INTERVENTION OUTCOMES FOR ACQUIRED APRAXIA OF SPEECH IN ADULTS: A SYSTEMATIC REVIEW

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ALL INDIA INSTITUTE OF SPEECH AND HEARING

MANASAGANGOTHRI, MYSURU-570006

SEPTEMBER, 2023

Dedicated to My

Nani and My Parents

CERTIFICATE

This is to certify that this dissertation entitled **"Intervention outcomes for Acquired Apraxia of Speech in Adults: A Systematic Review"** is a bonafide work submitted in part fulfilment for degree of Master of Science (Speech-Language Pathology) of the student Registrat0025. This has been carried out under the guidance of a faculty of this institute and has not been submitted earlier to any other University for the award of any other Diploma or Degree.

Mysuru
September 2023

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CERTIFICATE

This is to certify that this dissertation entitled **"Intervention outcomes for Acquired Apraxia of Speech in Adults: A Systematic Review"** has been prepared under my supervision and guidance. It is also been certified that this dissertation has not been submitted earlier to any other University for the award of any other Diploma or Degree.

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DECLARATION

This is to certify that this dissertation entitled **"Intervention outcomes for Acquired Apraxia of Speech in Adults: A Systematic Review: A systematic Review"** is the result of my own study under the guidance a faculty at All India Institute of Speech and Hearing, Mysuru and has not been submitted earlier to any other University for the award of any other Diploma or Degree.

Mysuru **Registration No. P01II21S0025**

September 2023

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॥ श्री गणेशाय नमः ॥
वक्रतुंड महाकाय सूर्यकोटि समप्रभ,
निर्विघ्नं कुरु मे देव सर्वकार्येषु सर्वदा ।

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CHAPTER-1
INTRODUCTION

Apraxia of Speech (AOS) is referred to as an impairment in spatial and temporal planning and/or programming of movements required for speech production and is characterized by slowness in speech rate with phoneme distortions, substitutions of the phoneme, and a tendency to segregate speech into individual syllables and they also tend to equalize stress across adjacent syllables (Duffy, 2013). This leads to a decrease in the quality of life of a person as well as their social and vocational participation. The presence of AOS signifies a pathologic condition that affects the language-dominant hemisphere, typically in the posterior frontal lobe (in the vicinity of Broca's area), sometimes in the parietal lobe, and occasionally in both the frontal and parietal lobes (Josephs et al., 2006). Stroke is the prominent etiology related to AOS in adults, but it can appear as a consequence of degenerative nervous system diseases (e.g., multiple sclerosis), traumatic brain injury, and brain tumor. Most patients with apraxia of speech additionally manifest hemiparesis or hemiplegia, spasticity, exaggerated reflexes, and somesthetic sensory impairments contralateral to the side of brain injury (the right side for right-handed individuals). Many patients with AOS also have buccofacial apraxia, although either may occur in isolation. Some patients with apraxia of speech also have limb apraxia.

AOS typically occurs in combination with non-fluent (Broca's) aphasia. In fact, descriptions of the speech characteristics of Broca's aphasia often resemble descriptions of apraxia of speech. Dysarthria is also frequently associated with AOS. According to Duffy (2005), 29% of the patients with a primary diagnosis of AOS at Mayo Clinic also exhibited dysarthria, usually appearing as unilateral upper motor neuron dysarthria or spastic dysarthria. As was true for the individuals with a primary

diagnosis of AOS, the patients with a primary diagnosis of dysarthria did not include those with dysarthria as a primary diagnosis and AOS as a secondary diagnosis.

Articulatory inconsistency is an important feature of apraxia of speech. It is manifested as correct articulatory targets of phonemes at one time and incorrect articulatory targets of the same phonemes at other times. Inconsistency in articulation often is related to variations in the context in which the phonemes are produced. A phoneme may be articulated correctly in one phonemic context and misarticulated in another (e.g., when contrasting phonemes occur in words or phrases). Most patients with apraxia of speech can produce individual sounds and monosyllable words correctly with lesser effort, but are unable to produce multisyllabic utterances and phonologically complex words. Speech that is smooth and effortless but the patients with apraxia of speech produce shorter and phonologically simpler utterances and they tend to produce slow speech with articulatory missteps when utterances are increased in length and complexity.

McNeil et al. (1997) described two general phonemic characteristics of the speech of persons with AOS:

a. Lengthened production of consonants and vowels, increased time intervals between sounds, syllables, and words which are often perceived as substitutions of sound, inappropriate stress, and prosodic impairments.

b. Errors are relatively consistent in their locations within utterances and are consistent in type.

Individuals with AOS do not have issues with discrimination the speech sounds and hence do not require auditory discrimination training. Some early studies of AOS

suggested that many were deficient in oral sensation and oral form identification (Guilford & Hawk, 1968; Larimore, 1970), but subsequent studies have failed to replicate those findings (Deutsch, 1981; Square & Weidner, 1976). Although sensory abnormalities sometimes coexist with AOS, the abnormalities are not strongly related to its severity, making work on oral sensation a questionable treatment option for most patients with apraxia of speech.

Various approaches to management of AOS have been published (Ballard et al., 2015; Galeoto et al., 2020; Van Sickle, 2016; Wambaugh, 2021; Wambaugh et al., 2006a; West et al., 2005). Two of them are systematic reviews which comprise all the study designs (Ballard et al.,2015; Wambaugh et al., 2006a). The study by Wambaugh et al. (2006a) included 59 articles with a wide spectrum of AOS therapies from research published between 1951 and 2003. He categorized AOS guidelines into four general treatment approaches to AOS treatment: (i) articulatory-kinematic treatments, (ii) rate/rhythm control treatments, (iii) intersystemic facilitation/ reorganization treatments, and (iv) augmentative and alternative communication (AAC) training (Wambaugh et al., 2006b).

Ballard et al. (2015) has compiled peer-reviewed studies on intervention of AOS from 2004 to 2012 in the age group 28-87 years. The authors identified that 24 out of 26 reports, or the majority of the research they included in their systematic review, were categorized as "articulatory-kinematic". The other two studies employed rate/ rhythm treatment. The systematic review did not classify any of the reports as intersystemic facilitation or AAC. All of the studies that were examined were high-quality according to quality appraisal checklists; however much of the evidence they provided was of a lesser standard.

The use of TMS (transcranial magnetic stimulation) (Marangolo et al., 2011), augmented visual biofeedback (Katz, McNeil, & Garst, 2010), and self-administered computerized therapy (Whiteside et al., 2012) are just a few examples of technological innovations that have come into existence in recent years in the management of AOS.

The trends noted in the 2015 systematic review study have persisted, and there is currently more support for advanced technology therapies. Even while articulatory-kinematic techniques still dominate AOS therapy and research, intersystemic reorganization is receiving increasing attention (e.g., Hurkmans et al., 2015; Mauszycki et al., 2016). Additionally, there are currently reports of studies looking at the combination of AOS and aphasia treatment.

Owing to the COVID-19 pandemic, speech-language therapy via tele-mode has been a continued practice due to its cost-effective solution for patients with a neurogenic communication disorder where physical disability frequently co-occurs and is a barrier to seek therapy services in person. Other various techniques for the intervention of AOS such as Electropalatography (Lundeborg,2007), Ultrasound (Preston,2013), Aided AAC (augmentative and alternative communication), and Modelling (Binger,2007) have gained much focus in recent years and are not studied in previous systematic reviews. Insight into the recent advances in the field of AOS is essential to drive an SLPs practice.

In a very recent systematic review Munasinghe et al. (2023), summarized and evaluated literature on speech and language therapy interventions for acquired apraxia from 2013 to 2020. The outcomes measure summarized were: (a) improvement in target behaviors, (b) generalization, and (c) maintenance of outcomes. However, the study review was restricted to only speech and language therapy approaches. Use of instruments and tele services for AOS intervention were not included.

So, there is a great need to understand the recent advances in the field of AOS. This will help an SLP informed and bring insights into the various management approaches thereby reducing the amount of time spent in deciding the most suitable and efficient approach for the management of AOS.

The evidence for AOS intervention needs to be carefully evaluated, and that evidence needs to be mapped into the clinical techniques. With a busy and diverse caseload, SLPs are in need to be better equipped to recognize the quality of the evidence for interventions that align with the strategy they decide for a person with AOS. Speech-language therapy objective is to enable effective communication exchange in this population. Knowing that any observable improvements are a result of intervention has become increasingly crucial for accountability. SLPs are expected to demonstrate evidence or documentation that the treatment they offer has made improvement in client's speech behavior. This suggests that objectively documenting their performance is becoming more important. This is a component of what is currently recognized as evidence-based practice (EBP). The EBP principles, which include recommendations for how practitioners might accurately record treatment outcomes, have been adopted by ASHA (2004, 2005). Interventions must be carried out in a methodical manner in order to be effective, efficient, and accountable. This entails using EBP concepts and what is already known from the body of literature to make educated decisions about each stage of the process.

1.1 Need for the study

There is a wealth of literature available that focuses on AOS intervention methods. However, there exists a significant difference in the intervention approaches that are based on different theoretical standpoints over the years,

beginning with the articulatory kinematic approach in 1973. With the advancement of different intervention techniques for AOS, there is need for SLPs and caregivers to understand and be aware of the approaches that provide more efficacy. SLPs who have demanding clinical schedules seldom have the time or resources to review pertinent literature and choose the best course of action for the clients they are working with. The literature findings based on diverse intervention techniques are also not properly documented.

In order to accurately appreciate the strength of the evidence for various interventions, higher rated studies are required. Thus, further exploration of evidences after 2012 and other evidence-based approaches including various instruments apart from speech language therapy approaches needs to be examined and reviewed. Further there are no Indian studies that were considered in the previous systematic review. Therefore, a study that covers a wider range of literary works and age groups is necessary.

The current study is being conducted to look into the AOS therapeutic strategies that have been published between 2012 and 2022. This will help the SLPs to understand and identify the advances in the area of AOS management in the last decade. So, the current study is essential since it is required to assemble the findings in order to improve our understanding of AOS intervention strategies. We will be able identify recent developments in the field through this study, which will assist SLPs in directing their evidence-based practice.

1.2 Aim of the study:

The aim of the present study is to systematically review the existing studies on various intervention approaches targeting speech and language skills in persons with Apraxia of Speech (AOS) delivered by Speech-language pathologists.

1.3 Objectives of the study:

1. To compile the different therapy procedures used in the intervention of AOS.
2. To examine the findings of the intervention techniques of AOS.
3. To investigate the impact of age of intervention on outcomes of approaches.

1.4 Research questions:

The study was conducted using the following questions:

1. What are the various intervention techniques used for AOS?
2. Which is the most commonly used intervention technique used for AOS?
3. What are the evidences reported for AOS intervention techniques?
4. What are the differences in the duration of intervention techniques of AOS?

CHAPTER-2

METHODS

2.1 Searches

The review was done following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Page et al., 2021). The three main components of the search strategy were:

1. Putting together a thorough and practical list of search terms for speech therapy.
2. Exploring a sufficiently wide range of databases to identify as many research articles, including published and conference proceedings, that might be the most reliable studies.
3. The precise definition of inclusion criteria that may be applied to check the validity of research and provide the dataset for analysis.

A list of possible keywords, related search terms, their derivatives, and Medical Sub Heading (MeSH) terms that were pertinent to the study was created and incorporated the following: “Apraxia of speech” OR “Apraxia” OR “Acquired Apraxia of speech” OR “Treatment of Acquired Apraxia of speech” OR “Intervention of Acquired Apraxia of speech” NOT “Childhood Apraxia” were the search words used. These search words were used in various databases (IndMed, J-ISHA, Shodhganga, ASHAWire and Institutional databases like AIISH Repository) and international databases (PubMed/Medline, Google Scholar, J-Gate, Science Direct, and Com-Disdome (ProQuest), Scopus, Cochrane, ERIC, ErMEd, PsyNet, EBSCOhost and Web of Science. Searched in wide range of databases to find extensive studies including

published works, and conference proceedings., and forward and backward citation searching was done to identify additional articles or missed outsources.

The studies that match the inclusion criteria were found by screening the titles and/or abstracts found through the search strategies. Any titles or abstracts that contained relevant keywords or MeSH terms were passed on for further analysis and, if they did not meet the requirements for inclusion, were rejected. The potential studies' full texts were then collected, and they were compared for eligibility.

2.2 Selection Criteria

The PICO (Population, Intervention, Comparison, Outcomes) approach was used to create the clinical questions and the criteria for inclusion of studies were established priorly (see Table 2.1).

Table 2.1

Inclusion criteria

	INCLUSION CRITERIA
Population	Participants included people of the age group 18 to 80 years of both genders diagnosed as AOS with or without comorbid conditions.
Intervention	Studies using approaches targeting speech accuracy with motor, linguistic or multimodality-based interventions. Any intervention (behavioral/ speech-language/ Augmentative and Alternative Communication methods/ tele-rehabilitation services) given to an individual or a group, with varying frequencies and durations, in a variety of situations (home, clinics and community).
Outcome	The outcome measures of speech production accuracy, consistency, connected speech, co-articulation accuracy and functional communication measures recorded pre, post intervention and follow up were included.
Study design	Articles considered were: - a. Published in peer-reviewed journals from 2012 to 2022 b. Grey literature of AIISH repository and from Shodhganga. c. Reports available in English (AOS intervention provided in any language)

2.3 Data Extraction (Selection and Coding)

To find studies that fit the inclusion criteria, the titles and/or abstracts from the search strategies were examined. Titles and abstracts that contained any pertinent keywords or MeSH phrases were sent for further analysis and were rejected if they did

not meet the requirements for inclusion. The potential studies' full texts were then retrieved and checked for eligibility.

A standardized form that had been pre-piloted was used to retrieve the data from the selected research (see Appendix). Two experts (Speech-Language Pathologists) in the field of communication issues validated the form. The required adjustments were made in accordance with their suggestions. The information that was retrieved covered the following topics: study population, methodology, participant, methodology, participant demographics and/or disorder characteristics, information on derived measures, including assessment techniques, and the outcomes of the derived measures. The year of publication, kind of publishing, study design, research type, research emphasis, source of the study, and author characteristics with their affiliation were also extracted from eligible publications that met the inclusion criteria. Studies that described apraxia with and without concomitant conditions were comprehensively reviewed.

2.4 Risk of Bias Assessment (Quality Assessment)

Studies that were qualified for quality assessment were evaluated utilizing-

1. For randomized controlled trial studies, the Cochrane risk-of-tool (RoB 2; Sterne et al., 2019) was used. This tool evaluates the risk of bias across five domains, comprising (a) bias arising during randomizing, (b) bias during the administration of intervention, (c) bias if outcome data are missed, (d) bias when measuring outcome, and (e) bias in the selection of the reported result (Sterne et al., 2019). The result as a whole is graded as having "low risk of bias" if all five domains scored low risk, "some concerns" if any of the domains had some concerns, and "high risk of bias" if any of the domains had high risk or concerns.

2. The Single-Case Experimental Design (SCED) Scale (Tate et al., 2008) was used to evaluate the methodological quality of single-subject designs. It is an 11-item rating scale. The first item concerns general information and methodological quality is assessed by rating items from 2 to 11. The scale items comprise (a) clinical history, (b) the target behavior, (c) design, (d) stability of the baseline, (e) sufficient sampling, (f) data record, (g) interrater reliability, (h) independence of assessors, (i) statistical analysis, (j) replication, and (k) generalization. It has a score range from 0 to10 (Tate et al., 2008).
3. For assessing the methodological quality of case series, Joanna Briggs Institute (JBI) critical appraisal tool for case series was used (JBI, 2017b). The tool consists of 10 items. Items 1, 4, and 5 address biases in the selection of study participants, Items 2 and 3 address biases in measuring outcomes, Items 6 and 7 address biases in reporting results, and Item 8 addresses biases resulting from the missing outcome data. Item 10 evaluates statistical analysis, while Item 9 deals with adequate reporting. It has a score range from 1 to 10 (JBI, 2017b).
4. For assessing the methodological quality of case reports, Joanna Briggs Institute (JBI) critical appraisal tool for case reports was used (JBI, 2017a). The tool comprises 8 items: (a) patient's demographic characteristics, (b) patient's history, (c) current clinical condition, (d) diagnostic tests or assessment methods and the results, (e) intervention(s) or treatment procedure(s), (f) postintervention clinical condition, (g) identification of adverse events (harms) or unanticipated events, and (h) takeaway lessons. The maximum score of the scale is 8 (JBI, 2017a).
5. For assessing the methodological quality of non-randomised studies, ROBINS-I tool was used (Sterne et al., 2016). It has seven domains. The first two domains cover confounding and selection of participants into the study, address issues

before the start of the interventions that are to be compared (“baseline”). The third domain addresses classification of the interventions themselves. The other four domains address issues after the start of interventions: biases due to deviations from intended interventions, missing data, measurement of outcomes, and selection of the reported result. The signalling questions are largely factual in nature and are designed to help determine the risk of bias. There are four possible answers: Yes, Probably Yes, Probably No, No, and No Information. Some questions can only be addressed if the previous question got a "Yes" or "Probably yes" (or "No" or "Probably no") response. Responses of “Yes” are intended to have similar implications to responses of “Probably yes” (and similarly for “No” and “Probably no”), nonetheless, permit a distinction between what is known and what is likely to be the case.

6. For assessing methodological quality of group experimental studies, the Physiotherapy Evidence Database quality assessment tool (PEDro-P) was used (Perdices and Tate in 2009). Eleven items analyze the content of the paper. The score ranges from 0 to 9. Higher ratings correspond to better methodological quality.

Each paper was read by at least two independent researchers, and if there was disagreement, it was supposed to be discussed and resolved. Higher scores for both tools were related to higher standards of technique used and reported in the study. According to earlier evaluations (Camarinos & Marinko, 2009; Maher et al., 2003), studies were deemed to be of acceptable quality and will be reviewed if they had a score of 6 or higher. These researches were then subjected to the classification of intervention strategies from most popular to least popular.

CHAPTER 3

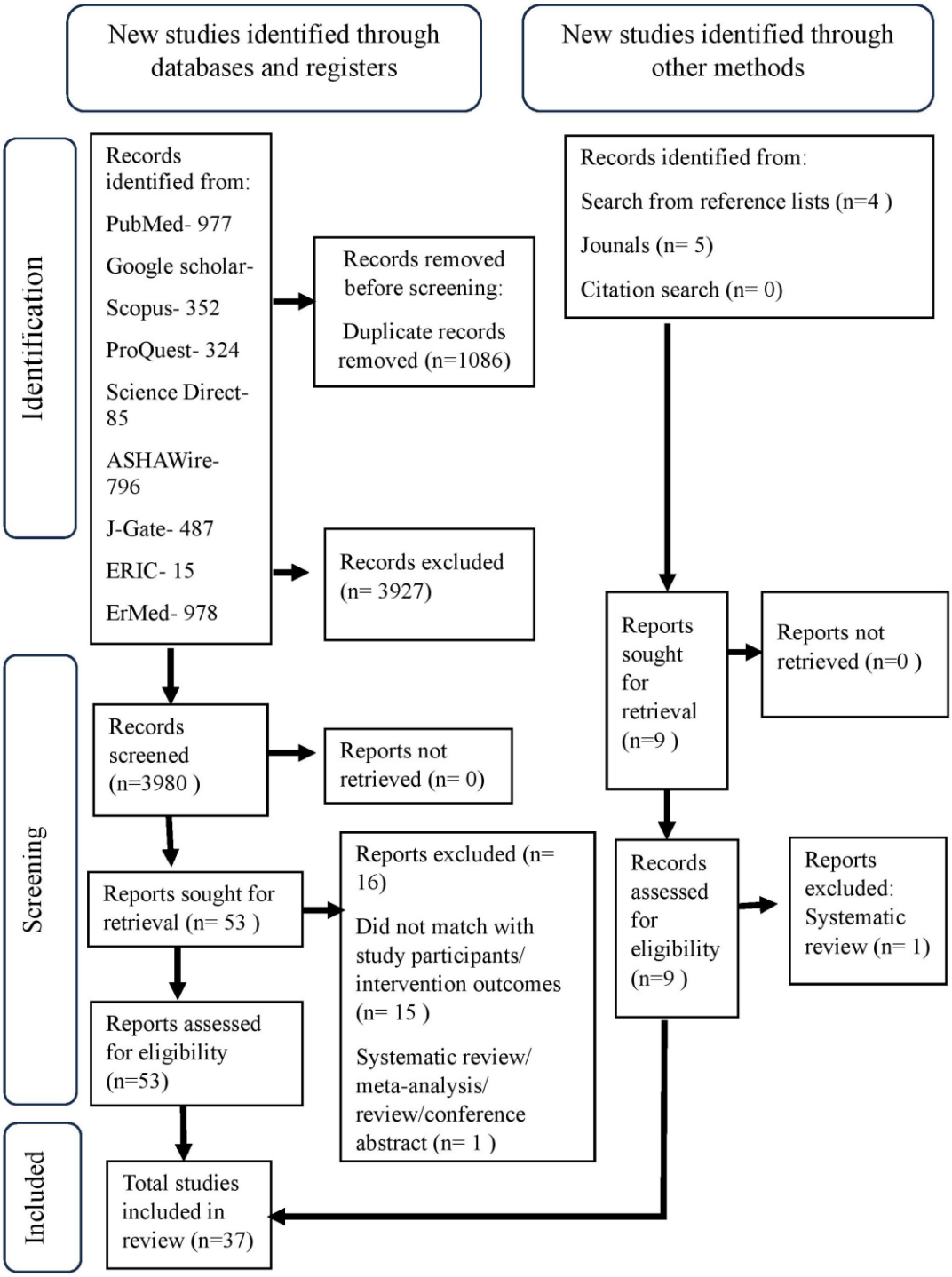
RESULTS

3.1 Records/Article Selection

A total of 5066 articles were found by database searches and via other methods (searching the reference lists and journals), including 1086 duplicates, which were eliminated. The title and abstract screening yielded a total of 259 articles. Fifty-three papers were chosen for full-text screening. Thirty-seven articles that met the inclusionary criteria were included in the study. Debate followed inter-judge selection, which served to verify the selection process. Following PRISMA guidelines, the relevant papers were selected. Figure 1 shows the precise PRISMA flow diagram for selecting studies.

Out of the total records/articles identified through database search (N=5066), 977 articles were obtained from PubMed, 324 from ProQuest, 796 from ASHAWire, 487 from J-Gate, 85 from Science Direct, 352 from Scopus, 15 from ERIC, 978 from ErMed and 1052 from Google Scholar. Endnote Citation Manager was used to remove 1086 duplicates that were obtained from various databases. After eliminating duplicate papers, 3980 articles underwent title and abstract screening. Out of which 3927 articles were rejected because they did not either include the study's keywords or fit the requirements for inclusion. Finally, 53 papers were selected for full-text analysis. Out of these 37 articles were selected for the review (Table 3.1).

Figure 3.1 shows the precise PRISMA flow diagram for selecting studies.



3.2 Study Characteristics

3.2.1 Population

All the studies included participants diagnosed with AOS with or without comorbid conditions within the age group 18 to 85 years in both genders.

3.2.2 Intervention

In this systematic review various intervention approaches used by SLPs were considered. The studies using approaches targeting speech accuracy with motor, linguistic or multimodality-based interventions were selected. Intervention approaches include behavioral and speech-language, Augmentative, and Alternative Communication methods, and telerehabilitation services (Johnson et al., 2018) given to an individual or a group, with varying frequencies and durations, were collected in various situations (home, clinics, and community) in various contexts. All except for one article, used behavioral and speech-language intervention. None of the studies used Augmentative and Alternative Communication methods.

3.2.3 Outcome

Studies included the outcome measures of co-articulation accuracy, speech production accuracy (Mauszycki et al., 2016; Mauszycki, S. C., & Wambaugh, J. L., 2020; Bislick, L., 2020; Mauszycki et al., 2016; Wambaugh et al., 2020; Wambaugh et al., 2018; Wambaugh et al., 2013; Johnson, R. K. 2018; Johnson et al., 2018; Marangolo et al., 2013; Jacks et al., 2015; Wambaugh et al., 2012; Buchwald et al., 2017; Nealon et al., 2021; Ballard et al., 2019; Zumbansen et al., 2014; Wambaugh et al., 2017; Wambaugh et al., 2021; Wambaugh et al., 2014; Wambaugh et al., 2016; Wambaugh et al., 2014; Wambaugh et al., 2014; Wambaugh et al., 2018; Bunker et al., 2018; Themistocleous et al., 2021; Wang et al., 2019; Zhao et al., 2022; Pisano et al., 2021;

Whiteside et al., 2012; Preston et al., 2014; Farias et al.,2014; Mozeiko et al., 2020; Johnson et al., 2018; Buchwald et al., 2020; Hurkmans et al., 2015), consistency (Mauszycki et al., 2016; Mauszycki, S. C., & Wambaugh, J. L., 2020; Johnson et al., 2018; Mozeiko et al., 2020; Johnson et al., Malfitano et al., 2019; Hurkmans et al., 2015) connected speech (Zumbansen et al., 2014; Henry et al., 2013;) and functional communication measures recorded, pre-intervention post-intervention, and follow-up were included.

3.2.4 Setting

All the studies targeted intervention conducted in clinical or home set-ups.

3.3 Results of Data Extraction

Table 3.1 summarizes all 37 articles that were selected for the study including information of authors and year of the article, country of origin, number of participants, age range of participants, study design of the studies, number of therapy sessions, frequency of sessions, length of each session, duration of intervention, intervention given and findings of the study.

Table 3.1

Summary of the selected studies

S. No	Author/ Year	Country of origin	Number of participants	Age range (years)	Study design (type of evidence)	No. of therapy sessions	Frequency of sessions	Length of each session	Duration of intervention	Intervention	Findings
1.	Wambaugh et al., 2012	USA	10	33-60	SCED	10	3 sessions/ week	NR	3.5 weeks	Repeated practice treatment & Articulatory-kinematic treatment	The study found that both types of treatment had an impact on the small alterations that were observed in all participants' untreated, repeatedly exposed lists.
2.	Whiteside et al., 2012	UK	50	28-86	RCT	For SPF group: 80, For SHF group: 83	1 session/ day	unspecified	16 weeks (4 weeks rest-phase)	Self-administered computer therapy Vs. visuo-spatial sham	According to the study, participants significantly improved their speech accuracy and fluency. The SPF group (who received speech therapy first) showed signs of maintenance, and the results showed that behavioral benefits were significantly maintained. These findings underscore the long-term effectiveness of early speech therapy interventions.

Table 3.1 Continued…

S. No	Author/ Year	Country of origin	Number of participants	Age range (years)	Study design (type of evidence)	No. of therapy sessions	Frequency of sessions	Length of each session	Duration of intervention	Intervention	Findings
3.	Wambaugh et al., 2013	USA	4	34-53	SCED	20	SPT-Intense: 4days/ week, SPT-T: 3days/ week	SPT-I: 240 minutes, SPT-T: 60 minutes	6.5 weeks	SPT	Results indicate that regardless of variations in treatment intensity or practice schedules, similar results are obtained in terms of acquisition, generalization, and maintenance of word accuracy.
4.	Marangolo et al., 2013	Italy	8	60-79	Group experimental study	10	7 sessions/ week	NR	6 w (2 weeks intersession interval)	tDCS + speech-language therapy	Following bihemispheric tDCS, the participants showed a significant improvement in their accuracy and speed when speaking the treated stimuli as well as in other language tasks.
5.	Henry et al., 2013	USA	1	73	Case report	12	One session/ week	60 minutes	12 weeks	Oral reading treatment	The outcomes revealed that structured oral reading therapy significantly improved the production of multisyllabic words during text reading, and this enhancement was consistently observed across all types of words.

Table 3.1 Continued…

S. No	Author/ Year	Country of origin	Number of participants	Age range (years)	Study design (type of evidence)	No. of therapy sessions	Frequency of sessions	Length of each session	Duration of intervention	Intervention	Findings
6.	Zumbansen et al., 2014	Canada	3	48-57	SCED	18	3 sessions/ week	60 minutes	6 weeks	MIT	The MIT resulted in the strongest generalization impact both to untreated stimuli and connected speech out of the three interventions (rhythmiconly, normally speaking, and MIT) to speech accuracy in trained phrases. With either treatment, there was no significant difference in the motor speech agility test. The use of rhythm and pitch together has positive MIT effects.
7.	Wambaugh et al., 2014	USA	6	46-71	SCED	40	3 sessions/ week	50-60 minutes	16 weeks (2 weeks no-treatment interval)	SPT	The study results showed that both blocked and random practice schedules successfully enhanced sound production accuracy in both treated and untreated words. Also, the two practice schedules may have different effects based on the participant as a whole and the target sound.

Table 3.1 Continued…

S. No	Author/ Year	Country of origin	Number of participants	Age range (years)	Study design (type of evidence)	No. of therapy sessions	Frequency of sessions	Length of each session	Duration of intervention	Intervention	Findings
8.	Wambaugh et al., 2014	USA	4	36-72	SCED	For 1 participant: 28, For 3 participants: 40	3 sessions/ week	60-75 minutes	For 1 partcipant: 9.5 weeks, For 3 participants: 13.5	CAAST	Speech production improvements showed variability among participants, suggesting the need for additional research on CAAST (Communication Augmentation and Assistive Systems Technology) to better understand its effectiveness and potential customization for individuals.
9.	Preston et al., 2014	USA	12	59	Case report	12	2 sessions/ week	60 minutes	6 weeks	Ultrasound visual feedback	Performance clearly improved with time, especially on postvocalic rhotics, and the individual moved up to more difficult levels as the trial went on.
10.	Farias et al., 2014	USA	1	56	Case report	12	3 sessions/ week	60-70 minutes	4 weeks	Implicit phoneme manipulation	According to the study, patients with AOS who received implicit phoneme modification therapy had improved speech production accuracy. The therapy has been demonstrated to stimulate the brain regions responsible for phonological processing, motor planning, and programming.

Table 3.1 Continued…

S. No	Author/ Year	Country of origin	Number of participants	Age range (years)	Study design (type of evidence)	No. of therapy sessions	Frequency of sessions	Length of each session	Duration of intervention	Intervention	Findings
11.	Jacks et al., 2015	USA	10	39-80	SCED	NR	NR	NR	unspecified	MAF, AAF	The findings from the study indicate that masking noise and AAF can have effects on speech measures such as syllable rate, disfluency duration, and vocal intensity. However, the significance and consistency of these effects varied among participants.
12.	Maas et al., 2015	USA	33	22-72	Non-randomized study	unspecified	unspecified	30-60 minutes	unspecified	Noise masking	When compared to the unmasked condition, those with AOS and aphasia significantly reduced their articulatory vowel space (AVS) and lengthened their vowels. The younger control group showed longer vowel durations under the masking condition but no effect of noise masking on vowel dispersion. Also, people with AOS and aphasia experienced a larger decline in AVS than age-matched controls.

Table 3.1 Continued…

S. No	Author/ Year	Country of origin	Number of participants	Age range (years)	Study design (type of evidence)	No. of therapy sessions	Frequency of sessions	Length of each session	Duration of intervention	Intervention	Findings
13.	Hurkmans et al., 2015	Netherlands	5	18-75	Case series	24	2 sessions/ week	30 minutes	12 weeks	SMTA	SMTA can be a useful intervention for people with AOS and aphasia who want to improve their speech and language skills. The findings revealed significant improvements in speak production, language comprehension, and communication efficacy.
14.	Mauszycki et al., 2016	USA	2	51-53	SCED	24	3 sessions/ week	45-60 minutes	6 weeks	MIT	Both participants experienced slight improvements in articulatory precision for both treated and generalized stimuli.
15.	Wambaugh et al., 2016	USA	4	37-83	SCED	For 2 participants: 20, For 2 participants: 40	3 sessions/ week	50-60 minutes	6.5, 13.5 for 2, 2 participants, respectively	SPT	All participants made improvements in accuracy of articulation of trained words in both training conditions for three participants but one participant had a better response with the random practice condition.

Table 3.1 Continued…

S. No	Author/ Year	Country of origin	Number of participants	Age range (years)	Study design (type of evidence)	No. of therapy sessions	Frequency of sessions	Length of each session	Duration of intervention	Intervention	Findings
16.	Mauszycki et al., 2016	USA	4	37-57	SCED	24	3 times/ week	35 minutes	3 weeks	Articulatory kinematic treatment in conjunction with VBFB via EPG	In terms of the accuracy of phonemes, all participants demonstrated good acquisition of the treated materials, and 50% demonstrated response generalization and better maintenance. According to the findings, VBFB plus SPT may benefit those with AOS.
17.	Buchwald et al., 2017	USA	4	44-66	SCED	NR	8 sessions/ week	30-50 minutes	unspecified	Repetition-based training	The results indicated that individuals with motoric locus of errors demonstrated significant improvement in producing both trained and untrained items during repetition training. However, those with phonological processing errors did not show any notable change in their performance, highlighting the distinct effects of the intervention for these two groups.

Table 3.1 Continued…

S. No	Author/ Year	Country of origin	Number of participants	Age range (years)	Study design (type of evidence)	No. of therapy sessions	Frequency of sessions	Length of each session	Duration of intervention	Intervention	Findings
18.	Wambaugh et al., 2017	USA	24	29-83	SCED	18 Participants: 40, 2 Participants: 20	3 sessions/ week	50-60 minutes	10 weeks	SPT	The study found that the sound production treatment for acquired AOS and aphasia significantly improved participants' speech production accuracy and intelligibility. Additionally, compared to a control treatment, treatment led to superior maintenance of treatment improvements for 3-month follow-up.
19.	Wambaugh et al., 2018	USA	5	44-64	SCED	54	SPT & SPT-T: 3 days/ week,	SPT-180 minutes & SPT-T: 60 minutes	12 weeks	SPT	Regardless of the intensity, improvements in treated items and response generalization were all observed. The traditional technique had greater maintenance effects. People with AOS might benefit from the traditional rather than intense practice.

Table 3.1 Continued…

S. No	Author/ Year	Country of origin	Number of participants	Age range (years)	Study design (type of evidence)	No. of therapy sessions	Frequency of sessions	Length of each session	Duration of intervention	Intervention	Findings
20.	Johnson, 2018	USA	2	55-61	SCED	25	2 sessions/ week	60 minutes	12-13 weeks	MLG treatment	While practicing low-dose (therapy only) and high-dose (therapy plus self-controlled practice) conditions, the participants demonstrated improvements in retention measures for the words/phrases that had been treated but not in generalization. Fewer targets achieved improvements in treated items, generalization, and maintenance. The study backs up the findings showing that MLG therapy for AOS is effective.
21.	Johnson et al., 2018	USA	2	61-68	SCED	18	2 sessions/ week	30 minutes	9 weeks	MLG treatment	The approach allowed for the identification of maintenance effects and word production accuracy in treated phrases. It is advised to employ both qualitative and quantitative metrics for assessing the intervention's success.

Table 3.1 Continued…

S. No	Author/ Year	Country of origin	Number of participants	Age range (years)	Study design (type of evidence)	No. of therapy sessions	Frequency of sessions	Length of each session	Duration of intervention	Intervention	Findings
22.	Wambaugh et al., 2018	USA	4	39-69	SCED	For 1 participant: 60, For 3 participants: 40	3 sessions/ week	60-75 minutes	For 1 participant: 20 weeks, for 3 participants: 13.5 weeks	CAAST	Three people showed better CIU production with treated picture sets, and two showed generalization to untreated sets. In an untrained discourse context, all participants significantly improved CIU production.
23.	Bunker et al., 2018	USA	8	36-72	SCED	For 7 participants: 28-40, for 1 participant: 42-60	NR	NR	unspecified	CAAST	The study revealed that following the administration of CAAST, the majority of participants exhibited enhancements in various morphosyntactic production and complexity measures, which extended to both the treated and untreated sets. Nevertheless, there was minimal observed change in terms of lexical diversity, indicating a particular area where the intervention had limited impact.

Table 3.1 Continued…

S. No	Author/ Year	Country of origin	Number of participants	Age range (years)	Study design (type of evidence)	No. of therapy sessions	Frequency of sessions	Length of each session	Duration of intervention	Intervention	Findings
24.	Johnson et al., 2018	USA	1	52	Case report	24	2 sessions/ week	NR	21 weeks (4 weeks break)	MLG	The study found that MLG was found to be beneficial in enhancing speech production in a patient with acquired AOS. The research indicated that compared to therapy-only and untrained phrases, phrases practiced both in therapy and at home fulfilled the criteria for mastery in fewer sessions.
25.	Ballard et al., 2019	Australia	5	60-73	SCED	20	4 sessions/ week	60 minutes	4 participants: 4 weeks. 1 participant: 5 weeks	Custom-built Word Trainer app	The study found that using ASR to provide augmented feedback on word production accuracy to patients with mild-moderate AOS+ undertaking self-administered speech therapy was effective in achieving high-intensity practice. Furthermore, the results demonstrated robust maintenance of treatment effects one month after the intervention, indicating its long-lasting benefits.

Table 3.1 Continued…

S. No	Author/ Year	Country of origin	Number of participants	Age range (years)	Study design (type of evidence)	No. of therapy sessions	Frequency of sessions	Length of each session	Duration of intervention	Intervention	Findings
26.	Wang et al., 2019	China	52	24-73	RCT	10	2 sessions/ day	50 minutes (30 min-speech training, 20 min-tDCS)	5 days	tDCS	In comparison to sham tDCS paired with speech therapy and speech therapy alone, the study demonstrated that anodal transcranial direct current stimulation (A-tDCS) combined with speech therapy significantly improved speech-language function in patients with poststroke AOS.
27.	Malfitano et al., 2019	Italy	1	53	Case report	10	5 sessions/ week	unspecified	2 weeks	rTMS	According to the study, rTMS can help AoS symptoms by having an impact on brain circuits that are at least somewhat different from other language circuits. The observed enhancement in the repetition of nonwords implies that the results may also reflect a more precise phonological analysis, pointing towards the treatment's effectiveness.

Table 3.1 Continued…

S. No	Author/ Year	Country of origin	Number of participants	Age range (years)	Study design (type of evidence)	No. of therapy sessions	Frequency of sessions	Length of each session	Duration of intervention	Intervention	Findings
28.	Bislick et al., 2020	USA	2	46-61	SCED	Participant TR= 38 Participant LL= 27	3 sessions/ week	60 minutes	For Participant 1: 12.5 weeks, For Participant 2: 9 weeks	Modified Phonomotor Treatment Program	The study revealed sustained accuracy improvements in both trained and untrained target production, upheld during follow-up. The treatment led to clinically meaningful enhancements in sound production accuracy, measured through percentage change exceeding the highest baseline performance.
29.	Wambaugh et al., 2020	USA	12	43-81	SCED	27	3 sessions/ week	240 minutes	12 weeks	SPT	Enhancements in treated elements (phoneme production accuracy) and generalization were evident regardless of intensity, with the majority displaying substantial maintenance effects for both conventional and intensive practice. Individuals with AOS could potentially gain from both traditional and intensive practice approaches.

Table 3.1 Continued…

S. No	Author/ Year	Country of origin	Number of participants	Age range (years)	Study design (type of evidence)	No. of therapy sessions	Frequency of sessions	Length of each session	Duration of intervention	Intervention	Findings
30.	Mozeiko et al., 2020	USA	1	51	Case report	10	5 sessions/ week	180 minutes	2 weeks	SPT	The individual performed well when it came to acquisition, generalization, and maintenance. The use of mass practice in therapy sessions is supported by research.
31.	Buchwald et al., 2020	USA	1	60	Case report	23 (5= baseline sessions)	unspecified	40 minutes (after tDCS application)	unspecified	tDCS	When compared to the Sham tDCS phase, the authors found that the Active tDCS phase significantly improved the production of stop-initial words. The production of fricative-initial words did not significantly differ between the two periods, though.
32.	Mauszycki et al., 2020	USA	2	40-73	SCED	48	1 session/ day	40-60 minutes	18 weeks	EPG treatment and SPT	Both approaches led to enhancements in response generalization, maintenance, and the accuracy of phoneme production. However, it is worth noting that the benefits of SPT were more substantial, indicating its superior effectiveness in these aspects.

Table 3.1 Continued…

S. No	Author/ Year	Country of origin	Number of participants	Age range (years)	Study design (type of evidence)	No. of therapy sessions	Frequency of sessions	Length of each session	Duration of intervention	Intervention	Findings
33.	Pisano et al., 2021	Italy	10	51-75	RCT	5	1 session/ day	unspecified	5 days	tDCS	The findings showed that, when compared to the sham control, the anodal tDCS condition was associated with a significantly greater improvement in the mean percentage of accuracy in both words and sentences tasks. One week following the conclusion of treatment, a follow-up assessment was done, and the improvement was still there.
34.	Nealon et al., 2021	USA	4	35-58	SCED	For 2 Participants: 24, For 2 Participants: 20	2 Participants: 3 session and 2 Participants: 2 sessions/ week	60 minutes	2 Participants: 8 weeks, 2 Participants: 10 weeks	VNeST	Treatment had positive effects on some aspects of speech production, including segmental speech errors, syllable segmentation, and false starts and pauses. However, the gains in production of correct number of syllables were limited to one participant, and one participant did not demonstrate increased accuracy on any measure of speech production.

Table 3.1 Continued…

S. No	Author/ Year	Country of origin	Number of participants	Age range (years)	Study design (type of evidence)	No. of therapy sessions	Frequency of sessions	Length of each session	Duration of intervention	Intervention	Findings
35.	Wambaugh et al., 2021	USA	20	29-83	SCED	12-14	3 sessions/ week	50-60 minutes	4-5 weeks	SPT	The study found a positive correlation between the number of treatment sessions and teaching episodes and changes in articulation accuracy above baseline performance, production mastery, and maintenance. Moreover, SPT-Random practice schedule was associated with a greater improvement in articulation accuracy than the SPT-Blocked practice schedule
36.	Themistocleous et al., 2021	USA	10	53-78	RCT	15	5 sessions/ week	20 minutes	3 weeks	tDCS	Segmental duration was dramatically reduced following tDCS, and tDCS benefits were generalized to untrained words. The effects of tDCS persisted in trained and untrained sounds for more than two months after treatment. Moreover, results demonstrate that tDCS over the left IFG may facilitate speech production by reducing segmental duration.

Table 3.1 Continued…

S. No	Author/ Year	Country of origin	Number of participants	Age range (years)	Study design (type of evidence)	No. of therapy sessions	Frequency of sessions	Length of each session	Duration of intervention	Intervention	Findings
37.	Zhao et al., 2022	China	24	18-80	RCT	10	2 sessions/ day	50 minutes (30 min-speech training, 20 min-tDCS)	5 days	tDCS	According to the study, patients who got active tDCS treatment significantly improved their ability to repeat words and auditory comprehension compared to patients who received asham tDCS treatment.

NOTE: VBFB- Visual Biofeedback, EPG- Electropalatography, SPT- Sound Production Treatment, MIT- Melodic Intonation Therapy, MLG- Motor Learning Guided, tDCS- Transcranial Direct Current Stimulation, MAF- Masked Auditory Feedback, AAF- Altered Auditory Feedback, VNeST- Verb Network Strengthening Treatment, CAAST- Combined Aphasia and Apraxia of Speech Treatment, rTMS- Repetitive Transcranial Magnetic Stimulation, SMTA- Speech Music Therapy for Aphasia

3.3.1 Number and availability of reports in different database

37 publications from around the world were found after a web search on the various popular databases that particularly studied the intervention of AOS as per our inclusionary criteria from 2012 to 2022 and is shown in Table 3.2.

Table 3.2

Number of studies obtained from different database

Databases	Number of studies identified, n=37 (%)
Google Scholar	11(29.7%)
Scopus	6(16.2%)
J-Gate	5(13.5%)
ProQuest	4(10.8%)
PubMed/ MedLine	4(10.8%)
ASHAWire	3(8.1%)
Science Direct	2(5.4%)
ERIC	1(2.7%)
ErMed	1(2.7%)
Total	**37 (100%)**

Concealed data (data not available online), severely impedes studying AOS because in-house publications are unknown and are unavailable to the researcher. Indian institutes and organizations such as AIISH repository, Bharti Vidyapeeth Pune, Ali Yavar Jung National Institute of Speech and Hearing Disabilities Kolkata, Shodhganga were searched for literature on intervention in AOS, however, was unable to obtain the same since they were not accessible to the investigator. Nevertheless, it should be noted that

if the studies are not made available in widely read venues, such as by current investigators, they risk missing out on essential research publications to the outside world.

3.3.2 Geographical Location (Country of study)

Table 3.3 summarizes the country of origin or where the study was conducted. Thirty-seven articles fulfilled the inclusion criteria on the database search.

Table 3.3

Country of the study

Country of study	**Number of studies identified, n=37 (%)**
USA	28 (75.6%)
Italy	3(8.1%)
China	2(5.4%)
Canada	1(2.7%)
Australia	1(2.7%)
Netherlands	1(2.7%)
UK	1(2.7%)
Total	**37 (100%)**

The literature search was carried out across languages spoken in the world. the study indicated that despite Asian and African continents being the largest and second-largest in the world, only two literary works were found from China, which is included in Table 3.3. Twenty-eight pieces of literature from the USA, three from Italy, one from the UK, one from Canada, one from Australia and one from the Netherlands were

obtained. This finding may indicate that there are fewer researchers working in the field of AOS, which shows that research in this area is still developing worldwide.

Additionally, the enormous breadth and practice of the profession must be explored across most of the countries in the world in this field. The findings recommend that action be taken swiftly to generate opportunities for experts to research and increase the number of researchers in the area of AOS. Few skilled experts in speech and hearing are interested in AOS. The lack of suitable resources for individuals/experts in AOS could be another major factor in the restricted research in the majority of countries, even with the professional courses being offered. SLPs have nevertheless made an effort to research intervention and use it in clinical settings.

3.4 Quality Assessment of Records

The final 37 studies selected for the review underwent quality assessment. Out of the total 37 studies, 22 studies were single-subject designs, 7 were case reports, 5 were randomized controlled, 1 was group experimental, 1 was non-randomized controlled trial and 1 case series study.

Single-Case Experimental Design Scale (SCED) was used to assess the quality method and statistical analysis. Twenty-two single-case studies were assessed using the SCED scale. Eleven item ratings in the scale analyzed the article to reduce the possibility of bias in single-case studies. The score ranged from 0 to 10. Higher ratings corresponded to better methodological quality. Table 3.4 shows the quality assessment for the single-subject designs used SCED scale. The finding shows most of the studies got 10/10 rating in most of the items and variability is there in rest of the items.

Five randomized controlled trial studies were assessed using Cochrane risk-of-bias tool for randomized trials (RoB 2) scale. The risk of bias was evaluated across five

domains. The result as a whole was graded as having “low risk bias" if all five domains scored low risk, "some concerns" if any of the domains had some concerns, and "high risk of bias" if any of the domains had high risk or concerns. The items in Table 3.5 were presented in the same sequence. All the studies got low risk of bias in each domain and overall risk of bias is also rated as having low risk.

Physiotherapy Evidence Database quality assessment tool (PEDro-P, Perdices & Tate, 2009) was used to assess the quality of eligible research in one group experimental study. Eleven questions analyzed the content of the paper. The items in Table 3.6 were presented in the same sequence. The study was rated 9 score in 10 out of eleven items. The study got score 9 in 10 out of 11 items, indicating low risk of bias.

Seven case reports were analyzed using Joanna Briggs Institute (JBI) critical appraisal tool for case reports. Eight items analyzed the studies and overall appraisal of each study was also analysed. The items in Table 3.7 were presented in the same sequence.

One case series study was analyzed using Joanna Briggs Institute (JBI) ctitical tool for case series. 10 items analyzed the study. The items in Table 3.8 were presented in the same order. One study was scored ‘yes’ on all the items i.e., having low risk of bias whereas in other studies there was a variability in the scores.

One non-randomized controlled trial study was analysed using ROBINS-I tool. The tool also evaluated the overall risk of bias. The items in the Table 3.9 were presented in the same order. The study had low risk of bias in all the domains except one domain which was scored as “No Information”. Thus, the overall risk of bias judgement was rated as ‘moderate’.

Table 3.4

Quality assessment for single-subject designs.

S. No.	Article author	Clinical history	Target behaviours	Design	Base line	Sampling behaviour during treatment	Raw data record	Inter-rater reliability	Independence of assessors	Statistical analysis	Replication	Generalisation
1.	Mauszycki et al., 2016	10	10	10	10	10	10	10	5	2	1	4
2.	Mauszycki et al., 2020	10	10	10	10	10	10	10	4	3	2	4
3.	Bislick et al., 2020	9	10	10	10	10	10	10	4	10	1	5
4.	Mauszycki et al., 2016	10	9	10	10	10	10	10	5	2	4	4
5.	Wambaugh et al., 2020	10	10	10	10	10	10	10	3	10	4	5
6.	Wambaugh et al., 2018	10	10	10	10	10	10	10	6	10	4	3
7.	Wambaugh et al., 2013	10	10	10	10	10	10	10	5	8	5	4

Table 3.4 continues

Table 3.4 continued

8.	Johnson, 2018	9	9	10	10	10	10	5	9	1	1	1
9.	Johnson et al., 2018	10	10	10	10	10	10	9	7	6	2	2
10.	Jacks et al., 2015	10	10	3	1	1	2	10	8	4	2	6
11.	Wambaugh et. al., 2012	10	10	10	10	10	10	8	8	8	4	3
12.	Buchwald et al., 2017	10	7	8	3	3	1	1	2	4	1	2
13.	Nealon et al., 2021	10	4	1	1	1	1	8	6	4	1	1
14.	Ballard et al., 2019	10	9	10	10	8	8	10	7	5	3	5
15.	Zumbansen et al., 2018	10	8	6	2	7	10	5	2	2	5	5
16.	Wambaugh et al., 2017	10	10	10	10	10	10	10	10	7	8	8
17.	Wambaugh et al., 2021	10	10	10	10	10	10	10	3	7	5	5

Table 3.4 continued

18.	Wambaugh et al., 2014	10	10	10	10	10	10	10	10	06	05	05
19.	Wambaugh et al., 2016	10	10	10	10	10	10	10	10	05	05	05
20.	Wambaugh et al., 2014	10	10	10	10	10	10	10	10	04	05	05
21.	Wambaugh et al., 2018	10	10	10	10	10	10	10	10	04	10	07
22.	Bunker et al., 2018	10	09	10	10	05	04	10	05	07	06	07

Table 3.5

Quality assessment for randomized controlled trials

S.No.	Items	Themistocleous et. al., 2021	Wang et. al., 2019	Zhao et. al., 2022	Pisano et. al., 2021	Whiteside et. al., 2012
1	Bias arising from the randomization process					
1.1	Was the allocation sequence random?	Probably Yes	Yes	Yes	Yes	Probably Yes
1.2	Was the allocation sequence concealed until participants were enrolled and assigned to interventions?	No Information	Probably Yes	Yes	Yes	Probably Yes
1.3	Did baselines differences between interventions groups suggest a problem with the randomization process?	No	No	Probably No	No	No
	Risk of bias judgement	Low	Low	Low	Low	Low
2	Risk due to deviations from intended interventions					
2.1	Were participants aware of the assigned intervention during the trial?	No Information	Probably No	No	No	No
2.2	Were carers and people delivering the interventions aware of participants' assigned intervention during the trial?	No Information	Probably No	No	No	Probably Yes
2.3	If Y/PY/NI to 2.1 or 2.2: Were there decisions from the intended intervention that arose because of the trial context?	No Information	Not Applicable	Not Applicable	Not Applicable	Probably Yes
2.4	If Y/PY/NI to 2.3: Were these deviations likely to have affected the outcome?	Probably No	Not Applicable	Not Applicable	Not Applicable	Probably No
2.5	If Y/PY/NI to 2.4: Were these deviations from intended intervention balanced between groups?	Not Applicable	Not Applicable	Not Applicable	Not Applicable	Probably Yes

2.6	Was an appropriate analysis used to estimate the effect of assignment to intervention?	Yes	Yes	Probably No	Probably Yes	Probably Yes
2.7	If Y/PY/NI to 2.6: Was there potential for a substantial impact [on the result] of the failure to analyse participants in the group to which they were randomized?	Probably No	Probably Yes	Not Applicable	Probably No	Probably No
	Risk of bias judgement	Low	Low	Low	Low	Low
3	Risk due to missing outcome data					
3.1	Were data for this outcome available for all, or nearly all, participants randomized?	Yes	Yes	Yes	Yes	Yes
3.2	If N/PN/NI to 3.1: Is there evidence that the result was not biased by missing outcome data?	Not Applicable	Not Applicable	Not Applicable	Not Applicable	Not Applicable
3.3	If N/PN to 3.2: Could missingness in the outcome depend on its true value?	Not Applicable	Not Applicable	Not Applicable	Not Applicable	Not Applicable
3.4	If Y/PY/NI to 3.3: Is it likely that missingness in the outcome depended on its true value?	Not Applicable	Not Applicable	Not Applicable	Not Applicable	Not Applicable
	Risk of bias judgement	Low	Low	Low	Low	Low
4	Risk in measurement of the outcome					
4.1	Was the method of measuring the outcome inappropriate?	No	Yes	No	Probably Yes	Yes
4.2	Could measurement or ascertainment of the outcome have differed between groups?	No	Probably No	Probably Yes	Probably No	No
4.3	If N/PN/NI to 4.1 and 4.2: Were outcome assessors aware of the intervention received by study participants?	No	No	Probably No	Probably No	Probably Yes
4.4	If Y/PY/NI to 4.3: Could assessment of the outcome have been influenced by knowledge of intervention received?	Not Applicable	Not Applicable	Probably No	Probably No	Probably No

4.5	If Y/PY/NI to 4.4: Is it likely that assessment of the outcome was influenced by knowledge of intervention received?	Not Applicable	Not Applicable	Not Applicable	Not Applicable	Not Applicable
	Risk of bias judgement	Low	Low	Low	Low	Low
5	Risk in selection of the reported result					
5.1	Were the data that produced this result analysed in accordance with a pre-specified analysis plan that was finalized before unblinded outcome data were available for analysis?	Probably Yes	Probably Yes	Probably Yes	Probably Yes	Yes
5.2	Is the numerical result being assessed likely to have been selected, on the basis of the results, from multiple eligible outcome measurements (eg, scales, definitions, time points) within the outcome domain?	Yes	Yes	Yes	Yes	Yes
5.3	Is the numerical result being assessed likely to have been selected, on the basis of the results, from multiple eligible analysis of the data?	Probably Yes	Probably Yes	Yes	Yes	Yes
	Risk of bias judgement	Low	Low	Low	Low	Low
	Overall Risk of bias judgement	Low	Low	Low	Low	Low

Table 3.6

Quality assessment for group experimental studies

S.No.	Items	Marangolo et. al., 2013
1.	Eligibility criteria were specified	7
2.	Subjects were randomly allocated to groups (in a crossover study, subjects were randomly allocated an order in which treatments were received)	9
3.	Allocation was concealed	9
4.	The groups were similar at baseline regarding the most important prognostic indicators	9
5.	There was blinding of all subjects	9
6.	There was blinding of all therapists who administered the therapy	9
7.	There was blinding of all assessors who measured at least one key outcome	9
8.	Measures of at least one key outcome were obtained from more than 85% of the subjects initially allocated to groups	9
9.	All subjects for whom outcome measures were available received the treatment or control condition as allocated or, where this was not the case, data for at least one key outcome was analysed by “intention to treat”	9
10.	The results of between-group statistical comparisons are reported for at least one key outcome	9
11.	The study provides both point measures and measures of variability for at least one key outcome	9

Table 3.7

Quality Assessment for case reports

S.No.	Items	Preston et. al., 2014	Farias et. al., 2014	Mozeiko et. al., 2020	Johnson et. al., 2018	Henry et. al., 2013	Buchwald et. al., 2020	Malfitano et. al., 2019
1.	Were patient's demographic characteristics clearly described?	Yes	Yes	Yes	Yes	Yes	Yes	Yes
2.	Was the patient's history clearly described and presented as a timeline?	Yes	Yes	Yes	Yes	Yes	Yes	Yes
3.	Was the current clinical condition of the patient on presentation clearly described?	Yes	Yes	Yes	Yes	Yes	Yes	Yes
4.	Were diagnostic tests or assessment methods and the results clearly described?	Yes	Yes	Yes	Yes	Yes	Yes	Yes
5.	Was the intervention(s) or treatment procedure(s) clearly described?	Yes	Yes	Yes	Yes	Yes	Yes	Yes
6.	Was the post-intervention clinical condition clearly described?	Yes	Yes	Yes	Yes	Yes	Yes	Yes
7.	Were adverse events (harms) or unanticipated events identified and described?	Unclear	Unclear	Unclear	No	No	Yes	Yes
8.	Does the case report provide takeaway lessons?	Unclear	Yes	Yes	Unclear	Yes	Unclear	Yes
9.	Overall appraisal:	Include	Include	Include	Include	Include	Include	Include

Table 3.8

Quality Assessment for case series study

S.No.	Items	Hurkmans et. al., 2015
1.	Were there clear criteria for inclusion in the case series?	Yes
2.	Was the condition measured in a standard, reliable way for all participants included in the case series?	Yes
3.	Were valid methods used for identification of the condition for all participants included in the case series?	Yes
4.	Did the case series have consecutive inclusion of participants?	Yes
5.	Did the case series have complete inclusion of participants?	Yes
6.	Was there clear reporting of the demographics of the participants in the study?	Yes
7.	Was there clear reporting of clinical information of the participants?	Yes
8.	Were the outcomes or follow-up results of cases clearly reported?	Yes
9.	Was there clear reporting of the presenting sites' /clinics' demographic information?	Yes
10.	Was statistical analysis appropriate?	Yes

Table 3.9

Quality Assessment for Non-randomized controlled trials

S.No.	Items	Maas et al., 2015
1	**Bias due to confounding**	
1.1	Is there potential for confounding of the effect of intervention in this study?	No
1.2	Was the analysis based on splitting participants' follow up time according to intervention received?	Probably
	If **N/PN**, answer questions relating to baseline confounding (1.4 to 1.6)	No
	If **Y/PY**, proceed to question 1.3.	
1.3	Were intervention discontinuations or switches likely to be related to factors that are prognostic for the outcome?	Not
	If **N/PN**, answer questions relating to baseline confounding (1.4 to 1.6)	Applicable
	If **Y/PY**, answer questions relating to both baseline and time-varying confounding (1.7 and 1.8)	
1.4	Did the authors use an appropriate analysis method that controlled for all the important confounding domains?	Probably Yes
1.5	**If Y/PY to 1.4:** Were confounding domains that were controlled for measured validly and reliably by the variables available in this study?	Probably Yes
1.6	Did the authors control for any post-intervention variables that could have been affected by the intervention?	Probably Yes
1.7	Did the authors use an appropriate analysis method that adjusted for all the important confounding domains and for time- varying confounding?	Probably Yes

S.No.	Items	Maas et al., 2015
1.8	**If Y/PY to 1.7:** Were confounding domains that were adjusted for measured validly and reliably by the variables available in this study?	Probably Yes
	Risk of bias judgement due to confounding	Low
2	**Bias in selection of participants into the study**	
2.1	Was selection of participants into the study (or into the analysis) based on participant characteristics observed after the start of intervention?	No
	If **N/PN to 2.1**: go to 2.4	
2.2	**If Y/PY to 2.1:** Were the post-intervention variables that influenced selection likely to be associated with intervention?	Not Applicable
2.3	**If Y/PY to 2.2:** Were the post- intervention variables that influenced selection likely to be influenced by the outcome or a cause of the outcome?	Not Applicable
2.4	Do start of follow-up and start of intervention coincide for most participants?	Probably Yes
2.5	**If Y/PY to 2.2 and 2.3, or N/PN to 2.4:** Were adjustment techniques used that are likely to correct for the presence of selection biases?	Probably Yes
	Risk of bias judgement in selection of participants into the study	Low
3	**Bias in classification of interventions**	
3.1	Were intervention groups clearly defined?	Yes
3.2	Was the information used to define intervention groups recorded at the start of the intervention?	Yes

S.No.	Items	Maas et al., 2015
3.3	Could classification of intervention status have been affected by knowledge of the outcome or risk of the outcome?	Probably No
	Risk of bias judgement in classification of interventions	Low
4	**Bias due to deviations from intended interventions**	
4.1	Were there deviations from the intended intervention beyond what would be expected in usual practice?	Probably Yes
4.2	**If <u>Y/PY to 4.1</u>:** Were these deviations from intended intervention unbalanced between groups and likely to have affected the outcome?	Probably Yes
4.3	Were important co-interventions balanced across intervention groups?	No Information
4.4	Was the intervention implemented successfully for most participants?	No Information
4.5	Did study participants adhere to the assigned intervention regimen?	No Information
4.6	**If <u>N/PN to 4.3, 4.4 or 4.5</u>:** Was an appropriate analysis used to estimate the effect of starting and adhering to the intervention?	No Information
	Risk of bias judgement due to deviations from intended interventions	No Information

S.No.	Items	Maas et al., 2015
5	**Bias due to missing data**	
5.1	Were outcome data available for all, or nearly all, participants?	Yes
5.2	Were participants excluded due to missing data on intervention status?	Probably No
5.3	Were participants excluded due to missing data on other variables needed for the analysis?	Probably No
5.4	**If PN/N to 5.1, or Y/PY to 5.2 or 5.3:** Are the proportion of participants and reasons for missing data similar across interventions?	Not Applicable
5.5	**If PN/N to 5.1, or Y/PY to 5.2 or 5.3:** Is there evidence that results were robust to the presence of missing data?	Not Applicable
	Risk of bias judgement due to missing data	Low
6	**Bias in measurement of outcomes**	
6.1	Could knowledge of the intervention received have influenced the outcome measure?	Probably No
6.2	Were outcome assessors aware of the intervention received by study participants?	Probably Yes
6.3	Were the methods of outcome assessment comparable across intervention groups?	Probably Yes
6.4	Were any systematic errors in measurement of the outcome related to intervention received?	No
	Risk of bias judgement in measurement of outcomes	Low

S.No.	Items	Maas et al., 2015
7	**Bias in selection of the reported result**	
7.1	Is the reported effect estimate likely to be selected, on the basis of the results, from multiple outcome measurements within the outcome domain?	Probably Yes
7.2	Is the reported effect estimate likely to be selected, on the basis of the results, from multiple analyses of the intervention-outcome relationship?	Probably Yes
7.3	Is the reported effect estimate likely to be selected, on the basis of the results, from different subgroups?	Probably Yes
	Risk of bias judgement in selection of the reported result	Low
	Overall Risk of bias judgement	Moderate

3.3 Review Question-1: What are the various intervention techniques used for AOS?

The 37 studies have used various intervention techniques for AOS such as melodic intonation therapy (MIT), sound production treatment (SPT), articulatory kinematic treatment, modified phonomotor treatment program, electropalatography, motor learning guided (MLG), transcranial direct current stimulation (tDCS), masked auditory feedback (MAF), altered auditory feedback (AAF), rate & rhythm control treatment, repetition-based training, verb network strengthening treatment (VNeST), Custom-built Word Trainer app, combined aphasia and apraxia of speech Treatment (CAAST), Self-administered computer therapy noise masking, repetitive transcranial magnetic stimulation (rTMS), ultrasound visual feedback, implicit phoneme manipulation, oral reading treatment and speech music therapy for aphasia (SMTA).

Table 3.10

Various intervention techniques used by authors in selected 37 articles

S.No.	Authors	Intervention Techniques used by the Author
1.	Mauszycki et al. (2016)	Articulatory kinematic treatment in conjunction with VBFB via EPG
2.	Mauszycki et al. (2020)	Articulatory kinematic treatment in conjunction with VBFB via EPG Vs. SPT
3.	Bislick et al. (2020)	Modified Phonomotor Treatment Program
4.	Mauszycki et al. (2016)	MIT
5.	Wambaugh et al. (2020)	SPT
6.	Wambaugh et al. (2018)	SPT

7.	Wambaugh et al. (2013)	SPT
8.	Johnson (2018)	MLG treatment
9.	Johnson et al. (2018)	MLG treatment
10.	Marangolo et al. (2013)	Tdcs + speech-language therapy
11.	Jacks et al. (2015)	MAF & AAF
12.	Wambaugh et al. (2012)	Repeated practice treatment, Articulatory-kinematic treatment & rate/ rhythm control treatment
13.	Buchwald et al. (2017)	Repetition-based training
14.	Nealon et al. (2021)	VNeST
15.	Ballard et al. (2019)	Custom-built Word Trainer app
16.	Zumbansen et al. (2014)	MIT
17.	Wambaugh et al. (2017)	SPT
18.	Wambaugh et al. (2021)	SPT
19.	Wambaugh et al. (2014)	SPT
20.	Wambaugh et al. (2016)	SPT
21.	Wambaugh et al. (2014)	CAAST
22.	Wambaugh et al. (2018)	CAAST
23.	Bunker et al. (2018)	CAAST
24.	Themistocleous et al. (2021)	Tdcs
25.	Wang et al. (2019)	tDCS
26.	Zhao et al. (2022)	tDCS
27.	Pisano et al. (2021)	tDCS

28.	Whiteside et al. (2012)	Self-administered computer therapy Vs. visuo-spatial sham
29.	Maas et al. (2015)	Masked Auditory feedback
30.	Preston et al. (2014)	Ultrasound visual feedback
31.	Farias et al. (2014)	Implicit phoneme manipulation
32.	Mozeiko et al. (2020)	SPT
33.	Johnson et al. (2018)	MLG treatment
34.	Henry et al. (2013)	Oral reading treatment
35.	Buchwald et al. (2020)	tDCS
36.	Malfitano et al. (2019)	rTMS
37.	Hurkmans et al. (2015)	SMTA

NOTE: VBFB- Visual Biofeedback, EPG- Electropalatography, SPT- Sound Production Treatment, MIT- Melodic Intonation Therapy, MLG- Motor Learning Guided, tDCS- Transcranial Direct Current Stimulation, MAF- Masked Auditory Feedback, AAF- Altered Auditory Feedback, VNeST- Verb Network Strengthening Treatment, CAAST- Combined Aphasia and Apraxia of Speech Treatment, rTMS- Repetitive Transcranial Magnetic Stimulation, SMTA- Speech Music Therapy for Aphasia

3.4 Review Question-2: Which is the most frequent intervention technique used for AOS?

Table 3.10 provides a list of various AOS intervention techniques used by the study's authors. The interventions approaches used in the thirty-eight papers that met the criteria for inclusion are discussed below.

Eight researches have used the Sound Production treatment (SPT) in the intervention of AOS (Wambaugh et al., 2013, 2014, 2016, 2017, 2018, 2020, 2021 and Mozeiko et al., 2020). SPT is an articulatory-kinematic treatment that has received more extensive and systematic study than any other treatment for AOS (Duffy, 2005; Wambaugh, 2002; Wambaugh et al., 2006). Positive results in articulation have been consistently noticed for treated sounds in trained and untrained utterances produced outside the context of treatment.

Six studies used Transcranial direct current stimulation for the treating people with AOS (Marangolo et al., 2013; Wang et al., 2019, Buchwald et al., 2020, Themistocleous et al., 2021, Pisano et al., 2021, Zhao et al., 2022). Two electrodes positioned on the scalp administered a weak polarizing direct current by transcranial direct current stimulation (tDCS) to the cortex. It has been applied in several studies on language recovery in poststroke aphasia and probed as a possible adjuvant to influence different aspects of language processing, such as speech fluency, repetition abilities, picture naming (Baker et al., 2010; Hamilton et al., 2011; Holland & Crinion, 2012; Monti et al., 2013), and lexical retrieval of action words (Branscheidt et al., 2018).

Three studies have used the Motor Learning Guided (MLG) treatment for treating individuals with acquired AOS (Johnson, 2018; Johnson et al., 2018 & Johnson et al., 2018). MLG approach is the first treatment approach introduced based on the principles of motor learning. The practice schedule and the type of clinician feedback used in the Motor Learning Guided (MLG) approach are different from those used in more conventional articulatory kinematic treatment regimens. The main variations include the utilization of serial repeated production as employed in conventional articulatory treatment protocols in place of an imposed 2-3s pause-time between productions. The participant is instructed to review their output before

creating their next one during this break. The kind and quantity of increased feedback is another obvious distinction between the treatment protocol's two approaches. A high level of clinician assistance is used in traditional therapy methods, along with frequent knowledge of performance comments. This input may include modeling, biofeedback, integral stimulation, and/or placement cues, depending on the patient's performance (e.g., Sound Production Treatment, Phonetic Placement Treatment, Eight Step continuum).

Three researches have used Combined Aphasia and Apraxia of Speech Treatment (CAAST) to study its efficacy in AOS intervention (Wambaugh et al., 2014,2018, Bunker et al., 2018). The primary goal of CAAST is to increase verbal language productivity by facilitating the elaboration of patient-initiated productions; flexible and generalized language use is expected (Kearns, 1985). The approach was advantageous due to the fact that AOS is typically accompanied with Aphasia.

Two researchers used Melodic intonation therapy (MIT). Mauszycki et al. (2016) used MIT to facilitate the production of wh-questions and articulatory accuracy. Limited improvement was observed for both participants. Zumbansen et al. (2014) observed the effect of both rhythm and pitch in the efficacy of original MIT.

Mauszycki et al. (2016, 2020) have used electropalatography for treating people with AOS. Articulatory-kinematic treatment was used in conjunction with visual biofeedback (VBFB) via electropalatography (Mauszycki et al., 2016). Positive results were observed in articulation accuracy for most of the treated speech sounds. Mausycki et al. (2020) compared two intervention approaches for AOS i.e., the articulatory-kinematic approach in conjunction with visual biofeedback (VBFB) via electropalatography with that of Sound Production Treatment. Positive effects were noticed in both the treatments. Moreover, In SPT participants

achieved greater articulatory accuracy during the treatment and had better long-term maintenance.

Two researches have used masked auditory feedback (MAF) for AOS to reduce auditory feedback during speech (Maas et al., 2015). The study aimed to test the two hypotheses about AOS derived from DIVA model: the feedforward system deficit hypothesis and the feedback system deficit hypothesis. Jacks et al. (2015) investigated the effects of masked auditory feedback (MAF) on speech fluency in adults with aphasia and/or apraxia of speech (APH/AOS), with comparison to altered auditory feedback (AAF). They hypothesized that individuals with AOS would increase speech fluency when speaking with noise, and that altered auditory feedback (AAF) would not improve speech fluency.

Wambaugh et al. (2012) have used repeated practice treatment, articulatory-kinematic treatment & rate/ rhythm control treatment in treating AOS. Repeated practice is a component of AOS therapy, regardless of overall approach (Wambaugh et al., 2006b). Repeated practice has been shown to be an important component of learning nonspeech motor skills (Schmidt & Lee, 2005), and it is expected to be important in the rehabilitation of people with AOS.

Bislick et al. (2020) used the Phonomotor Treatment (PMT) Program for the intervention of AOS. Findings showed that modified PMT could better generalize and maintain trained speech targets via a multimodal approach.

Only one research studied repetition-based training in the intervention of individuals with AOS (Buchwald et al., 2017). There is a decrease in motor planning errors following repetition-based practice structured according to principles of motor learning.

One literature work has used self-administered computer therapy (Whiteside et al., 2012). The study used block randomization of the participants to either speech first (SPF) or sham first (SHF) conditions and then noticed the results.

One research study used Verbal Network Strengthening Treatment (VNeST) for the intervention of AOS (Nealon et al., 2021). This treatment aimed to activate the semantic, lexical, and syntactic connections between verbs and their thematic roles (Edmonds, 2014).

One literature work has used a custom-built word trainer app to treat individuals with AOS (Ballard et al., 2019). The app was installed onto their personal iPads. The app used Automatic Speech Recognition (ASR) to recognize the target words and progress the participant to a prompt to attempt production of a sentence containing that target word.

Preston et al. (2014) have used Ultrasound visual feedback to provide knowledge of performance to individuals with AOS. Ultrasound is a more widely available and less-invasive technology than electromagnetic articulography. Within the last ten years, articulation problems in children, adults, and those with hearing loss have been corrected using ultrasound visual feedback (Adler-Bock et al., 2007; Bacsfalvi, 2010; Bacsfalvi & Bernhardt, 2011; Bacsfalvi et al., 2007; Bernhardt et al., 2005; Bernhardt et al., 2005; Bernhardt et al., 2003; Fawcett et al., 2008; Modha et al., 2008).

Farias et al. (2014) used an implicit protocol that activates speech motor areas via inner speech in treating AOS. This method was derived from early models on inner speech. In order to create a new word, implicit phoneme manipulation needs the participant to covertly move and combine phonemes. Fully conscious inner speech is a self-monitoring mechanism that is used in this process.

Henry et al. (2013) implemented a treatment method using structured oral reading as a tool for improving multisyllabic word production with mild AOS and non-fluent variant Primary Progressive Aphasia. The study also highlighted the potential benefits of using structured oral reading as a treatment method.

Malfitano et al. (2019) investigated the effects of repetitive transcranial magnetic stimulation (rTMS) in persons with AOS. The rTMS treatment targeted the pre-central gyrus, inferior frontal gyrus (Broca's area), and rolandic operculum, which were the areas of the brain most affected by the patient's stroke. They also reported that rTMS is a safe and non-invasive treatment option for AOS with no significant side effects. The authors suggest that rTMS may be a promising approach for treating AOS in other patients, but further research is needed to confirm its effectiveness and optimal treatment parameters.

Hurkmans et al. (2015) investigated the effectiveness of Speech-Music Therapy for Aphasia (SMTA) in individuals with AOS and Aphasia. SMTA integrates speech therapy and music therapy.

3.5 Review Question-3 What is the evidence reported for various AOS intervention techniques?

3.5.1 Intervention techniques for AOS

Apraxia of Speech (AOS) is referred to as an impairment in spatial and temporal planning and/or programming of movements required for speech production and is characterized by slowness in speech rate with phoneme distortions, substitutions of the phoneme, and a tendency to segregate speech into individual syllables and they also tend to equalize stress across adjacent syllables (Duffy, 2013). Numerous authors have contributed to

a variety of intervention strategies, and there is a wealth of literature available for the treatment of AOS.

Mauszycki et al. (2016) studied the effects of articulatory-kinematic treatment in conjunction with electropalatography (EPG) treatment on speech production accuracy and consistency in individuals with AOS. The study involved 10 participants with AOS who received EPG treatment in home setup. The study consisted of three treatment phases. In the first phase, each participant received instruction on how to speak using the experimental speech sound for that treatment set in bi-syllabic syllables. The subject proceeded to the subsequent treatment phase when the treatment criterion was satisfied. The participant delivered the first phase's bi-syllabic word together with the previous one-syllable word in the second phase. The participant alternated between creating the two-word treatment phrases and two-word filler phrases in the third phase. The outcomes demonstrated that EPG therapy enhanced speech production consistency and accuracy in those with AOS. Between 1.94 to 5.50 was the range of effect sizes for the generalization items in both the treatment phase and the follow-up phase. According to the study, receiving therapy was linked to a change in speech production accuracy of at least 49%. The study provides valuable insights into the use of EPG treatment for AOS and highlights the need for further research in this area.

Mauszycki et al. (2020) compared the effectiveness of two treatment approaches for AOS and aphasia: electropalatography treatment (EPG) and sound production treatment (SPT). The study involved two participants with chronic AOS and aphasia. The treatment protocol consisted of 48 sessions (24 sessions for each treatment approach) over 18 weeks. The study used a multiple-baseline design across behaviors to evaluate the effects of each treatment approach on articulatory accuracy, speech intelligibility, and communication efficiency. The

results showed that both EPG and SPT led to positive changes in articulatory accuracy, speech intelligibility, and communication efficiency. However, SPT produced greater gains in articulatory accuracy and communication efficiency than EPG. The study also found that the positive effects of SPT were maintained in the long-term follow-up. The authors suggest that SPT may be a more effective treatment approach for individuals with chronic AOS and aphasia, and that the use of self-evaluation and feedback may be beneficial for treatment outcomes.

Bislick, L. (2020) used modified Phonomotor Treatment Program on two participants with AOS and aphasia, involving a series of tasks that targeted different aspects of speech production, including phoneme production, syllable production, word production, and sentence production. The treatment also included the use of Socratic questioning to facilitate self-monitoring and self-correction of errors, rather than the use of corrective feedback. The treatment was delivered by a trained speech-language pathologist. The study found that the modified Phonomotor Treatment Program was effective in improving motor planning in both participants, as evidenced by improvements in accuracy of production of trained and untrained targets. The study also found that the treatment effects were maintained at follow-up, indicating that the treatment had lasting effects. The study also found that the treatment resulted in clinically significant improvements in sound production accuracy, as measured by percent change above highest baseline performance. According to the study's findings, people with AOS may benefit from the modified Phonomotor Treatment Program because it repeatedly exposes and practices speech information using a multimodal approach, promoting generalization and preservation of treatment benefits for taught speech targets. According to the study, treating both verbal processing and motor planning deficiencies at once is probably more successful and efficient. The study also emphasizes the demand for successful therapies

that concurrently address AOS and aphasia. Overall, this study supports the possibility of treating the speech and language deficits brought on by AOS and aphasia at the same time. The findings of this study have important implications for the development of effective treatments for individuals with AOS and aphasia.

In a study conducted by Wambaugh et al. (2012), the effects of repeated practice treatment were examined on 10 participants diagnosed with acquired AOS. These participants underwent extensive practice sessions with 32 different sets of experimental stimuli. The results showed that the extent of improvement varied among participants, and some individuals achieved significant progress through repeated practice treatment alone. However, for most participants, additional treatment in the form of rate/rhythm control was necessary. This was because high levels of production accuracy made it difficult to apply rate/rhythm treatment fully, with only two participants benefiting entirely and two others experiencing partial benefits. The study also observed that the positive effects of treatment persisted over time for the majority of participants, with some individuals continuing to show improvement even after the treatment had concluded. However, two participants did not exhibit any changes in the accuracy of their speech production in response to either treatment. The study suggested that the complexity of the stimuli used in the study might have posed challenges for these individuals, potentially affecting their ability to generalize accuracy levels during the baseline assessment. In summary, the study underscores the significance of repeated practice treatment in enhancing articulation accuracy in individuals with acquired apraxia of speech. Additionally, it highlights the potential advantages of incorporating rate/rhythm control treatment to further enhance the overall effectiveness of therapy.

Buchwald et al. (2017) aimed to investigate the relationship between error types and improvements in cluster production following repetitive speech motor learning practice sessions among individuals diagnosed with aphasia and AOS. The study involved four participants, with two of them displaying errors that were indicative of a phonological source, while the other two exhibited errors stemming from a motoric origin. These participants received training focused on a set of words containing clusters that posed challenges for them due to their speech production difficulties. During the training, they repeatedly practiced these target words while receiving feedback from a clinician, with the goal of enhancing their ability to accurately and fluently produce the target clusters. Additionally, the study sought to investigate whether this repetition-based intervention could bring about improvements in the production of both the trained words and untrained items in individuals with aphasia and AOS. The findings indicated that the two participants with motoric errors demonstrated enhancements in their production of both trained and untrained items. In contrast, the two participants with phonologically-driven errors did not show any improvement in their performance during the repetition training task. Consequently, the study suggests that analyzing the acoustic properties of deletion errors can serve as a predictive factor for determining who would benefit from a repetition-based intervention. However, it's important to note that the study had certain limitations, including a lack of experimental control and a limited analysis of error types. Nevertheless, it does offer a valuable metric for identifying the underlying sources of sound production errors in individuals coping with both apraxia of speech and aphasia, potentially aiding in the identification of predominant error types in individuals with complex speech deficits.

A study by Nealon et al. (2021) aimed to assess whether engagement with the Verb Network Strengthening Treatment (VNeST) had an impact on speech production errors in individuals who had both AOS and aphasia. The study involved four participants, each with varying types and degrees of aphasia and AAOS. The VNeST protocol was utilized to facilitate lexical retrieval and support the generation of thematic roles associated with specific trained verbs. The results of the study indicated that the treatment had positive effects on certain aspects of speech production. These improvements encompassed segmental speech errors, the ability to segment syllables, and reductions in false starts and pauses during speech. However, the participants' gains in the production of the correct number of syllables were observed in only one participant. Another participant did not exhibit increased accuracy in any measure of speech production. The remaining two participants displayed significant decreases in syllable segmentation, a characteristic that has been recognized as diagnostically relevant for AOS. The protocol involves a hierarchy of linguistic tasks, ranging from single words to sentences and discourse, and it has previously demonstrated improvements in lexical retrieval of untrained words across these tasks. Notably, the VNeST protocol was not specifically designed to target sound-level or speech-production errors directly. However, it appeared to have the potential to facilitate speech production among individuals with aphasia and AOS. In conclusion, the study suggests that VNeST could be a promising treatment approach for individuals with dual diagnoses of AOS and aphasia. Nonetheless, further research is necessary to ascertain its efficacy and applicability across a broader range of cases.

Ballard et al. (2019) evaluated the efficacy of an iPad-based speech therapy app that provides feedback on voice correctness using Automatic Speech Recognition (ASR) software. This study specifically focused on patients dealing with both AOS and aphasia. The research

involved a relatively small sample of five participants who were instructed to complete 20 therapy sessions per week, totaling up to 400 trials. They had the flexibility to arrange these sessions in either the traditional format of one hour per day, four times per week, or in a manner that suited their individual schedules. Additionally, one in-person session per week was offered, either by Skype or in a clinical setting. The study found that using ASR to give mild to moderate AOS patients who were having self-administered speech therapy better feedback on word production accuracy was beneficial in encouraging high-intensity practice. Furthermore, the results demonstrated robust maintenance of treatment effects over the course of one month. However, it's important to note that the study posed certain limitations, such as small sample size and the absence of item-specific feedback during testing. As a result, the authors suggest for future research endeavors should aim to enhance the experimental design and compare this approach to other models of therapy delivery.

Bunker et al. (2018) sought to describe the lexical and morphosyntactic alterations connected to increases in content generation in non-fluent aphasic patients who received Combined Aphasia and Apraxia of Speech Treatment (CAAST). CAAST is a treatment approach that blends elements from existing protocols for addressing language deficits linked to non-fluent aphasia and speech production deficits related to AOS. The effectiveness of CAAST was evaluated through a range of measures assessing morphosyntactic production and complexity. Frequency counts, the percentage of closed-class words, the ratio of nouns to pronouns, the ratio of nouns to verbs, the determiner index, the percentage of inflected verbs, the complexity index, the percentage of well-formed sentences, the percentage of words occurring in sentences, the average sentence length, the average number of embeddings per

sentence, and the average length of utterance were some of the measurements used. The results of the study showed that CAAST was effective in boosting many facets of morphosyntactic complexity and production, displaying benefits for both the treated and untreated language sets. Improvements were shown, specifically, in metrics like the percentage of closed-class words, the overall auxiliary score, the percentage of well-formed sentences, the average length of an utterance, and other pertinent variables. However, there were minimal changes in terms of lexical diversity. Additionally, the study noted that these improvements generally remained consistent at similar levels during the 6-week follow-up period, suggesting the durability of the treatment effects over time.

In their study, Wambaugh et al. (2020) MIT's effectiveness in enhancing verbal production in people with aphasia, with an emphasis on deficiencies in sentence creation, was examined. Their study involved two individuals diagnosed with chronic Broca's aphasia and acquired apraxia of speech. The researchers implemented MIT within the context of a multiple baseline design. The study initially introduced the linguistic principles that underpin MIT and explained how these principles can guide treatment for individuals experiencing difficulties with producing sentences. Furthermore, the experiment included one participant who had chronic moderate to severe Broca's aphasia and apraxia of speech due to a stroke. The results of the study demonstrated that after 16-22 treatment sessions, the participants achieved high levels of production accuracy in the trained sentence structures. Interestingly, the generalization of improvements to untrained sentence constructions began to emerge after approximately 12 treatment sessions. This suggests that MIT can be applied in a linguistically principled manner and may hold promise as an effective therapeutic approach for individuals with aphasia. However, the study also underscores the need for further research to gain a more comprehensive

understanding of the effects of MIT on individuals with aphasia and to explore its potential benefits in a broader range of cases.

In their study, Wambaugh et al. (2018) explored how treatment intensity affected patients with acquired AOS's results. They focused on the efficacy of Sound Production Treatment (SPT) for those with persistent AOS and aphasia. Incorporating modelling and repetition, contrastive practice, orthographic cues, integral stimulation, and articulatory cues, SPT is an AOS therapy that focuses on articulatory-kinematic features. SPT also includes verbal feedback and repeated repetition. The treatment was administered using a response-contingent hierarchy, which included presenting an audio-visual model of the word or phrase and requesting the participant to repeat it. For monosyllabic words, sub-steps of the hierarchy were employed to facilitate contrastive practice when incorrect production occurred. In the case of multisyllabic words, contrastive practice was omitted, and the next step was undertaken. In order to evaluate the impact of treatment intensity on outcomes for people with acquired AOS, the research included both an intense and a non-intense application of SPT. The research involved 12 participants with chronic AOS and aphasia who received SPT. These participants were divided into two groups: an intense treatment group and a non-intense treatment group. Both groups underwent 24 sessions of SPT over an 8-week period. However, the intense group received three sessions per week, while the non-intense group received one session per week. Using a single word speech intelligibility technique, the study assessed the precision of articulation for target sounds within treated and untreated experimental words. The results indicated that both groups exhibited improvements in articulation accuracy. However, the non-intense treatment group demonstrated better preservation of the achieved improvements over time.

Wambaugh et al., (2013) delved into the effects of different treatment intensities and practice schedules on articulation accuracy in individuals living with chronic AOS and aphasia. The primary focus was on assessing the utility of sound production treatment (SPT) in addressing AOS. The study yielded positive outcomes for all participants, suggesting that various treatment approaches could yield similar improvements in articulation accuracy. It was found that intensive treatment regimens were feasible for individuals with AOS, and participants expressed enthusiasm for the intensive treatment, despite the significant time commitments it required. However, it was noted that certain medical or individual factors might make intensive treatment less suitable. It's worth noting that the participants in this study were relatively young and generally healthy, which may not be representative of the broader population of individuals with AOS and aphasia. Fatigue during intensive treatment was a concern for only one participant. The research indicated that both traditional and intensive applications of SPT led to comparable outcomes in terms of articulation accuracy for both trained and untrained words. The effect sizes observed in the study were consistent with those reported in previous investigations involving SPT. However, the study didn't provide an interpretation of the magnitude of these effect sizes, as there isn't an appropriate comparative metric available for AOS treatments. Additionally, the study highlighted that effect sizes during the traditional-random treatment phases were relatively lower for two participants compared to their other treatment phases. This suggests that the effectiveness of treatment may vary among individuals. In conclusion, the study has implications for treatment approaches that employ similar techniques, emphasizing the need for further research to determine the most effective treatment strategies for individuals with AOS.

Mauszycki & Wambaugh (2020) investigated the use of Melodic Intonation Therapy (MIT) as a means to enhance verbal production in adults with aphasia, particularly in the context of difficulties related to sentence production. The study involved two participants: one with chronic Broca's aphasia and the other with AOS. The application of MIT focused on wh-questions, guided by the linguistic principles that underlie MIT. These principles influenced the selection of treatment items and the measurement of generalization effects. The study assessed the production of wh-questions and articulatory accuracy, measured as the percentage of correctly articulated consonants in wh-question production. The findings of the study indicated that after 16-22 treatment sessions, both participants achieved high levels of accuracy in producing the trained sentence constructions. Moreover, generalization to untrained sentence constructions became evident after approximately 12 treatment sessions. The study highlighted the potential of MIT in improving articulatory accuracy and sentence production skills in individuals with chronic aphasia and AOS. Furthermore, the study discussed previous research on the effects of MIT in individuals with aphasia and emphasized the need for further investigations to gain a more comprehensive understanding of the specific mechanisms behind generalization effects associated with MIT. In summary, the study suggested that MIT can be a valuable treatment approach for individuals with aphasia who struggle with sentence production deficits, showcasing its potential to enhance articulatory accuracy and overall language skills in this population.

Johnson et al. (2018) focused on investigating the impact of practice frequency and the number of targets on speech-motor learning (MLG treatment) in individuals with acquired AOS. To examine these effects, a multiple baseline design was employed across participants, behaviours, and conditions. The study involved two participants: a 61-year-old male (P1) who

had experienced a left hemisphere stroke 19 months prior, and a 55-year-old male (P2) who had bilateral embolic strokes 28 months prior. Both individuals presented with chronic AOS and aphasia. P1 and P2 both exhibited moderate to severe AOS, as assessed through the Apraxia Battery of Adults-2 (ABA-2) and the Apraxia of Speech Rating Scale (ASRS-VI). They were also categorized as having Broca's aphasia based on the Western Aphasia Battery-Revised (WAB-R), with functional reading skills determined through the reading subtests of the WAB-R. Treatment sessions were conducted twice a week, each lasting 60 minutes, and took place in a university clinic. The study's results revealed improvements in speech-motor learning for both participants, regardless of whether they received a high or low frequency of practice. Mean retention ratings for the high-frequency phrases were slightly higher than those for the low-frequency phrases. Treatment effect sizes were notably large for both treated and untreated phrases, indicating the robustness of the treatment's impact. Social validity measures also indicated positive changes in communication effectiveness for both participants. In conclusion, the study provided support for the effectiveness of the motor learning guided treatment approach for individuals with acquired AOS. The observed data patterns suggested that speech-motor learning, rather than mere practice effects, played a significant role in the participants' progress. This study's differentiation from traditional treatment approaches was notable due to its use of varied stimuli and phrases as stimuli.

Wambaugh et al. (2014) examined the effectiveness of the Aphasia and AOS Treatment (CAAST) in helping people with chronic aphasia and AOS produce words and sentences more fluently. The study involved four participants with ages ranging from 36 to 72 years, all of whom presented with agrammatic aphasia and had been diagnosed with either Broca's aphasia or anomic aphasia. CAAST, the intervention utilized in the study, consisted of a predetermined

number of treatment sessions, with 20 sessions allocated per treatment phase (i.e., per experimental set). The study's findings showed that CAAST significantly improved the creation of accurate information units (CIUs) for treated photo sets. Moreover, positive generalization effects were observed, extending to untreated picture sets and discourse samples. That means, CAAST can be an effective approach of treatment for individuals with aphasia and AOS, particularly in terms of improving CIU production for treated picture sets. The study also hinted at the possibility that CAAST might be more efficacious in achieving these outcomes compared to traditional treatments like Response Elaboration Training (RET) and Modified RET (M-RET). This finding underscores the potential benefits of CAAST in addressing the communication challenges faced by individuals with chronic aphasia and AOS. In summary, the study provides evidence of the positive effects of CAAST on language and speech production, highlighting its potential as a valuable treatment option for individuals dealing with these communication disorders.

Wambaugh et al. (2016) evaluated the impact of blocked and random practice on the production of multisyllabic words in individuals with acquired AOS. The goal was to determine which practice schedule was more effective in enhancing speech production accuracy and promoting the generalization of treatment effects. The study recruited four participants, two women and two men, with chronic acquired AOS and Broca's aphasia. At the outset of the study, the participants were at varying intervals ranging from 17 to 259 months after onset of a single left-hemisphere stroke. Participants were native speakers of English, aged between 37 and 83 years. They all passed hearing screening test. The intervention used in the study was Sound Production Treatment (SPT), which involves a structured hierarchy of tasks increasing in complexity, starting from single sounds and progressing to multisyllabic words and phrases.

Participants received SPT under two different practice schedules: blocked and random. In the blocked practice schedule, participants practiced producing the same set of words in a fixed order, while in the random practice schedule, they practiced producing different words in a random order. The study's findings indicated that both the blocked and random practice schedules resulted in improvements in speech production accuracy for all participants. However, the random practice schedule was found to be more effective in sustaining these gains over time. Furthermore, the study revealed that the extent of response generalization to untreated words which was varied among individuals. Three participants showed positive stimulus generalization to the production of words when completing sentences, whereas two participants showed positive stimulus generalization to the creation of phrases. In summary, the study contributes valuable data regarding the effectiveness of SPT in improving articulation in treated items and extends our understanding of the impact of the therapy on several targets in multisyllabic words.

Two years later, Wambaugh et al. (2018) established CAAST as a revolutionary therapeutic strategy for those who have both aphasia and AOS. The study featured four adult participants with chronic aphasia and AOS, referred to as P1, P2, P3, and P4. Following the implementation of CAAST, the study reported substantial increases in the production of correct information units (CIUs) for all participants, both for treated and untreated sets of experimental pictures. It's significant that these increases in CIU production persisted throughout follow-up tests done two and six weeks after therapy. Furthermore, the study observed variations in speech production improvements across the individual participants. The study used CDC criteria, which were satisfied during both treatment periods. This suggests that the therapy was connected with a systematic increase in performance. During the treatment periods, effect size

studies for Sets 1 and 2 showed substantial effect sizes. Set 1 showed a medium effect size in the follow-up phases, whereas Set 2 showed a significant impact size. However, a negligible effect size was obtained for the untreated set. In conclusion, the authors suggested that the revised CAAST protocol yielded promising results in terms of betterment in speech production for individuals with both aphasia and apraxia of speech. This treatment approach showed encouraging outcomes, particularly in enhancing CIU production and maintaining these gains over time.

Johnson et al. (2018) assessed verbal motor acquisition in people with acquired AOS who received motor learning-guided therapy by comparing multiple outcome measures. The study included two participants diagnosed with acquired AOS and employed a treatment protocol consisting of three stages. The first stage of the treatment involved presenting stimuli in written form along with a clinician model, followed by the participants producing the stimuli. Subsequent stages (second and third) were similar to the first stage, except for the absence of an initial clinician model and an increased pause-time between productions in the third stage. Speech productions during baseline, retention, and maintenance measurements were the study's dependent variables, and they were first scored using an 11-point multidimensional rating scale. To assess speech motor learning, the researchers employed different outcome measures, including the multiple dimension rating scale, articulatory kinematic analysis, and a speech intelligibility test. The study's findings revealed that the multiple-dimension rating scale was the most effective outcome measure for evaluating speech-motor learning in AOS when using motor learning guided treatment. As seen by a decline in performance just after treatment assistance, the study also showed that improvements in speech-motor learning were subsequent to the intervention. In conclusion, this study offers insightful information on the efficacy of

multiple outcome measures for evaluating speech motor learning in patients with acquired AOS receiving motor learning-directed therapy. These findings have practical implications for clinical practice and can inform the treatment of persons having acquired AOS.

Marangolo et al. (2013) aimed to determine if bihemispheric stimulation may improve language recovery in those with chronic aphasia and AOS, especially in terms of language articulation. The study involved 10 participants who had been living with chronic aphasia and AOS. During the study, these patients received 10 sessions of bihemispheric transcranial direct current stimulation (tDCS) applied over both the left and right inferior frontal regions of the brain. The researchers assessed the effectiveness of bihemispheric tDCS on aphasia recovery by employing a standardized language test. This exam includes a variety of linguistic activities, including visual descriptions, verb and noun repetition, reading and writing while being dictated to, matching pictures to words, and understanding simple instructions. The study's results revealed several positive outcomes. Bihemispheric tDCS was found to significantly reduce articulatory errors in patients and also led to improvements in their performance across various oral language tasks. Importantly, these improvements were sustained at follow-up assessments and were observed to generalize to other language tasks. Overall, the study suggested that bihemispheric tDCS holds promise as a potential tool for the treatment of chronic aphasia. The results provided hope for better communication skills and quality of life for people with long-term aphasia by showing that this type of brain stimulation may have a positive influence on language articulation and rehabilitation in these people.

Jacks et al. (2015) explored the effects of masked auditory feedback (MAF) on speech fluency in adults with aphasia and/or apraxia of speech (APH/AOS), comparing them to the effects of altered auditory feedback (AAF). The researchers aimed to investigate how these

feedback conditions impacted syllable rate, disfluency duration, and vocal intensity, and they also compared the responses of individuals with APH/AOS to those of neurologically healthy (NH) participants. The study included ten adult participants with APH/AOS, of which eight had AOS, and two had aphasia. Additionally, ten NH participants were included in the study. The participants with APH/AOS were recruited from a speech and language clinic, while the NH participants were recruited from the community. The APH/AOS participants had diverse etiologies, including stroke, traumatic brain injury, and degenerative disease. All participants were native English speakers with no history of hearing loss or other neurological disorders. The researchers employed modified auditory feedback, specifically masked auditory feedback (MAF) and altered auditory feedback (AAF). The study used an ABACA design, where A and C conditions involved normal auditory feedback (NAF), while B conditions involved modified feedback (either MAF or AAF). Participants in the study created sentences using an ABACA paradigm, with NAF in the A conditions and modified feedback in the B and C conditions, according to a treatment introduction and withdrawal design. Twenty sentence trials were used in each experimental phase, with the stimuli coming from the Harvard sentences corpus and being given in a random sequence. According to the study's findings, some people with APH/AOS may become more fluent while speaking with masked auditory feedback (MAF). Seven of the ten APH/AOS individuals increased their fluency with masking, mostly by speaking more quickly, speaking less slowly, or doing both at once. It's noteworthy that none of the NH participants spoke faster when using MAF. However, just one APH/AOS person had better fluency in the AAF condition, whereas four APH/AOS participants and eight NH participants reduced their speech pace. In summary, the study suggests that MAF could enhance fluency in specific cases of APH/AOS, highlighting the potential role of auditory feedback

monitoring in their speech disorder presentation. The findings provide insights into how altered auditory feedback conditions can affect speech fluency in individuals with APH/AOS compared to neurologically healthy individuals.

Zumbansen et al. (2014) assessed the effectiveness of Melodic Intonation Therapy (MIT) on connected speech in individuals with Broca's aphasia AOS. Their objectives included measuring both the direct and indirect treatment effects of MIT on trained and non-trained stimuli, as well as evaluating the generalization effect on connected speech. Additionally, they aimed to assess the impact of MIT on motor-speech ability and mood. The study involved 12 participants who underwent a 4-week course of MIT treatment. The researchers conducted multiple assessments within each evaluation period, with at least a 2-day interval between assessments, to take into consideration daily differences in the overall health of the participants. Through the repetition of both trained and untrained stimuli, language outcomes were assessed, which allowed the researchers to measure direct and indirect treatment effects. The primary focus was on the improvement in connected speech, specifically discourse informativeness, assessed when completing a picture-description challenge. Adapted versions of regular tests were also used to evaluate mood and motor-speech abilities. The shift in discourse informativeness from pre-treatment to post-treatment, expressed as a percentage of Correct Information Units (CIU) in linked speech, was the study's main finding. The study's findings showed that MIT was successful in improving linked speech in people with Broca's aphasia AOS. Participants exhibited significant improvements in discourse informativeness, as well as in the number of correct syllables produced in both trained and non-trained sentences. Importantly, these improvements in connected speech were sustained at a 3-month follow-up assessment. In conclusion, this study provides evidence supporting the effectiveness of MIT in

enhancing connected speech for individuals with Broca's aphasia. The findings suggest that MIT may be a valuable treatment approach for individuals experiencing this type of language disorder, potentially improving their overall communication abilities and quality of life.

Wambaugh et al. (2017) examined how the Sound Production Treatment (SPT) for people with acquired AOS and aphasia affected by blocked and random practice regimens. Their investigation's main goal was to evaluate how well the improvements from these two practice routines were retained. Participants in the research had aphasia and chronic acquired AOS. A total of 24 individuals were included in the study, with 12 allotted to the blocked practice schedule group and 12 allotted to the random practice schedule group. The treatment targeted both monosyllabic and multisyllabic words and was administered using a response-contingent hierarchy. The results of the study showed that people with acquired AOS and aphasia significantly improved their speech production accuracy with both the blocked and random practice regimens. However, neither the level of progress nor the persistence of these gains was significantly different across the two practice programs. Furthermore, the study noted that the effect sizes, which represent the magnitude of change, were larger than the change scores themselves. This discrepancy could be attributed to the variability observed in the baseline data. In summary, the results of the study imply that both blocked and random practice regimens can help people with AOS and aphasia improve the correctness of their speech. However, the choice between these practice schedules may not significantly impact the overall outcomes or the retention of treatment gains. Additionally, the study highlights the importance of considering variability in baseline data when interpreting treatment effects.

Wambaugh et al. (2014) examined the effects of random and blocked practice in Sound Production Treatment (SPT) for acquired AOS. Six people participated in the study, including

five males and one woman. All subjects experienced a single incident of left hemisphere middle cerebral artery stroke, which led to persistent acquired AOS and Broca's aphasia. Participants were between 28- and 87 months post-stroke at the beginning of the research. They were native English speakers between the ages of 46 and 71 who had never used drugs or alcohol and had no history of mental illness or other neurological diseases than the stroke. A baseline phase and a treatment phase made up the two primary sections of the treatment procedure. Using two sets of experimental words, the accuracy of sound generation in target words was frequently assessed throughout the baseline period. Participants in the treatment phase went through a 20-session regimen for one set of words, a 2-week break from therapy, and then another 20-session regimen for the second group of words. The study's findings showed that sound production accuracy for treated sounds inside treated words significantly improved with both blocked and random practice SPT. These improvements were sustained during the follow-up period. Additionally, the study observed the generalization of treatment effects, with improvements extending to untreated words, phrases, and sentences. Importantly, the study did not find any significant differences between the blocked and random practice conditions. This suggests that both practice schedules, blocked and random, were equally effective in improving sound production accuracy in individuals with acquired apraxia of speech and Broca's aphasia. In summary, the study provided evidence that SPT, regardless of whether it was administered with blocked or random practice, had beneficial benefits on those with acquired AOS and aphasia brought on by stroke in terms of sound production accuracy. These findings contribute to our understanding of effective treatment approaches for these speech and language disorders.

Themistocleous et al. (2021) explored how individuals with primary progressive aphasia who had AOS would respond to transcranial direct current stimulation (tDCS) on sound

length. The study included 10 participants having primary progressive aphasia and AOS. The participants' ages at the start of therapy ranged from 53 to 78 years, with an average age of 65 years. The researchers utilized a combined approach involving tDCS and speech therapy. During the therapy sessions, participants engaged in oral word repetition tasks, which included repeating increasingly complex words. The tDCS or sham stimulation was administered concurrently with the speech therapy for the initial 20 minutes of each therapy session. The study's findings showed that when compared to the sham group, the group getting tDCS together with speech therapy significantly improved sound duration accuracy. This implies that using tDCS in combination with speech therapy improved sound duration accuracy in people with primary progressive aphasia who had AOS.

Wang et al. (2019) sought to ascertain which portion of the primary motor cortex (M1), located in the left lip, or Broca's area, would be more useful for anodal transcranial direct current stimulation (A-tDCS) in enhancing articulatory skills in patients with poststroke aphasia and AOS. 52 inpatients with post-stroke apraxia of speech, ranging in age from 24 to 73, were included in the research (37 males and 15 women). All participants were right-handed native Chinese speakers who had experienced a single left hemispheric stroke within 1 to 4 months prior to recruitment. They too suffered a lesion that impacted the left frontal lobe and had no prior brain traumas. Anodal transcranial direct current stimulation (A-tDCS) was used by the researchers as their intervention. Two surface saline-soaked sponge electrodes were used in conjunction with an electrical stimulator that provided a continuous current as part of the A-tDCS procedure. For 20 minutes, 1.2 mA of stimulation was applied at a certain intensity. A-tDCS over M1 (A-tDCS-M1), A-tDCS over Broca's region (A-tDCS-Broca), and a sham tDCS group (S-tDCS) were applied to the participants in turn. Various tests and assessments were

conducted to evaluate participants' articulatory abilities and neural responses. According to the study, the A-tDCS-M1 group demonstrated significant improvements in four tests compared to the A-tDCS-Broca and S-tDCS groups. No significant differences were found between the A-tDCS-Broca and S-tDCS groups. Additionally, ApEn (Approximate Entropy) indices indicated higher values in certain brain regions during word repetition after treatment. The authors concluded that A-tDCS over the left M1 might be a more effective treatment for AOS than A-tDCS over Broca's area or sham tDCS. In summary, this research suggests that targeting the left M1 with A-tDCS may offer potential benefits for individuals with poststroke aphasia and AOS, but more investigation is needed to fully explore this treatment approach.

Zhao et al. (2022) explored changes in functional connectivity after transcranial direct current stimulation (tDCS) applied to the left lip region of the primary motor cortex (M1), also in combination with speech and language therapy (SLT), in individuals with post-stroke aphasia and AOS. authors also assessed the impact of tDCS on speech function. Study recruited 24 participants who underwent initial speech evaluations, including the Boston Diagnostic Aphasia Examination-Chinese Version used to assess type and severity of aphasia, as well as the Psycholinguistic Assessment in Chinese Aphasia to evaluate auditory comprehension performance. The tDCS group had a mean age of 47.42 ± 10.87 years, while the control group's mean age was 52.17 ± 14.10 years. In the experimental setup, participants in the tDCS group received active tDCS targeting the left lip region of M1, whereas the control group received sham tDCS. Both groups underwent tDCS or sham tDCS sessions along with SLT twice daily for five continuous days. Sessions lasted 30 minutes each and started with simpler and more visible motor tasks, progressively increasing in difficulty and articulation length. The training regimen began with basic vowels, transitioned to consonants, and eventually incorporated

consonant-vowel combinations forming single syllables in Chinese characters. Subsequently, two-syllable words were introduced for repetition. The participants viewed images on a computer screen, listened to the pronunciation of simple words, repeated them two to three times, and then mimicked the speech-language pathologist's (SLP) oral movements while repeating the word. As time passed, the reliance on auditory cues, visual cues, and SLP-guided speech movement decreased, and the training shifted toward picture naming in a gradual manner. The authors found that combining tDCS with SLT yielded more substantial improvements in speech function among post-stroke aphasia participants compared to SLT alone. Both groups exhibited significant enhancements in AOS assessments compared to their baseline performance, but the tDCS group demonstrated significantly greater improvements in four out of the five subtests compared to the control group.

Whiteside et al. (2012) assessed the efficacy of a self-administered computer-based therapy aimed at improving speech accuracy and fluency in individuals with AOS. The therapy specifically targeted whole word production and included strategies to reduce errors. The study included a total of fifty participants who had AOS, and many of them also had coexisting aphasia. Participants were randomly assigned to one of two conditions: speech first (SPF) or sham first (SHF). Participants age ranged between 28 and 86 years. The self-administered computer therapy, designed to enhance whole word production while implementing error-reduction strategies, yielded significant improvements in speech accuracy and fluency among the participants. Importantly, the results indicated that the gains achieved by the SPF group were maintained over time, with significant behavioral improvements persisting for up to 18 weeks following the intervention. Moreover, there were no significant differences observed in the participants' communication ability test (CAT) scores between the beginning and end of the

study. To conclude, the study by Whiteside et al. concluded that the self-administered computer therapy, focusing on whole word production and error reduction strategies, effectively reduced struggle and groping behaviors in individuals with acquired apraxia of speech. Additionally, the research indicated that the positive treatment effects were sustained for a significant duration, up to 18 weeks post-intervention.

Maas et al. (2015) conducted a study to test two hypotheses derived from the DIVA model of speech production in individuals with AOS using auditory feedback masking. They aimed to analyze acoustic measures of vowel contrast, variability, and duration to investigate the effects of noise masking on speech production in individuals with AOS and aphasia, as well as age-matched and younger control groups. Study included three group: (1) Individuals with AOS and aphasia (12 participants), (2) Age-matched controls (12 participants), and (3) Younger controls (11 participants). All participants in the study had been diagnosed with motor speech disorders. The younger control group had no history of speech or language disorders. This was achieved by presenting speech-shaped masking noise over headphones, calibrated at 95 dB SPL. The study stated that the Individuals with AOS and aphasia exhibited a significant reduction in articulatory vowel space (AVS) and increased vowel duration in the noise masking condition compared to the unmasked condition. The younger control group showed no effect of noise masking on vowel dispersion but did demonstrate longer vowel durations in the masking condition. The reduction in AVS was greater in individuals with AOS and aphasia compared to age-matched controls. To conclude, the study provided evidence that auditory feedback masking had distinct effects on speech production in individuals with AOS and aphasia, leading to changes in vowel articulation and duration. These findings were consistent with certain hypotheses derived from the DIVA model of speech production.

In a study conducted by Hurkmans et al. (2015), they explored the effectiveness of Speech-Music Therapy for Aphasia (SMTA) in total of five individuals who had both AOS and aphasia, age ranged from 18 to 75 years. The study yielded positive results, indicating that SMTA had a beneficial impact on the participants' verbal communication in their daily lives. Specifically, significant improvements were observed in verbal communication, speech production, and language skills among all five participants. To conclude, SMTA is an effective intervention for enhancing verbal communication in daily life for individuals grappling with both AOS and aphasia.

In a study conducted by Farias et al. (2014), the main focus was on looking into the effects of an implicit-based treatment for AOS. The study included a single participant of 56 year, right-handed, college-educated, African-American male who was a native English speaker. The intervention used was an implicit-based approach, which consisted a series of tasks that required the participant to manipulate phonemes in a manner that was not explicitly related to speech production. This approach aimed to indirectly target and improve speech production abilities affected by AOS. The study's findings indicated that the implicit-based treatment for AOS led to significant improvements in the participant's ability to produce complex consonant clusters. Furthermore, the treatment resulted in the generalization of these treatment effects to simpler consonant blends. The participant also exhibited improvements in speech production accuracy and speech rate.

In the study conducted by Mozeiko et al. (2020), they examined the effectiveness of Intensive Sound Production Treatment (ISPT) for individuals with severe, chronic AOS. The treatment was administered intensively, with sessions lasting 3 hours each weekday for a duration of 2 weeks. Response times were recorded for the targeted treatment items, both at the

word level and concerning the manner of articulation. The assessment focused on evaluating the effectiveness of communication and the participant's ability to self-correct errors. Two independent raters recorded each treatment session, and initial responses were categorized as either correct or incorrect. Additionally, each way a word was pronounced within a response was individually examined. The study also tracked the number of successful and unsuccessful self-corrections made by the participants. The authors monitored the development of trained materials using various baseline measurements across different behaviors. They evaluated the precision of trained repeated productions, untrained similar exemplars, more self-corrections, and less severe aphasia. The accuracy of trained repeated productions, untrained equivalent exemplars, self-corrections, and aphasia severity were all shown to have improved. Oddly, the study found no evidence of a substantial benefit from increased repetitions of a particular articulation style. The study highlighted the importance of self-correction attempts, as these often preceded or coincided with improvements in production accuracy. This suggests that training individuals to self-correct could be valuable, especially for those who do not naturally self-correct.

In the study conducted by Johnson et al. (2018), they aimed to investigate factors influencing the effectiveness of the motor learning guided (MLG) treatment approach for AOS. The study focused on a single participant was named as BP in the study, who was a 52-year-old left-handed male. This treatment was employed for structured practice, feedback, and error correction in order to help the participant learn and refine speech movements. The treatment was done in two phases, each lasting for six weeks. In the first phase, the treatment was given by clinicians, while in the second phase, the participant had more control over the treatment process. The treatment stimuli consisted of words and phrases that were relevant to the

participant's daily life and work. The study demonstrated that the MLG treatment for AOS was effective in improving speech production in the participants with acquired AOS. The authors found mainly two factors influencing treatment outcomes, home practice and stimuli selection. To conclude, MLG treatment is an effective approach for treating AOS. The findings emphasized the importance of incorporating home practice and highlighted the significance of the specific stimuli used during treatment. The study also suggested the need for future research using experimental designs to further strengthen the evidence for MLG treatment.

In the study conducted by Buchwald et al. (2020), they looked at using transcranial direct current stimulation (tDCS) along with speech-motor learning therapy to treat those who had developed speech disability after a stroke. The study recruited six participants who had experienced speech impairment due to stroke. These participants received speech-motor learning treatment, with half of them receiving active tDCS, while the other half received sham tDCS. The treatment consisted of two phases, each lasting for two weeks. The order of treatment phases (active tDCS first or sham tDCS first) was counterbalanced across participants. The primary outcome measure was the change in speech production accuracy, quantified as the percentage of correctly produced target sounds. They found that there was a significant improvement in speech production accuracy following the speech motor learning treatment, regardless of whether the participants received active tDCS or sham tDCS. However, there was no significant difference in the magnitude of improvement between the two groups. They suggested that the study's findings provided preliminary evidence that tDCS may be a feasible adjunct to speech-motor learning treatment for stroke participants. However, the study did not identify a significant advantage of active tDCS over sham tDCS in terms of improving speech production accuracy. To conclude, this study suggests that for people with post-stroke

speech impairment, tDCS may be a useful adjunct to speech-motor learning therapy. However, the study's small sample size and the absence of a significant difference between active and sham tDCS groups underscore the need for further research to elucidate the potential advantages and best practices for tDCS in stroke rehabilitation.

In the study conducted by Malfitano et al. (2019), they explored the effectiveness of repetitive transcranial magnetic stimulation (rTMS) as a treatment for post-stroke AOS. The study majorly focused on a participant who had experienced language deficits following a stroke. These deficits were only partially responsive to standard speech treatment. The participant had been diagnosed with isolated AOS, which is a speech disorder characterized by difficulties in planning and coordinating the movements necessary for speech. The study found significant improvements in the participant's speech production abilities. These improvements were assessed using standardized tests, as well as subjective ratings provided by the participant and their family members. The authors suggested that rTMS may hold promise as an effective treatment approach for AOS in participants who have experienced strokes. However, they emphasized the need for further research to confirm its effectiveness and establish optimal treatment parameters. To conclude, the study provides valuable insights into the potential use of rTMS as a treatment option for post-stroke AOS. The findings suggest that rTMS could be a promising avenue for addressing AOS in stroke survivors.

3.6 Review Question-4: What are the differences in the duration of intervention techniques of AOS?

3.6.1 Duration of various intervention techniques

The total intervention period refers to the time frame in which the intervention is provided. The table 3.11 shows the duration of various intervention techniques given to participants by different authors. The duration of intervention in the studies ranged from 5 days to 21 weeks. The study by Johnson et al. (2018) has given the highest duration of intervention whereas the study by Wang et al. (2019), Zhao et al. (2022) and Pisano et al. (2021) have given the lowest duration of intervention.

Table 3.11

Duration of various intervention techniques in the review articles

S. No.	Authors	Intervention Techniques used by the Author	Duration of Intervention
1.	Mauszycki et al. (2016)	Articulatory kinematic treatment in conjunction with VBFB via EPG	3 weeks
2.	Mauszycki et al. (2020)	Articulatory kinematic treatment in conjunction with VBFB via EPG Vs. SPT	18 weeks
3.	Bislick et al. (2020)	Modified Phonomotor Treatment Program	12.5 weeks for participant 1 & 9 weeks for participant 2
4.	Mauszycki et al. (2016)	MIT	6 weeks
5.	Wambaugh et al. (2020)	SPT	12 weeks
6.	Wambaugh et al. (2018)	SPT	12 weeks
7.	Wambaugh et al. (2013)	SPT	6.5 weeks

8.	Johnson (2018)	MLG treatment	12-13 weeks
9.	Johnson et al. (2018)	MLG treatment	9 weeks
10.	Marangolo et al. (2013)	tDCS + speech-language therapy	6 w (2 weeks intersession interval)
11.	Jacks et al. (2015)	MAF & AAF	Unspecified
12.	Wambaugh et al. (2012)	Repeated practice treatment, Articulatory-kinematic treatment & rate/ rhythm control treatment	3.5 weeks
13.	Buchwald et al. (2017)	Repetition-based training	Unspecified
14.	Nealon et al. (2021)	VNeST	2 Participants: 8 weeks, 2 Participants: 10 weeks
15.	Ballard et al. (2019)	Custom-built Word Trainer app	4 participants: 4 weeks. 1 participant: 5 weeks
16.	Zumbansen et al. (2014)	MIT	6 weeks
17.	Wambaugh et al. (2017)	SPT	10 weeks
18.	Wambaugh et al. (2021)	SPT	4-5 weeks
19.	Wambaugh et al. (2014)	SPT	16 weeks (2 weeks no-treatment interval)
20.	Wambaugh et al. (2016)	SPT	For 2 participants: 6.5 weeks, For 2 participants: 13.5 weeks
21.	Wambaugh et al. (2014)	CAAST	For 1 partcipant: 9.5 weeks, For 3 participants: 13.5
22.	Wambaugh et al. (2018)	CAAST	For 1 participant: 20 weeks, for 3 participants: 13.5 weeks
23.	Bunker et al. (2018)	CAAST	Unspecified

24.	Themistocleous et al. (2021)	tDCS	3 weeks
25.	Wang et al. (2019)	tDCS	5 days
26.	Zhao et al. (2022)	tDCS	5 days
27.	Pisano et al. (2021)	tDCS	5 days
28.	Whiteside et al. (2012)	Self-administered computer therapy Vs. visuo-spatial sham	16 weeks (4 weeks rest-phase)
29.	Maas et al. (2015)	MAF	Unspecified
30.	Preston et al. (2014)	Ultrasound visual feedback	6 weeks
31.	Farias et al. (2014)	Implicit phoneme manipulation	4 weeks
32.	Mozeiko et al. (2020)	SPT	2 weeks
33.	Johnson et al. (2018)	MLG treatment	21 weeks (4 weeks break)
34.	Henry et al. (2013)	Oral reading treatment	12 weeks
35.	Buchwald et al. (2020)	tDCS	Unspecified
36.	Malfitano et al. (2019)	rTMS	2 weeks
37.	Hurkmans et al. (2015)	SMTA	12 weeks

NOTE: VBFB- Visual Biofeedback, EPG- Electropalatography, SPT- Sound Production Treatment, MIT- Melodic Intonation Therapy, MLG- Motor Learning Guided, tDCS- Transcranial Direct Current Stimulation, MAF- Masked Auditory Feedback, AAF- Altered Auditory Feedback, VNeST- Verb Network Strengthening Treatment, CAAST- Combined Aphasia and Apraxia of Speech Treatment, rTMS- Repetitive Transcranial Magnetic Stimulation, SMTA- Speech Music Therapy for Aphasia

CHAPTER-4

DISCUSSION

This systematic review study aimed to compile and disseminate various intervention approaches targeting speech and language skills delivered by SLPs in persons with acquired AOS. The study aimed to address four review questions. Using keywords like apraxia of speech, apraxia, acquired apraxia of speech, treatment of acquired apraxia of speech, intervention of acquired apraxia of speech, etc., national and international databases were searched. So, out of 5066 articles, 53 research articles were selected for the systematic review. Further 37 articles were shortlisted based on the selection criteria.

Individuals of AOS manifest articulatory inconsistencies, inability to produce multi-syllabic utterances, and phonological complex words. Over the years, various speech-language therapeutic approaches were devised and developed by various researchers including various advanced techniques such as electropalatography and ultrasound, etc. However, evidences of AOS intervention is required to be carefully evaluated so that pieces of evidence can be mapped into clinical techniques. Hence, the current systematic review was carried out to understand various intervention outcomes in the population 18-80 years from 2012-2022 for 10 years.

The quality assessment of the eligible studies was carried out by using the latest version of the Cochrane risk-of-tool (RoB-2) for 5 randomized controlled trial studies, Single-Case Experimental Design (SCED) Scale for 22 single-subject design studies, Joanna Briggs Institue (JBI) critical appraisal tool for 1 case series, ROBINS-I tool for 1 non-randomised study, Physiotherapy Evidence Database quality assessment tool (PEDro-P) for 1 group experimental studies and Joanna Briggs Institute (JBI) critical appraisal tool for 7 case reports. The study

findings showed that United States, followed by Italy, China, Canada, Australia, Netherlands, United Kingdom reported the highest number of literature works on using different intervention approaches for AOS.

4.1. Widely used AOS intervention approach

Various approaches used for AOS found from articles were melodic intonation therapy (MIT), sound production treatment (SPT), articulatory kinematic treatment, modified phonomotor treatment program, electropalatography, motor learning guided (MLG), transcranial direct current stimulation (tDCS), masked auditory feedback (MAF), altered auditory feedback (AAF), rate & rhythm control treatment, repetition-based training, verb network strengthening treatment (VNeST), Custom-built Word Trainer app, combined aphasia and apraxia of speech Treatment (CAAST), Self-administered computer therapy noise masking, repetitive transcranial magnetic stimulation (rTMS), ultrasound visual feedback, implicit phoneme manipulation, oral reading treatment and speech music therapy for aphasia (SMTA).

Of all the above-mentioned approaches, we found that SPT is the most frequent intervention technique used among the researchers for AOS. this approach uses a treatment hierarchy for sound production/ accuracy in the management of AOS.

4.2. Evidences reported for various AOS intervention techniques

Sound Production Treatment (SPT)

SPT is an articulatory-kinematic treatment that has received more extensive and systematic study than any other treatment for AOS. SPT also includes verbal feedback and repeated repetition. Eight researches have used this approach in the intervention of AOS (Wambaugh et al., 2013; 2014; 2016; 2017; 2018; 2020; 2021 & Mozeiko et al., 2020). Positive

results in articulation accuracy have been consistently noticed for treated sounds in trained and untrained utterances produced outside the context of treatment. Various studies have been done comparing non-intense/ traditional SPT and intense SPT. However, the non-intense treatment demonstrated better preservation of the achieved improvements over time. Also, the effectiveness of treatment may vary among individuals. Also, several studies have been comparing blocked practice and random practice in SPT. The results showed improvements in speech production accuracy for all participants. However, the random practice schedule was found to be more effective in sustaining these gains over time (Wambaugh et al., 2016) whereas Wambaugh et al. (2014) did not find any significant differences between the blocked and random practice conditions.

In a study done by Mauszyki et al. (2020), SPT produced greater gains in articulatory accuracy and communication efficiency than electropalatography. The positive effects of SPT were maintained in the long-term follow-up. The authors suggest that SPT may be a more effective treatment approach for individuals with chronic AOS and aphasia, and that the use of self-evaluation and feedback may be beneficial for treatment outcomes.

Transcranial Direct Current Stimulation (tDCS)

tDCS uses two electrodes positioned on the scalp to administer a weak polarizing direct current to the cortex. It has been applied in several studies on language recovery in poststroke aphasia and probed as a possible adjuvant to influence different aspects of language processing, such as speech fluency, repetition abilities, picture naming (Baker et al., 2010; Hamilton et al., 2011; Holland & Crinion, 2012; Monti et al., 2013), and lexical retrieval of action words (Branscheidt et al., 2018).

Six studies used Transcranial direct current stimulation for the treating people with AOS (Marangolo et al., 2013; Wang et al., 2019, Buchwald et al., 2020, Themistocleous et al., 2021, Pisano et al., 2021, Zhao et al., 2022).

Bihemispheric tDCS was found to significantly reduce articulatory errors in patients (Marangolo et al., 2013). Various studies have compared the sham group and the group getting tDCS together with speech therapy, the group getting both significantly improved sound duration accuracy. This implies that using tDCS in combination with speech therapy improved sound duration accuracy in people with primary progressive aphasia who had AOS (Themistocleous et al., 2021; Zhao et al., 2022).

Also, in a study Buchwald et al., 2020, significant improvement in speech production accuracy following the speech motor learning treatment was noticed, regardless of whether the participants received active tDCS or sham tDCS. However, there was no significant difference in the magnitude of improvement between the two groups.

Motor Learning Guided (MLG) treatment

MLG approach is the first introduced treatment approach based on principles of motor learning. The practice schedule and the type of clinician feedback used in the MLG approach are different from those used in more conventional articulatory kinematic treatment regimens. The main variations include the utilization of serial repeated production as employed in conventional articulatory treatment protocols in place of an imposed 2-3s pause-time between productions. The participant is instructed to review their output before creating their next one during this break. The kind and quantity of increased feedback is another obvious distinction between the treatment protocol's two approaches. A high level of clinician assistance is used in

traditional therapy methods, along with frequent knowledge of performance comments. This input may include modeling, biofeedback, integral stimulation, and/or placement cues, depending on the patient's performance (e.g., Sound Production Treatment, Phonetic Placement Treatment, Eight Step continuum). MLG treatment has led to improvement in speech-motor learning regardless of whether the participants were given a high or low frequency of practice (Johnson et al., 2018). Thus, MLG treatment is effective in improving speech production in the participants with acquired AOS.

Combined Aphasia and Apraxia of Speech Treatment (CAAST)

The primary goal of CAAST is to increase verbal language productivity by facilitating elaboration of patient-initiated productions; flexible and generalized language use is expected (Kearns, 1985). Three works of literatures have used CAAST to study its efficacy in AOS intervention (Wambaugh et al., 2014,2018, Bunker et al., 2018). The results of the study showed that CAAST was effective in boosting many facets of morphosyntactic complexity and production, displaying benefits for both the treated and untreated language sets. Improvements were shown, specifically, in metrics like the percentage of closed-class words, the overall auxiliary score, the percentage of well-formed sentences, the average length of an utterance, and other pertinent variables. Minimal changes in terms of lexical diversity were observed using CAAST. Additionally, the study noted that these improvements generally remained consistent at similar levels during the 6-week follow-up period, suggesting the durability of the treatment effects over time (Bunker et al., 2018). Also, the study's findings showed that CAAST significantly improved the creation of accurate information units (CIUs) for treated photo sets. Moreover, positive generalization effects were observed, extending to untreated picture sets and discourse samples (Wambaugh et al., 2014).

Melodic intonation therapy (MIT)

Two researches have used MIT (Mauszycki & Wambaugh., 2020; Zumbansen et al., 2014). High levels of production accuracy in the trained sentence structures were achieved by using MIT. Significant improvements in discourse informativeness, as well as in the number of correct syllables produced in both trained and non-trained sentences were seen (Zumbansen et al., 2014). Importantly, the improvements in connected speech were sustained at a 3-month follow-up assessment. Also, the generalization of improvements to untrained sentence constructions began to emerge after approximately 12 treatment sessions (Wambaugh et al., 2020; Mauszycki & Wambaugh 2020).

Electropalatography

Mauszycki et al. (2016, 2020) have used electropalatography for treating people with AOS. Articulatory-kinematic treatment was used with visual biofeedback (VBFB) via electropalatography (Mauszycki et al., 2016). Positive results were observed in articulation accuracy for most of the treated speech sounds. Mausycki et al. (2020) compared two intervention approaches for AOS i.e., the articulatory-kinematic approach in conjunction with visual biofeedback (VBFB) via electropalatography with that of Sound Production Treatment. Positive effects were noticed in both treatments. However, SPT produced greater gains in articulatory accuracy and communication efficiency than EPG. The study also found that the positive effects of SPT were maintained in the long-term follow-up. The authors suggest that SPT may be a more effective treatment approach for individuals with chronic AOS and aphasia, and that the use of self-evaluation and feedback may be beneficial for treatment outcomes.

Combination of repeated practice treatment, articulatory-kinematic treatment & rate/ rhythm control treatment

Wambaugh et al. (2012) have used repeated practice treatment, articulatory-kinematic treatment & rate/ rhythm control treatment in treating AOS. Repeated practice is a component of AOS therapy, regardless of overall approach (Wambaugh et al., 2006b). Repeated practice has been shown to be an important component of learning nonspeech motor skills (Schmidt & Lee, 2005), and it is expected to be important in the rehabilitation of people with AOS. Wambaugh et al. (2012) observed that the positive effects of treatment persisted over time for the majority of participants, with some individuals continuing to show improvement even after the treatment had concluded. However, two participants did not exhibit any changes in the accuracy of their speech production in response to either treatment. The complexity of the stimuli used in the study might have posed challenges for these individuals, potentially affecting their ability to generalize accuracy levels during the baseline assessment. observed that the positive effects of treatment persisted over time for the majority of participants, with some individuals continuing to show improvement even after the treatment had concluded. However, two participants did not exhibit any changes in the accuracy of their speech production in response to either treatment. The complexity of the stimuli used in the study might have posed challenges for these individuals, potentially affecting their ability to generalize accuracy levels during the baseline assessment.

Phonomotor Treatment (PMT) Program

Phonomotor Treatment Program repeatedly exposes and practices speech information using a multimodal approach, promoting generalization and preservation of treatment benefits for taught speech targets**.** Bislick et al., 2020 used the Phonomotor Treatment (PMT) Program

for the intervention of AOS. Results showed that modified PMT could better generalize and maintain trained speech targets via a multimodal approach. PMT program was effective in improving motor planning in both participants, as evidenced by improvements in accuracy of production of trained and untrained targets. The study also found that the treatment effects were maintained at follow-up, indicating that the treatment had lasting effects. The study also found that the treatment resulted in clinically significant improvements in sound production accuracy.

Repetition-based Training

Only one research studied repetition-based training in the intervention of individuals with AOS (Buchwald et al., 2017). According to principles of motor learning, motor planning errors decrease following repetition-based practice structured. The participants received training focused on a set of words containing clusters that posed challenges for them due to their speech production difficulties. During the training, they repeatedly practiced these target words while receiving feedback from a clinician, with the goal of enhancing their ability to accurately and fluently produce the target clusters. The study sought to investigate whether this repetition-based intervention could bring about improvements in the production of both the trained words and untrained items in individuals with aphasia and AOS. The findings indicated that the two participants with motoric errors demonstrated enhancements in their production of both trained and untrained items. In contrast, the two participants with phonologically-driven errors did not show any improvement in their performance during the repetition training task. Consequently, the study suggests that analyzing the acoustic properties of deletion errors can serve as a predictive factor for determining who would benefit from a repetition-based intervention.

Self-administered Computer Therapy

One literature work has used self-administered computer therapy (Whiteside et al., 2012). The participants were block-randomized to either speech first (SPF) or sham first (SHF) conditions and then noticed the results. The participants significantly improved their speech accuracy and fluency. The SPF group (who received speech therapy first) showed signs of maintenance, and the results showed that behavioral benefits were significantly maintained. These findings underscore the long-term effectiveness of early speech therapy interventions.

Verbal Network Strengthening Treatment (VNeST)

This treatment aims to activate the semantic, lexical, and syntactic connections between verbs and their thematic roles (Edmonds, 2014). The VNeST protocol is utilized to facilitate lexical retrieval and support the generation of thematic roles associated with specific trained verbs. One research has used Verbal Network Strengthening Treatment (VNeST) for the intervention of AOS (Nealon et al., 2021). The improvements encompassed segmental speech errors, the ability to segment syllables, and reductions in false starts and pauses during speech. However, the participants' gains in the production of the correct number of syllables were observed in only one participant. Another participant did not exhibit increased accuracy in any measure of speech production. The remaining two participants displayed significant decreases in syllable segmentation, a characteristic that has been recognized as diagnostically relevant for AOS. In conclusion, the study suggests that VNeST could be a promising treatment approach for individuals with dual diagnoses of AOS and aphasia.

Custom-built Word Trainer App

One literature work has used a custom-built word trainer app to treat individuals with AOS (Ballard et al., 2019). The app was installed onto their personal iPads. The app used

Automatic Speech Recognition (ASR) to recognize the target words and progress the participant to a prompt to attempt the production of a sentence containing that target word.

The study found that using ASR to give mild to moderate AOS patients who were having self-administered speech therapy better feedback on word production accuracy was beneficial in encouraging high-intensity practice. Furthermore, the results demonstrated robust maintenance of treatment effects over the course of one month.

Ultrasound Visual Feedback

Ultrasound is a more widely available and less-invasive technology than electromagnetic articulography. Word production accuracy improves. Preston et al. (2014) suggested that people who have acquired AOS as a result of CVA may benefit from using ultrasound visual feedback to aid an improvement in performance. The study provides some preliminary evidence that this method works. However, more participants who are learning different sound patterns using lingual phonemes in a replication of the study would be helpful in confirming the method's effectiveness. Additionally, greater training and experience using ultrasound visual feedback may improve treatment results still further. The study emphasizes ultrasound visual feedback's potential as a therapeutic strategy for those with AOS.

Implicit Phoneme Manipulation

Farias et al. (2014) used an implicit protocol that activates speech motor areas via inner speech in treating AOS. This method was derived from early models of inner speech. In order to create a new word, implicit phoneme manipulation needs the participant to covertly move and combine phonemes. Fully conscious inner speech is a self-monitoring mechanism that is used in this process. The intervention used was an implicit-based approach, which consisted a series of tasks that required the participant to manipulate phonemes in a manner that was not

explicitly related to speech production. This approach aimed to indirectly target and improve speech production abilities affected by AOS. the treatment resulted in the generalization of these treatment effects to simpler consonant blends. The participant also exhibited improvements in speech production accuracy and speech rate.

Structured Oral Reading

Henry et al. (2013) implemented a treatment method using structured oral reading as a tool for improving multisyllabic word production with mild AOS and non-fluent variant Primary Progressive Aphasia. The predominant use of written word forms as a cue for speech output may offer orthography-based visual signals that aid in implementing the proper speech-motor program.

Repetitive Transcranial Magnetic Stimulation (rTMS)

Malfitano et al., 2019 investigated the effects of repetitive transcranial magnetic stimulation (rTMS) in persons with AOS. The rTMS treatment targeted the pre-central gyrus, inferior frontal gyrus (Broca's area), and rolandic operculum, which were the areas of the brain most affected by the patient's stroke. They also reported that rTMS is a safe and non-invasive treatment option for AOS with no significant side effects. The authors suggest that rTMS may be a promising approach for treating AOS in other patients, but further research is needed to confirm its effectiveness and optimal treatment parameters.

Speech-Music Therapy for Aphasia (SMTA)

SMTA integrates speech therapy and music therapy. Significant improvements were observed in verbal communication, speech production, and language skills in patients with

aphasia and AOS (Hurkmans et al., 2015). The findings have implications for the clinical application of evidence-based treatments for these disorders.

MAF & AAF masked auditory feedback (MAF) altered auditory feedback (AAF)

Jacks et al. (2015) found that seven of the ten APH/AOS individuals increased their fluency with masking, mostly by speaking more quickly, speaking less slowly, or doing both at once. It is noteworthy that none of the neurologically healthy participants spoke faster when using MAF. However, just one APH/AOS person had better fluency in the AAF condition, whereas four APH/AOS participants and eight Neurologically healthy participants reduced their speech pace. Maas et al. (2015) stated that the Individuals with AOS and aphasia exhibited a significant reduction in articulatory vowel space (AVS) and increased vowel duration in the noise-masking condition compared to the unmasked condition. The younger control group showed no effect of noise masking on vowel dispersion but did demonstrate longer vowel durations in the masking condition.

4.3. Therapy duration of AOS intervention

The fourth review question was the differences in the duration of techniques of AOS. The duration of the intervention techniques for AOS in the studies ranged from 5 days to 21 weeks. Study by Johnson et al. (2018) stated the highest duration of intervention (Motor Learning Guided treatment) whereas study by Wang et al. (2019), Zhao et al. (2022) and Pisano et al. (2021) indicated lowest duration of intervention (in tDCS intervention).

Thus, the results of this study increase SLPs' awareness of many facets of the often-employed AOS intervention approaches/strategies. Also, this will help the SLPs to understand and identify the therapeutic advances in AOS in the last decade.

CHAPTER-5
SUMMARY AND CONCLUSION

This systematic review aimed to review the studies on the existing literature on the various intervention techniques applied for acquired apraxia of speech (AOS). Using keywords related to AOS worldwide, a literature search was conducted in several national and international databases from the years 2012 to 2022 with PRISMA guidelines were followed i.e., title screening was done and then duplicates were eliminated. Prior to full-text screening, abstract screening was done. The pertinent articles meeting the inclusion criteria were selected. The review was chosen to focus on thirty-seven out of 5066 works of literature that met the inclusion criteria. All the thirty-seven articles were subjected to quality assessments. The information that was relevant to our study was collected in detail from each article.

We found that the majority of research on the technique for treating AOS was conducted in the USA, followed by Italy and China. Canada, Australia, Netherlands and United Kingdom got the least studies. Africa being the second largest continent in the world, no literature work was found from there. Sound Production treatment (SPT) is the most frequent intervention technique for acquired apraxia of speech. The duration of intervention in the studies ranged from 5 days to 21 weeks. The study by Johnson et al. (2018) provided the highest duration of intervention whereas the study by Wang et al. (2019), Zhao et al. (2022) and Pisano et al. (2021) provided the lowest duration of intervention.

5.1 Clinical implications of the study

- This systematic review provides SLP with up-to-date review on all the AOS intervention approaches and evidences in the last decade.

- This systematic review study informs evidence-based decisions on the different approaches used for individuals with AOS. This helps SLP in their clinical decision making and guiding through the intervention.
- The study suggests areas in AOS intervention lacking high-quality research like electromagnetic articulography, ultrasound and augmentative and alternative communication which requires researchers and funding organisations to prioritise on.
- According to our systematic review, non-intense/traditional sound production treatment, was found to provide higher generalisation over intense sound production treatment. Hence, changes such quality improvements in the therapy guidelines can be implemented accordingly.
- SLPs can educate and counsel patients and caregivers on various approaches and their potential effects to make informed choices about therapy.

5.2 Future directions

- This systematic review recommends more RCTS for comparing various approaches. Future research can advance the existing literature on the intervention of AOS.
- Exploring intervention approaches using large sample size and designing methods with blind evaluators improves the study evidence level.

Thus, current systematic review aided in identifying the knowledge gap regarding intervention strategies for acquired AOS. Also, it helps with understanding the most popular, previously unstudied apraxia of speech intervention strategies. Such review studies help SLPS to develop their intervention plans from a more comprehensive viewpoint.

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Appendix
Sample Form for Data Extraction

Article No:		
Name of the Article:		
Authors:		
Year of Publication:		
Journal Published on:		
Country of origin:		
Retrieved from (Name of database)		
Methodology		
1. Type of research		
2. Study Design		
3. Type of Research		
4. Participants	a) Total	
	b) Study group with age range	
	c) Control group with age range	
Procedure	a) Technique used	
	b) Duration of intervention	
	c) Frequency of intervention	
	d) No. of therapy sessions	
Results		