all the 3 stages the participant were asked question on what they heard. (ii) ***improving auditory working memory:*** Stage 1: a story was read with emphasis		

					on explanation, and patients were asked questions about the same. Stage 2: the story was read with the omission of few words, and the participants had to fill in the missing words. Also, this stage included a multitalker situation. (iii) ***shared reading*** **Combined therapy: the** combination of Dichotic listening training and improving auditory attention.		
Barker & Bellis (2017)	Pre experimental study	Impact of a New Computer/Tablet-Based dichotic listening training program (Zoo	15 children with dichotic listening deficit aged from 8-12 years	Dichotic digit test.	• Zoo Caper Skyscraper, a Computer-based or iPad-based interactive video game that uses ITD in a progressive	• Following ZCS therapy, DD scores improved dramatically, with the most significant improvement	ZCS is easy to access and is suitable for use at home or in the classroom.

		Caper Skyscraper, (ZCS)) on Children's dichotic Listening Skills.			algorithm to teach dichotic listening. • The player must Listen to sounds of animals and determine the animal name. After selecting the suitable animals, the player attempts to stack them as high as possible, and collects points. The difficulty level increases as the level of the game progresses. • *6 levels of play:* 1st level – 2 sounds presented to each ear separately in time. As the level increases, the degree of overlap, number of stimuli increases and the length of stimuli decreases. 6th level: fully overlapped (true dichotic)	occurring in the left ear. • There was no correlation between number of Sessions and degree of improvement.	

					presentation, two 0.5 s stimuli are presented to each ear. *Therapy duration:* a session of 15-20min, twice per week.		
Moncrieff et al. (2017)	Pre experimental study	Evidence of binaural integration benefits for children and adolescents with amblyaudia following ARIA training	Children and adolescents aged from 5 to 19 years (n=125) diagnosed with amblyaudia (AMB) (n=58), dichotic dysaudia (DD) (n=7) amblyaudia plus (AMB+) (n=16) (MIX) mixed performance patterns on 2 dichotic listening tests (n=9) (UND) undiagnosed based on the dichotic listening test but had abnormal scores on other	RDDT, DWT, DDT	**Training: ARIA** (dichotic listening training) a list of dichotic words and digits presented. When relative performance on one side was better by more than10%, the intensity was reduced for the dominant ear and increased when performance on the opposite side was better by more than 10%. The intensity was adjusted in 1 dB increments while constantly evaluating performance differences in the two	DL scores in *DD group*: had higher ear scores and less interaural asymmetry but were not statistically significant. *MIX group:* significant improvements were observed in the non-dominant ears, but not at the post-ARIA assessment. *UND group:* considerable improvements in non-dominant ears with digits, and substantial	• ARIA training resulted in significant improvements in DL test scores in persons with APDs, with the highest advantages seen in those with amblyaudia. • Significant increases in non-dominant ear scores were sustained even after

			auditory processing tests. (n=25)		ears close to or below 10%. *Duration of ARIA:* 1 hour weekly session for 4 weeks with each session of 20 min followed by rest period of 20 min. Participants DL skills were reassessed after 4th training session.	improvements in non-dominant ears for both digits and words on post-ARIA evaluation. *AMB, AMB+ group:* significant improvements in non-dominant ear scores for both words and digits. Interaural asymmetry was reduced significantly for both digits and words in the AMB group, but only in the AMB+ group.	intervals of 2 to 12 months. Following the Completing ARIA training, dominant ear scores continued to improve, indicating improved capacity to comprehend verbal material.
Melo et al. (2018)	Pre experimental study	evaluate the effectiveness of computerized auditory training in children with APD having typical or	14 children diagnosed with APD are divided into: Group 1: 7 children with APD and typical phonological system;	**Initial evaluations*:*** • Anamnesis: to collect information regarding psychomotor and language development,	**Computerized auditory training:** Using the Escuta Ativa program, 12 tasks were used to test auditory figure-ground skills, binaural integration skills and binaural	*Latency measures of LLAEP components:* Negative peak N2 and positive peak P3 latency in the left ear decreased in group 1, while	Latency measurements changed after the therapy intervention, indicating neurofunctional

		atypical phonological learning	Group 2: 7 children diagnosed with APD and having atypical phonological acquisition, independent of the degree of speech.	prenatal history, and family history. • Detailed Audiological assessment • Behavioral test: RGDT, PSI, NVDT, PACS **<u>Subjective measure:</u>** SAB **<u>Electrophysiological evaluation:</u>** LLAEP	separation skills, temporal resolution ability and temporal standardization, auditory localization, and auditory discrimination. Training duration: 12 sessions, twice a week, with each session lasting for ~ 30 minutes.	P2 latency decreased in G2. on comparing pre- and post-CAT groups, there was a significant difference in P1 latency in the left ear and P2 latency in the right ear, pre-intervention. In both groups, the SAB score after CAT.	alterations in auditory processing. A significant The difference were seen in the N2 and P3 components (in group1) indicated that the attentional element in children had enhanced.
Ahmadpour & Asadollahfam (2018)	Pre experimental study	The impact of bottom-up and top-down training on the development of children's auditory processing skills	A total of 30 children (aged from (10 to 12 years) divided into 2 experimental group: Bottom-up (n=15) and top-down (n=15)	LIFE questionnaire	**Bottom-up auditory training:** ***Auditory Processing Studio app*** *Task:* choosing an image from two possibilities that represented what was spoken, determining whether two spoken words were equal or	No significant differences in performance between the bottom-up and top-down groups. Both bottom-up and top-down strategies were equally beneficial	• Auditory workout game (top-down method): The purpose of general training skills like auditory attention and memory is to

					different, and verbally filling in gaps in a sentence. **Top-down auditory training:** ***Auditory Workout app*** *Task:* Listen to a series of precise commands, recognize the cue image, and choose an appropriate picture from the five options provided. The correct response will be reinforced. For a wrong answer, the subjects were instructed to redo the assignment. Training duration for both the program: 20 minutes each day, 4 days per week, for 2 weeks	in improving auditory processing skills in learners with processing impairments.	generalize to more specific auditory processing abilities and linguistic capacity. • Auditory processing studio app (Bottom-up method): Auditory discrimination, auditory closure, and phonological awareness are all skills that can be improved by training.
Graydon et al. (2018)	Pre experimental study	Effectiveness of deficit-specific	16 children aged 6.3years to 10 years (mean age	**Pre-training assessment:**	**LiSN and Learn auditory training:**	• Post-training a significant improvement was	In the listening

		remediation in the intervention of spatial processing disorder (SPD) and to determine the remediation's long-term effects.	7;8 ± 1;2; 7) diagnosed with SPD were included in the study. The long-term effects of remediation were monitored in 13 participants.	*Baseline assessment 1:* Detailed Audiological evaluation, LiSN-S • Questionnaire related to: subject - LIFE Parent - FAPC Teacher -TEAP *Baseline assessment 2:* To ensure that the SPD diagnosis may be repeated Audiological evaluation and LiSN-S.	To generate speech reception thresholds, the subject had to repeat target words in four different listening conditions: same voice 0^0 (SV0), same voice 90^0 (SV90), different voice 0^0 (DV0), and different voice 90^0 (DV90) (SRTs). Three advantage measures are obtained: SA scores: When the target sentence is separated by 90^o from the competing speech (i.e. SV90 – SV0), which improves the SRT (in dB). TA score: improvement seen when the target sentence differs merely in voice	seen in SA, and no significant difference was observed for TA scores. • There was no evidence of a link between age during training and DV90 improvement. • The post training data and the late-outcome evaluation showed no significant changes (on average 10 months after training). • Overall, the impact of training on questionnaire responses showed that mean scores for all the three advantage	situations that used binaural cues, significant improvement s in SRTs were reported after training, with the largest mean improvement seen during DV90 condition. • The effects of remediation will last longer than three months, and ability will remain stable. .

					quality (i.e. DV0 - SV0). When spatial and verbal cues are provided (i.e., DV90 – SV0), the ToA score shows the total SRT improvement (in dB). *Training duration:* 2 training games a day, five days a week, until a total of 100 games had been completed.	measures improved.	
Delphi & Abdollahi (2018)	Compartive study	Efficacy of DIID and DOT in participants with dichotic listening disorders	12 children aged from 8–9 years (mean age 8.41 years ±0.51) were diagnosed with APD divided into 2 groups, wherein group 1(n=6) received DIID training and group 2(n=6) received DOT.	**Tests used for diagnosis of APD:** DDT, PPT, mSAAT	**Candidacy criteria for DIID:** normal or near-normal limits performance in the poorer ear at the crossover level and stimulus intensity presented to the better ear not dropping below the hearing threshold. ***DIID training:***	No significant difference was seen between the two groups. Significant REA was observed in all the cases. Because DIID is based on ILD, DOT is based on ITD and activates different auditory pathways in the	The DIID's purpose is to improve the functioning of the weaker ear so that it can meet the age-appropriate normal limit. DOT might be a good replacement

					Target: to reduce the IID of >5dB from the point of crossover. Poorer ear level: 50dBHL. *Task:* DCV and sentences and story presented dichotically with background music. Patients were given the option of attending to both ears (free recall), or only one ear at a time (directed recall). Session duration: 4 sessions per week, lasting for thirty minutes each. Session details: If the performance was ≤80% in poorer ear interaural intensity difference was increased in 1 dB increments until it	brainstem. It took a longer time for DOT to achieve the same effects.	for DIID training if DIID is not applicable and DIID candidacy conditions are not met.

					reached 80% or starting level. DDT was retested after every session. 10% asymmetry was considered normal, anything less than 10% then the training was stopped and 2 weeks later DDT was retested. **DOT:** letters and CVs *Presentation mode:* Two letters and CVs were addressed towards the right ear and left ear, with an offset for letter presentation and the initial phoneme of CVs. Competing elements were separated by 500 ms, with the offset gradually decreasing by 100ms for following		

					circumstances. The offset was reduced when the patient could finish the task with ≥80% accuracy at a specified offset. Task: to repeat the correct order all four items.		
Jutras et al. (2019)	Randomized control trail	Effect of listening in noise training in children with APD.	Children diagnosed with APD aged from 8-12 years are divided into: Experimental group: n=10 (mean age of 10.6 years) received auditory training in noise Control group: n=6 (mean age of 9.10 year) did not receive training	**<u>Pre and post-training assessment:</u>** HINT (French version), LLAEP **<u>Questionnaire for participants teachers:</u>** SAB, SIFTER (adapted in French)	**Auditory training in noise** (at the school) using Logiciel d'_ecoute dans le bruit" (**Listening in Noise Software**) which included: 13 themes, with each theme having 19 listening activities Among the 19 activities: Task 1-4: auditory discrimination of non-words Task 5-7: auditory identification of the last word in the sentence.	The percentage of correct responses was significantly higher for the first 6 sessions than the last 12 sessions. *<u>HINT:</u>* no significant improvement was noticed in the experimental group. *<u>LLAEP:</u>* The latency and amplitude of P1 and N2 appeared to be unaffected by the therapeutic effect due to large	Children with APD can improve their listening in noisy environments with instruction. This training method, however, may be effective for some children with APD, but not all.

					Task 8&9: auditory identification of mono, bi, and tri-syllable words. Task 10: sentence identification Task 11: sentence identification with last word missing. Task 12: identification of object, animal or people (closed set of 24 images) Task 13: connecting lines by listening to 2 numbers presented and identifying the drawing made at the end. Task 14-19: oral text comprehension. Scoring for each activity was done out of 10. Noise used: a mixture of crow voices. The volume of the noise	variability across subjects. Questionnaire: The ability of subjects in the APD group to discriminate and identify speech sounds and to comprehend rapid or muffled speech improved.	

					was adjusted based on the subject's performance across the themes. Training duration: two 30 min session each per week for 13 weeks. Total therapy sessions: 24		
Stavrinos et al. (2020)	Randomized control trial	Impact of RMHA on classroom listening, listening in noise, and attention skills in children with APD	26 children aged from 7-12 years (mean age of 9.8 years) and diagnosed with APD were randomly assigned into an intervention group (n=13) and control group (n=13)	**<u>Screening tests:</u>** AFG and speech in noise subtest of the SCAN-3 C test. **<u>Auditory processing test:</u>** DDT, GiN/RGDT FPT, DPT, LiSNS **<u>Test Primary outcome measures:</u>** LIFE-R **<u>Behavioral outcome measures</u>*:*** LiSN-S, TEACh	**RMHA** system used was a Micro-mic coupled with a ReSound ultra-power hearing aid which was worn binaurally. The receiver was connected wirelessly to a microphone worn by teachers. RMHA was used daily during school hours (inside the classroom) for 5 days per week for 6 months.	On LIFE-R, significant improvement in scores was noted in the RMHA group when compared from baseline to 3 months and 6 months. *LiSN-S scores*: No treatment effect observed. *TEACH:* in the RMHA group, scores of DVA improved from	Children's ratings of classroom listening condition improved after 3 months and 6 months of RMHA use, as evidenced by questionnaire results.

				<u>Non-verbal cognitive Ability Test:</u> WNVSA.		baseline to 6 months.	

Note: BS-Binaural Separation, SPIN-speech perception in noise, GDT –Gap detection test, MLD – masking level difference, AFG- Auditory figure-ground, SSW- staggered spondee word, DDDP- dichotic digits double pairs, SIFTER - screening instrument for targeting educational risk, LIFE- Listening inventory for education, HINT- Hearing in noise test, BASC-2 -Behaviour assessment system for children: second edition, SSI- ICM – synthetic sentence identification – ipsilateral competing message, BAEP- Brainstem auditory evoked potential, DIID- Differential Interaural Intensity Difference, PSI- Paediatric speech intelligibility, DDT- dichotic digits test, DNVT- dichotic nonverbal test, MLR- middle latency response, RAVLT- Rey Auditory Verbal Learning Test, DDDT-Double Dichotic Digit Test , TAPS-3- Test of Auditory Processing–3rd Edition, NVD- nonverbal dichotic test, FPT-frequency pattern test, LiSN-S - Listening in Spatialized Noise– Sentences Test, NMF- Number memory forward, NMR- Number memory reversed, COSI-C -Client Oriented Scale of Improvement– Children, SPD- Spatial processing disorder, SRT- speech recognition threshold, ACAT - Acoustically controlled auditory training, CHAPS - children's auditory performance scale, RGDT - Random Gap Detection Test, CELF-4- Clinical Evaluation of Language Fundamentals Fourth Edition, SIR - Standard Integration Ratio, DOM-Dichotic Offset Measure, RC- right competing, LC- left competing, LNC- left non competing, BMQ - Buffalo Model Questionnaire, SWRS - spatial word recognition score, mSAAT - monaural selective auditory attention test, RGDT-E- Random-Gap Detection Test Expanded, ITD- interaural time difference, ILD- interaural level difference, DD- dichotic digit, DL- dichotic listening, UND- undiagnosed, ARIA- Auditory Rehabilitation for Interaural Asymmetry, DWT- Dichotic Words Test, PSI- paediatric speech intelligibility test, NVDT-nonverbal dichotic test, PACS- Phonological assessment Of child speech, LLAEP- long latency auditory evoked potential, TEAP- Teacher Evaluation of Auditory Performance, FAPC- Fisher's Auditory Problems Checklist, SA- Spatial advantage,TA- Talker advantage,ToA- Total advantage, IID-Interaural intensity difference, DOT- Dichotic offset training, DCV- dichotic CV, GiN- Gap in noise, WNVSA - Wechsler Non-Verbal Scale of Ability, RMHA- remote microphone hearing aid, LIFE-R - Listening inventory for education – revised

3.2 Quality Assessment

The Critical Appraisals Skills Programme for randomized controlled trials (CASP) (Marques-Carneiro et al., 2020) was used to assess the quality of the studies. It is a generic tool for appraising the strengths and limitations of any qualitative research methodology. It consists of 11 questions to assess the article in depth across each section to reduce bias. The questions in the tool are marked as "Yes', 'No' or "Can't tell," depending on the question's requirement. The results of the quality assessment for all of the selected studies are provided in Table 3.2.

Table 3.2. Results of the quality assessment for all of the selected studies.

	Questions										
	Section A: Is the basic study design valid for a randomised controlled trial?			***Section B:*** Was the study methodologically sound?			***Section C:*** What are the results?			***Section D:*** Will the results help locally?	
	1. Did the study address a clearly focused research question?	2. Was the assignment of participants to interventions randomised?	3. Were all participants who entered the study accounted for at its conclusion ?	4. Were the participant and/or investigators blinded to intervention given and for the outcome measure?	5. Were the study groups similar at the start of the randomised controlled trial?	6. Apart from the experimental intervention, did each study group receive the same level of care ?	7. Were the effects of intervention reported comprehensi -vely?	8.Was the precision of the estimate of the intervention effect reported?	9. The experimental intervention benefits surpass its drawbacks and costs?	10. Can the results be applied to your local population ?	11. Would the experimental intervention provide greater value to the people in your care ?
Putter-Katz et al.(2008)											
Johnston et al. (2009)											
Alonso et al. (2009)											
Schochat et al. (2010)											
Umat et al. (2011)											
Hoen et al. (2011)											

Maggu and Yathiraj (2011)											
Kishon-Rabin et al. (2013)											
Cruz et al. (2013)											
Cameron et al. (2015)											
Morais et al. (2015)											
Loo et al. (2016)											
Kaul et al. (2016)											
Lotfi et al. (2016)											
Osisanya et al. (2017)											
Baker &Bellis (2017)											
Moncrieff et al. (2017)											
Melo et al. (2018)											

Ahmadpour et al. (2018)											
Graydon et al. (2018)											
Delphi et al. (2018)											
Jutras et al. (2019)											
Stavrinos et al. (2020)											
Total % of yes	100%	39%	86%	13%	100%	100%	100%	100%	100%	60%	0%

Yes No Can't tell

On analysis, as depicted in Table 3.2, it was found that all the studies were of good quality. Six out of 11 questions (question numbers 1, 5, 6, 7, 8, 9) were answered as "Yes," for all the studies, indicating good quality appraisal. In all the studies, the research questions were addressed, and all the participants included in the intervention group were treated equally, and the treatment effects were reported comprehensively. All of the participants who entered the study were accounted for at the conclusion in 21/23(91%). In comparison, 2/23(8.6%) of the studies reported dropouts not accounted for at the conclusion. 9/23 (39%) studies reported randomized assignment of participants in their study. In comparison, in the remaining 13/23 (56%) studies, randomization was not clearly stated. Only 3/23 studies (13%) reported blinding the participants and/or the investigator while blinding was not clearly stated in the remaining 20/23 (86%) studies. The experimental intervention's benefits did not outweigh its harms and costs in any of the studies.

Chapter 4

DISCUSSION

This systematic review on listening strategies for auditory processing disorder explored various training programs, rehabilitation options, and listening strategies available for patients with an auditory processing disorder. The first line of intervention focuses on the type of auditory processing deficit. In the CAPD group, individualized intervention programs works well with the generalized intervention approach due to their heterogeneous nature (Taneja, 2017).

4.1 Bottom-up approaches

Formal auditory training involves using acoustically controlled stimuli (such as tones, noise, voice, and digits) delivered by a computer or CD player. For more precise control over stimulus levels, the stimuli can also be routed through an audiometer, and a sound booth can be used to eliminate background noise (Weihing et al., 2015).

4.1.1 Binaural interaction training

Auditory localization/lateralization training may improve the ability of children to use spatial clues to distinguish target speech from competing signals/noise in everyday listening conditions (Lotfi et al., 2016). In the present review, four studies investigated the effect of auditory localization/lateralization training in patients with (C) APD (Lotfi et al., 2016; Melo et al., 2018; Osisanya & Adewunmi, 2017; Schochat et al., 2010).

Lotfi et al. (2016) investigated the impact of auditory lateralization training on speech perception skills in the presence of competing signals/noise in children suspected with (C) APD. A significant improvement was noted in the outcome measures (mSAAT and spatial WRS in noise) following a 6-week auditory lateralization training. Similarly, (Osisanya & Adewunmi, 2017) reported that sound localization training alone showed significant improvement compared to sound localization combined with other top-down approaches like auditory attention and auditory working.

Schochat et al. (2010) studied the effectiveness of auditory training with localization training as a part of the training program. Similarly (Melo et al., 2018) investigated the effect of computerized auditory training, which included localization training as one of the activities in the module. However, sound localization training in these three studies (Melo et al., 2018; Osisanya & Adewunmi, 2017; Schochat et al., 2010)was used with other bottom-up and top-down approaches, generalizing the use of auditory localization training remains questionable.

4.1.2 Binaural integration

In dichotic listening training, the relative intensity of signals provided to each of the two ears is systematically altered. At the same time, individuals are encouraged to pay attention to both ears (integration) or the target ear solely (separation) (Bellis, 2003). In the present review, six studies have investigated the dichotic listening training (Alonso & Schochat, 2009; Delphi & Zamiri Abdollahi, 2018; Kaul et al., 2016; Moncrieff et al., 2017; Murphy et al., 2013; Osisanya & Adewunmi, 2017; Schochat et al., 2010).

Osisanya & Adewunmi (2017) studied the efficacy of both single (dichotic listening training (DLT) as a part of the bottom-up intervention) and compensatory strategies (CS)) and combined (combination of DLT and compensatory strategies) intervention in children with CAPD. The DLT included binaural integration, binaural separation, speech in noise, and sound localization. The goal of the compensatory strategy was to improve auditory attention, shared reading, and auditory working memory. The enhanced listening ability in children following the training was measured using the cocktail party effect and sound localization ability. The results revealed that sound localization ability improved following DLT, but the cocktail party effect did not. It is unclear whether sound localization training alone or combined with binaural integration or binaural separation training influenced this improvement t in sound localization ability. However, combined therapy superseded both the effects, as both the training processes were integrated, and the flaws in one treatment were eliminated in the other.

Two other training programs for dichotic listening deficits include Differential Interaural Intensity Difference (DIID) and Dichotic Offset Training (DOT). DIID employs interaural intensity difference (IID). DIID training aims to improve the poorer ear's performance to the age-appropriate normal limit. The DOT employs interaural time difference (ITD), which is based on the dichotic lag phenomenon, which states that the ear receiving a lagged stimulus can process the data faster than the ear receiving a leading input. (Delphi & Abdollahi, 2018).

Schochat et al. (2010) evaluated the MLR characteristic in 30 children with CAPD receiving auditory training. The CAPD group underwent an 8-week auditory training program with DIID as a part of formal auditory training. The results revealed a significant increase in the Na-Pa complex amplitude at the C3 electrode (left hemisphere) in the CAPD group following training. In children with (C) APD, there is evidence of decreased callosal input to the left hemisphere in dichotic hearing tests. The myelin growth in the corpus callosum and adjacent auditory pathways could be linked to the diminished left hemisphere input. Secondary topographic mapping has revealed that a loss of callosal input to the left hemisphere may result from corpus callosum degradation (demyelination) due to age. In addition, dichotic interaural intensity difference training was one of the training methods used in this study. The goal of this particular technique is to improve the brain's callosal functions and corticocallosal connections. Hence, the authors speculated that these are some of the underlying mechanisms of left hemisphere results seen in this study.

Delphi & Abdollahi (2018) compared the efficacy of these two dichotic training strategies. In their study, 12 children with the dichotic deficit (abnormal right ear advantage on dichotic digit test) were randomly assigned to 2 groups (DIID and DOT groups). Results revealed a significant right ear advantage in all the cases, and the training strategy effectively improved the dichotic listening. However, a significant difference was observed between the two groups regarding training duration in the DIID group. The distinct underlying mechanisms in these two pieces of training accounted for the difference in training length.

Moncrieff et al. (2017) administered “Auditory Rehabilitation for Interaural Asymmetry” (ARIA) training on children and adolescents diagnosed as having amblyaudia. Amblyaudia is an auditory processing disease (APD) in which the binaural integration of speech information is impaired. During dichotic listening (DL) activities, the defining pattern of amblyaudia is an abnormally wide asymmetry between the two ears, with either normal or below normal performance in the dominant ear. ARIA training aims to improve the non-dominant ear function, particularly those with the greatest interaural asymmetry due to non-dominant ear weakness. During ARIA, a clinician adjusts the relative intensity of information to the two ears through sound-field speakers in a methodical manner. Results revealed significant improvements in dichotic non-dominant ear performance and reductions in interaural asymmetry on the fourth ARIA training session. Retention of training persisted two or more months of training. The fundamental goal of ARIA is to improve performance in the non-dominant ear of the listener by increasing activation along the auditory pathway of the non-dominant ear, resulting in neuroplastic changes that lead to more symmetrical binaural integration of verbal material.

Alonso & Schochat (2009) investigated the efficacy of formal auditory training in children with CAPD through behavioral and electrophysiological measures (P300). Dichotic intensity difference training was a part of the formal auditory training. Substantial differences in all behavioral measures were observed post auditory training. Statistically lower mean P300 latency values were observed before and after AT, but amplitudes remained unchanged. Nine subjects had no detectable P300 waveform before AT whereas, only one patient failed to capture a discernible P300 waveform post-AT. The lack of a control group makes it impossible to draw any firm conclusions about the causes of these variations in P300.

Kaul et al. (2016) studied the effectiveness of formal auditory training (based on the Buffalo model) in children with APD. The training included dichotic offset training (DOT) as a part of formal auditory training. The effectiveness of the buffalo model-based therapy was measured using dichotic offset measure (DOM), competing for message scores for both ears and standard integration ratio (SIR) and buffalo model questionnaire. Post-training moderate improvement was seen in the dichotic offset measure, and competing scores for both ears improved, and SIR measures showed least or no effect. After training, all of the BMQ categories improved significantly. The examination of auditory processing and the therapies utilized in this study were exclusive to the Buffalo Model, a disadvantage. All professionals do not share this model. As a result, more research is needed to see if improvements in auditory processing may be achieved when additional therapies are applied.

4.1.3 Binaural separation training

4.1.3.1 Auditory figure-ground

The auditory figure-ground (AFG) ability is an auditory processing system that distinguishes necessary and relevant sounds from background noise. Despite having normal hearing acuity, those with AFG deficiencies have trouble understanding speech when there is background noise as the spoken message is distorted, making it harder to interpret (Hassaan & Ibraheem, 2016).

Cruz et al. (2013) studied the effectiveness of formal auditory training in adults (aged 17 and 38 years) with APD. The formal auditory training focused on auditory figure-ground skills for both verbal and nonverbal sound on tasks of both monotic and dichotic listening (SSI, DDT, NVD, DCV) as a part of the training. The efficacy of the training was checked using the duration Pattern Test (DPT), frequency Pattern Test (FPT), staggered Spondaic Word (SSW) test, and synthetic Sentence Identification (SSI) test. Post-training, only males showed substantial improvement on the SSW, and only the females showed significant improvement on the SSI. Since the improvement also focused on other auditory training, the influence of auditory figure-ground alone is not clearly stated. Hence, the generalization of the results is questionable.

4.1.3.2 Noise desensitization Training

Maggu and Yathiraj (2011) administered noise desensitization training using ambient noise (fan noise), speech noise, and speech babble mixed with target passages presented binaurally. During the training, six hierarchical levels of noises and signal-to-noise ratios (SNRs; +15 to 0 dB SNR) were provided. According to their findings, the open- and closed-set performance of words and phrases in the presence of noise improved. Also, improvements in binaural listening conditions were more pronounced than monaural conditions. As speculated by the authors following training, noise may be prevented from reaching the limbic and autonomic nervous systems, preventing it from being perceived and interfering with the speech signal. These preliminary findings imply that noise desensitization training can benefit individuals during listening activities involving various types of speech material in noisy environments.

4.1.4 Temporal processing training

In the present review, 4 studies have explored temporal processing training (Cruz et al., 2013; Kishon-Rabin et al., 2013; Morais et al., 2015; Schochat et al., 2010)

4.1.4.1 Temporal patterning training

Poor performance on Frequency and /or Duration Patterns testing in labeling and humming conditions can indicate auditory temporal pattern deficits (Bellis, 2003). Temporal patterning underlies the listener's capacity to use speech's pitch, prosody, and pragmatics and interpret degraded speech signals amid background noise in everyday listening (Tomlin & Vandali, 2019).

Cruz et al. (2013) studied the effectiveness of formal auditory training in adults (aged 17 & 38 years) with APD. The formal auditory training focused on temporal ordination skills using duration pattern test (DPT) and frequency pattern test (FPT) as a part of the training. The efficacy of the training was checked using the duration Pattern Test (DPT), frequency Pattern Test (FPT), staggered Spondaic Word (SSW) test, and synthetic Sentence Identification (SSI) test. Post-training significant improvement was seen on DPT and FPT for both males and females. These findings demonstrated the impact of auditory training. The neural plasticity mainly influences the improvement seen in this study as listening skills stimulation “activates” brain plasticity, which improves the chances of successful treatment. Although this study focused on adults aged 17 to 38 years, a certain level of plasticity persists throughout an individual's life, justifying auditory training in adults.

4.1.4.2 Temporal resolution training

Temporal resolution ability is the shortest duration that the subject can distinguish between two auditory stimuli. Two studies have explored temporal processing training (Kishon-Rabin et al., 2013; Schochat et al., 2010).

After multisession training, Kishon-Rabin et al. (2013) assessed the progression of improvement in a gap-detection (GD) task in older and younger adults. Results revealed that the elder group's initial GDTs were substantially lower than that of the young adults. However, by the fourth training day, the mean GDTs of the two groups were nearly identical, and both groups improved at the same rate in subsequent sessions. Learning retention after one month of training was also demonstrated in both groups. As the older adults began their training with significantly greater GDTs than the young individuals, they demonstrated faster learning in the first phase, which was the influence of non-perceptual factors on acoustic performance. GDTs of elderly persons were similar to those of young adults after the effect was diminished with task practice. These preliminary findings reflect the presence of intact temporal resolution abilities in older adults.

Schochat et al. (2010) assessed the MLR features in 30 children with CAPD who underwent auditory training. The CAPD group went through an eight-week auditory training program that included temporal training (Gap detection training) as a part of the formal auditory training. Following training, the CAPD group showed a considerable increase in the Na-Pa complex amplitude at the C3 electrode (left hemisphere).

Morais et al. (2015) studied the efficacy of auditory training in elderly individuals diagnosed with APD. The formal auditory training, known as the acoustically controlled auditory training, focused on ordering and discrimination of pure tones and gaps perception as part of the training program. The efficacy of the training was measure using an auditory processing test and electrophysiological measures (P300). There was a substantial change between the pre-training and post-training conditions for all auditory skills on behavioral measures. However, P300 potential measurements, on the other hand, did not yield the same result.

4.1.5 Auditory closure training

Putter-Katz et al. (2008) examined the effect of speech in noise training as part of the bottom-up intervention fitting of an FM system and a top-down intervention program for 20 children with CAPD. Among twenty children, 11 were diagnosed with only monaural low-redundancy deficits and grouped as "noise group." Post-training results revealed significant speech in noise performance in the left ear, the marginal improvement in the left ear on the long competing sentence test for the noise group. In contrast, no improvement was seen on the short competing sentence test. The intervention group improved significantly on speech-in-noise, whereas the control group showed no improvement. However, no significant difference was seen between treatment effects for both the right and left ears.

Morais et al. (2015) studied the efficacy of auditory training in elderly individuals diagnosed with APD. As part of the formal auditory training program, 'acoustically controlled auditory training' (ARIA) was employed to focus on sentence comprehension in the presence of competing speech and various types of noise. The efficacy of the training was measure using an auditory processing test and electrophysiological measures (P300). There was a substantial change between the pre-training and post-training conditions for all auditory skills on behavioral measures. However, P300 potential measurements, on the other hand, did not yield the same result.

4.1.6 Auditory discrimination training

Auditory discrimination training includes a variety of activities which includes temporal and spectral pure-tone discrimination tasks. Since frequency, intensity, and timing differences are significant for detecting and processing acoustic changes in speech, and phonological processing has been referred to as a discrimination task (Sharma et al., 2012).

Kaul et al. (2016) studied the effectiveness of Buffalo model therapy in children with APD. The training program included phonemic synthesis training, phonemic awareness, and phonemic recognition training as a part of other formal auditory training. The efficacy of the training was measured using Phonemic Synthesis Test quantitative and qualitative scores, Phoneme Recognition Test and Phoneme-Word association test, and buffalo model questionnaire (BMQ). Post-training, the large effect of improvement was seen for all three outcome measures, and all the categories in BMQ showed a marked improvement. However, this study did not include any control group to compare the training effects, so generalizing these findings to a similar group of APD individuals is questionable.

4.1.7 Signal enhancement techniques

Access to auditory-presented information is improved by modifying the environment. Modifications include improving the acoustic signal's clarity and the ease with which individuals may learn and listen in various settings, such as at home, at work, in school, and social situations. It employs both bottom-up and top-down strategies. Bottom-up approaches include using signal enhancement devices like remote microphone hearing aids (RMHA) and frequency-modulated (FM) devices, reducing the reverberation through architectural modifications, preferential seating to aid for visual cues, methods to eliminate any sources of mechanical or competing noise within the same premises. Top-down approaches are primarily concerned with creating a rich redundant listening and learning environment and improving access to information in various settings (Taneja, 2017).

4.1.7.1 Frequency modulated (FM) systems

The frequency modulated (FM) system is one alternative way for managing APD children in the classroom. Children with APD have significant difficulties recognizing speech in noisy contexts such as schools. The usage of FM equipment is the most effective technique to boost SNR in the classroom. The teacher's voice is picked up and radio transmitted to a receiver worn by the student (Hoen et al., 2010). The FM system comprises a microphone, a transmitter, and a receiver. The microphone, which is around 10 cm from the speaker's lips, reduces the problem of signal transmission distance and reverberation, resulting in higher SNRs and a more pleasant listening environment (Umat et al., 2011). In this present review, three studies have stated the benefit of using FM systems in children with CAPD in school and/or classroom setup (Hoen et al., 2010; Johnston et al., 2009; Umat et al., 2011)

Johnston et al. (2009) evaluated the efficacy of the FM system in 10 children with APD and compared them with the control group having typically developed children. Subjects in the APD group were binaurally fitted with FM systems by Phonak (Phonak EduLink a non-occluding with an ear-level receiver). They were recommended to use in all lecture-based classroom situations. The benefit of FM systems was measured using Screening instruments for targeting educational risk (SIFTER), Listening inventory for education (LIFE) for assessing the academic performance, using hearing in noise test (HINT) in quiet and noisy conditions for assessing speech perception. Psychosocial measures were assessed using a behavior assessment system for children: second edition (BASC-2). After five months of FM system usage, results revealed that children with APD outperformed the control group in terms of speech perception using FM technology. Notably, with extended FM use, even unaided (no FM device) speech-perception skills improved in children with APD, implying the possibility of fundamentally improved auditory system function. The APD group improved significantly on the LIFE questionnaire in three conditions: other students making noise, instructor talking from the front, and teacher talking when turned back. On SIFTER, marginal improvement was observed for academics, communication, and class participation only. On psychosocial measures, parents saw improvement in leadership and functional communication.

Hoen et al. (2010) studied the effect of the EduLink FM device on speech understanding in classroom contexts in children with APD. With the EduLink FM device, the teacher's voice is directly transmitted into the child's ear. The ear canal is fully open. As a result, the external sound is unchanged, and the child does not feel acoustically "isolated." Speech comprehension in noise was evaluated using the German language adapted, German-language Oldenburg Sentence Test, which determined the speech reception threshold (SRT). The noise used in the test was broadband noise and multi-talker babble. All the children in the APD group had worn the FM device binaurally. When children with APD used the EduLink in the speech in speech condition (which mimicked ordinary classroom situations), they attained the same level of speech understanding as to the control group.

Umat et al. (2011) assessed the impact of FM devices on auditory working memory in children with APD over one year and three months. The subgroup of 40 children worn FM devices binaurally and monaurally in school set up for 12 weeks. Working memory and best learning scores improved significantly for both unilateral and bilateral groups compared to the control group. However, the retention of information subtest showed no improvement after the usage of the FM device. There was no significant difference between patients in the monoaurally and binuarally fitted groups for all three auditory memory tests. This finding shows that the improvements in memory scores shown in the FM-fitting groups over time were unrelated to the number of FM receivers used.

All the three studies showed substantial improvement from FM devices on different measures like academic performance, speech perception and psychosocial measures (Johnston et al., 2009), auditory memory (Umat et al., 2011), and speech comprehension in noise (Hoen et al., 2010) when used in the classroom setting for children. Therefore, in addition to conventional training, FM devices will be beneficial for children to understand speech in a noisy environment.

4.1.7.2 Remote microphone hearing aid

One of the recommended management strategies for children with APD is using Remote Microphone Hearing Aids (RMHAs) in the classroom. This method improves children's signal-to-noise (SNR) ratio and avoids the harmful impacts of background noise and reverberation in the classroom situation. Remote microphone hearing aids are radio/hearing aid hybrid systems designed for normal peripheral hearing subjects. The child wears the hearing aid receivers at ear level, while the radio transmitter microphone is worn by the parent, teacher, or other talkers. Remote microphone hearing aids for APD are not accessories to other hearing devices because they transmit the amplified signal directly to the ear (Keith & Purdy, 2014). In the present review, only one study explored the benefit of RMHA in children with CAPD (Stavrinos et al., 2020).

Stavrinos et al. (2020) assessed the impact of RMHA on classroom listening, listening in noise, and attention skills in children with APD. The RMHA used in the study was a Micro-mic coupled a ReSound Ultrapower hearing aids worn binaurally, and the receiver was connected wirelessly to a microphone worn by teachers. Significant improvement in LIFE-R scores was observed in the RMHA group from baseline to 3 months and 6 months. LiSN-S showed no treatment effect, and on TEACH, divided visual attention scores for the RMHA group improved substantially from baseline to 6 months post-training.

4.1.8 Informal auditory training

Auditory training can be done informally at home or school. They may be useful in generalizing specialized auditory skills to real-world events and school curriculum needs when used in conjunction with formal auditory training (Campbell et al., 2011)

Schochat et al. (2010) determined the MLR characteristics in 30 children with CAPD receiving auditory training. The CAPD group underwent an 8-week auditory training with informal auditory training (done at home and with parents or caregiver 15 min/per day). The results revealed a significant increase in the Na-Pa amplitude at the

C3 electrode in the CAPD group following training. In this study, both formal and informal auditory training was coupled, which maximized the treatment efficacy. However, the influence of only informal training is not clearly stated.

4.1.9 Computer-based auditory training programs

In recent times, various AT (and auditory-language) tasks are computer-administered (i.e., CBAT). Computer-assisted AT has been more popular these days due to its ability to keep the participants engaging while delivering intense training along with suitable feedback and reinforcements appropriately. The computer-based auditory training (CBAT) technique is used in several types of formal training (Weihing et al., 2015). In the present review, seven studies have investigated computer-based auditory training (Ahmadpour & Asadollahfam, 2018; Barker & Bellis, 2017; Cameron et al., 2015; Graydon et al., 2018; Jutras et al., 2019; Loo et al., 2016; Melo et al., 2018)

Cameron et al. (2015) carried out auditory training through LiSN & learn program for children with spatial processing disorder (SPD) (a type of CAPD defined by a lack of ability to use binaural cues to obtain spatial release from masking), children with binaural integration with verbal memory deficit (trained memory booster software) and binaural interaction deficit (trained with FM systems). Children with SPD underwent the LiSN-S test following training, which revealed a significant improvement in low-cue SRT, high-cue SRT, spatial advantage, and total advantage. Children with verbal memory deficit underwent the TAPS-3 test, which revealed post-training performance on the NMF and NMR scaled scores was significantly higher. On outcome measures, in all three training regimens, significant changes were noted on LIFE and COSI-C. This study highlighted the importance of deficit-specific intervention for children with

APD. However, this study cannot be generalized to a similar group of APD patients, as all the three training groups had dropouts.

Another study by Graydon et al. (2018) explored the remediation strategies for children with spatial processing disorder (SPD). The auditory training was given through LiSN & Learn software, and following training, the SPD group underwent LiSN-S test and questionnaires (subject-related, parent-related, and teacher-related). Post-training, there was a considerable improvement in spatial advantage and total advantage score but no difference in talker advantage score. Overall, the effect of training on questionnaire responses revealed improvement in mean scores for all three advantage measures. Long term effect of training (on that is average, ten months post-training) was assessed using late outcome measures, which showed no significant difference from that of post-training. The findings indicate that training is successful in precisely teaching the child how to use binaural cues. Based on improvements in LiSN-S scores, the training approach appeared to remediate SPD and overall had a good effect on functional listening, as rated by the parents.

Barker and Bellis (2017) studied the effectiveness of a novel computer/ tablet-based DLT program (Zoo Caper Skyscraper (ZCS) by Acoustic Pioneer, Ltd.), an interactive video game that can be played through stereo headphones which compatible with the Apple iPad app or using any internet browser on a conventional computer. The program is based on the interaural timing differences (ITD) approach in which one ear initially receives the stimulus earlier than the other ear. This study showed a significant improvement in DL skills following direct auditory training using the ZCS program twice a week. These benefits were seen in both ears but were most noticeable in the left ear on-ear interaction. In contrast, a significant main effect of the ear was seen in the right ear indicating a right ear advantage for the dichotic task in children.

Loo et al. (2016) reported on 39 children (7 to 11 years old) diagnosed with APD who were randomized into AT group and underwent intense training (3 months, 5 days/week). The auditory training programs involved three different computer-based listening games for speech-in-noise training (for words in sentences, isolated CVC monosyllabic words, words in phrases), aiming to improve speech understanding, discrimination of fine phonetic detail, and keyword extraction in the presence of various types of background noises and dichotic speech listening training with directed attention to one ear. The AT group showed improved hearing in noise post-training. Furthermore, the improvements were associated with higher scores on the Children's Auditory Processing Performance Scale questionnaire and were maintained for at least three months after training.

Melo et al. (2018) assessed the impact of computerized auditory training (CAT) in APD children who were having the typical or atypical acquisition of phonological skills using an electrophysiological test (LLAEP) and subjective measurements (SAB). Children with APD were divided into two groups. Group 1 consisted of APD children with typical phonological skills and Children diagnosed with APD and atypical acquisition (group 2), regardless of speech impairment. Auditory training was carried out through the Escuta Ativa software, which focused on auditory figure-ground skills, binaural integration and temporal resolution, temporal standardization, binaural separation, auditory localization, and auditory discrimination. Results revealed that Negative peak N2 and positive peak P3 delay reduced in group 1 for the left ear, while P2 latency in the right ear decreased in group 2 on LLAEP. A considerable difference was observed on pre-and post-CAT group’s comparison in P1 latency for the left ear and latency P2 for the right ear before intervention. The SAB score changed before and after the CAT in both groups.

A significant change was found P3 wave of the left ear, notably in group 1, which indicates the enhanced activation of the callous corpus involvement, which is accountable for the link between the hemispheres and auditory verbal stimuli are processed more efficiently. Children's auditory processing was altered both electrophysiologically and behaviorally before and after therapeutic intervention, demonstrating that the CAT was a good treatment for children with APD. Substantial behavioral improvements (increased scores) were also seen in the SAB score, which is proven to be a valuable technique for determining the efficacy of therapy.

Ahmadpour & Asadollahfam (2018) investigated the role of bottom-up and top-down auditory training on children's development of auditory processing. Bottom-up auditory training was provided using the "Auditory Processing Studio app," focusing on phonological awareness, auditory closure, and auditory discrimination abilities. The "Auditory Workout app " provided top-down auditory training, focusing on auditory attention and memory. In the post-test, there were no significant differences in performance between the bottom-up and top-down groups. However, bottom-up and top-down techniques are equally useful in strengthening auditory processing abilities in learners with processing deficits. The use of both bottom-up and top-down approaches enhanced the auditory processing skills. However, as no control group was involved in the study, the generalization of these findings is questionable.

Jutras et al. (2019) investigated speech in noise training on speech perception test scores, electrophysiological measures, and auditory behaviors and life habits in children with an auditory processing disorder. Auditory training was provided using "Logiciel d'_ecoute dans le bruit" (listening in noise software). Post-training, children in the APD group showed significant improvement on speech perception test scores and electrophysiological measures on individual data. However, group data revealed no improvement. Significant improvement was observed in the children's capacity to discriminate and recognize speech sounds and interpret rapid or muffled speech from teachers, measured by Scale of Auditory Behaviours questionnaire scores on group data only. Other than the targeted noise condition during training, the training was reported to aid individuals in listening during other poor hearing environments.

4.2 Top-down approach

The top-down approach of auditory training is also known as a compensatory strategy. These strategies are designed to improve higher-order language, cognitive, memory, and associated abilities. They work to improve the residual CAPD dysfunctions that cannot be treated with auditory/direct skill training and address cognitive, language, and academic skills impairments. These approaches indirectly address central auditory process impairments by giving benefits, applying clinical intervention for other functional deficits, and improving spoken language understanding and listening. These strategies are intended to improve the use of metacognitive (attention and memory) and metalinguistic skills and assist a listener in monitoring their auditory understanding skills and self-regulating their retention capacities by enhancing general problem-solving tasks (Taneja, 2017). In the present review, two studies have explored the top-down approach of auditory training (Osisanya & Adewunmi, 2017; Putter-Katz et al., 2008)

Putter-Katz et al. (2008) investigated the top-down approach of auditory training and the bottom-up approach for children with APD. The top-down technique involved aiding the child in learning to manage hearing issues through auditory closure, speech reading, metacognitive awareness enhancement, classroom, instructional, and learning strategies, along with home adjustments assignments. Following training, significant improvement was noted. However, as the training effect was assessed using the auditory processing tests, improvement in the top-down approach alone was not clearly stated.

Similarly, Osisanya & Adewunmi (2017) also explored the top-down approach as a part of the training program and the bottom-up approaches in children with APD. The top-down strategies used in this study were to improve auditory attention, shared reading, and auditory memory. The enhanced listening ability in children following the training was measured using the cocktail party effect and sound localization ability. The results revealed that compensatory strategy improved the listening skills in the cocktail party effect. However, combined therapy (both bottom-up and top-down) showed significant enhancement in listening for both effects. These findings suggest the importance of both bottom-up and top-down approaches.

Chapter 5

SUMMARY AND CONCLUSION

The intervention of Central auditory processing disorder (CAPD) or Auditory processing disorder (APD) has been a research focus in the recent past due to its heterogeneous nature. There is a dearth of data to support the efficacy of certain treatment techniques for APD. Thus, the study reviewed the listening strategies available to rehabilitate individuals with APD from 2005 to 2020.

The present systematic review has described the auditory training programs and the listening strategies available for the intervention of CAPD. The training focused on one or more auditory processes such as binaural integration, binaural separation, temporal processing, auditory closure, environmental modifications using FM systems and RMHAs, computer-based auditory training programs, and top-down approaches. The present study shows that the direct remediation technique (mainly bottom-up approach of training) showed a marked improvement in the performance ability of individuals with an auditory processing disorder. Furthermore, compensatory and certain signal enhancement techniques should help people with APD deal with daily issues.

In the recent past, computer-based auditory training programs (CBAT) have focused on the bottom-up approaches majorly than the top-down approaches. However, in the present review, all the studies indicated a significant difference in post-training outcome measures when a combination of bottom-up and top-down treatment approaches was employed. Individuals with APD who use a combination of these approaches will have a greater ability to cope up with difficult situations and learn to adapt better in real-world situations.

5.1 Clinical implication:

- The outcomes of the present review would be a preliminary attempt to understand the evolution of remediation strategies over the years, which are essential for individuals with APD to have a good quality of life.
- The review can update the Audiologist to select appropriate deficit-based individualized intervention strategies to improve communication more effectively in everyday contexts.

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