NEUROFEEDBACK INTERVENTIONS FOR SPEECH AND LANGUAGE IMPAIRMENT: A SYSTEMATIC REVIEW

Ismail Shahin, University of Sharjah
Ali Bou Nassif, University of Sharjah
Ashraf Elnagar, University of Sharjah
Sara Gamal, University of Sharjah
Said A. Salloum, University of Sharjah
Ahmad Aburayya, Dubai Health Authority

ABSTRACT

Language disparities in Arabic-speaking individuals with Speech and Language Impairment (SLI) can increase the limitations faced by SLI specialists. There is a need to improve neurofeedback interventions for patients who belong to this group. In contrast to studies that rely solely on behavioral measures, neurofeedback training can capture cognitive changes in response to learning not seen in time or accuracy measures alone. However, rigorous systematic literature reviews on neurofeedback interventions are limited. This research aims to perform a systematic literature review and analyze neurofeedback studies where Electroencephalography (EEG) or Magnetic Resonance Imaging (MRI) measurements were utilized with the isolation of the effect of a particular behavioral intervention on SLI cognitive profiles. We conducted a systematic literature review of studies on neurofeedback training published between 1992 and 2020. PRISMA guidelines have been used to achieve the review; we choose many keywords to be used in our search. The use of combinations of these keywords in searching of eight digital libraries (Springer Link, Science Direct, PLOS One, Taylor and Francis Online, Wiley Online Library, ISNR online, SAGE Publishing, and Google scholar) generated 155 publications. Out of these, 60 articles were found to be duplicates, and hence, they were removed. Therefore, the total number of final papers that form the primary data for this systematic literature review is 50. We identified 50 studies relevant to the objective of this research. After a rigorous review, we observed that 36 out of 50 (72%) selected studies used EEG or MRI to analyze the effects of neurofeedback on individuals with SLI, and 38% performed comparative analysis and hence improved the quality of their studies. We recommend the standardization of applications of EEG and MRI using BCI methods. EEG and MRI neurofeedback training methods are less expensive and yet more potent compared with pre-existing behavioral intervention and assessment methods with methods that use SLI Neurofeedback.

Keywords: Electroencephalography; Magnetic Resonance Imaging; Neurofeedback Interventions; Speech and Language Impairment.

INTRODUCTION

Speech is the gateway to human communication, and it manifests in the form of verbal sounds and legible writing (Nassif et al., 2019; Sattar et al., 2019; Al-Khayyal et al., 2020; Shahin et al., 2020; Al-Maroof et al., 2021; Al Kurdi et al., 2021; Capuyan et al., 2021; Elnagar et al., 2021; Salloum et al., 2021). The formation of speech is necessary for finalizing court proceedings (Vickers, 2017).

Citation Information: Shahin I., Nassif A.B., Elnagar A., Gamal S., Salloum S.A., & Aburayya A. (2021). Neurofeedback interventions for speech and language impairment: A systematic review. *Journal of Management Information and Decision Sciences, 24*(S1), 1-30.

There are severe consequences of inaccurate speech, such as an error in a contract, or even prosecution or life imprisonment. The power of accurate speech is comparable with the authority of a statement from a witness, which can free or imprison a prosecuted man. Hence, speech validity and accuracy is of great value and worthy of further research.

To the best of the authors' study, there has been a lack of consensus regarding the best label to use in epidemiological studies for addressing the various sub-types of affected speech or linguistic skills regardless of the causative agents involved. In this paper, we have selected "Speech and Language Impairment (SLI)" as our label for identifying these various sub-types. Furthermore, there are distinctions between linguistic grammar factors and social communication factors. There are also further variations to consider regarding the affected skills of the receptive vs. expressive aspects of speech or language and their combination. Even the level of an individual's skill may hinder the distinction when it is limited to the verbal context or the non-verbal forms of speech. Further disparities are based on degrees of literacy, and causative pathology is set. Additional considerations of pre-diagnosed disorders such as Down Syndrome (DS) and Autism Spectrum Disorder (ASD) are additional filters that could separate via labels. Consequently, all of the distinctions above have been considered with the label of SLI (Goldbart & Sen, 2013) in a review by Reilly et al. (2014), where the authors faced difficulty in finding an overall consensus.

Concerning the US prevalence of SLI, two frequently cited reports, Tomblin et al. (1997) and Hoffman and Gillam (2004) were reviewed. Tomblin et al. (1997) studied kindergarteners (7,218 children) in Iowa and reported that 7% out of all participants were speech and language-impaired. However, as the study progressed, the researchers confirmed that only one-third of the children were speech and language-impaired based on a consensus of reports by parents and teachers. On the other hand, Hoffman and Gillam (2004) reported that 10% of participants in their study, with a consideration of children below the age of 18, were speech and language-impaired.

In contrast, outside the US, Australian reports showed up to 18% SLI (Brinkman et al., 2009) What was even more shocking was the consideration of Indian national census held by the World Health Organization (WHO), which reported 0.2% SLI (Office of the Registrar General & Census Commissioner, 2001) in contrast with Australian reports. Another consideration of prevalence that is essential to this review is that of the Middle East (ME). In the case of Saudi Arabia, the incidence of physical disabilities affecting speech, such as the cleft lip and palate, had a rate of 0.3–2.19 per 1000 live births (Battle, 2012). While in Palestine, a reported rate of 0.37–1.56 per 1000 live births with different race distinction criteria. Other studies have considered hearing disabilities to be part of SLI. For example, Mustafa reported that about 8 in 1000 children born in Egypt have SLI (Mustafa, 2004).

Due to medical and scientific advances, caregivers can attenuate the challenges individuals with SLI experience. Caregivers include Speech And Language Therapists (SLTs), Speech Language Pathologists (SLPs), otolaryngologists, and audiologists. Therefore, these professionals should educate individuals with SLI and their caregivers with great immediacy. Unfortunately, caregivers of individuals with SLI are limited in the ME and worldwide. Furthermore, the consideration of the Arabic language specifically would reduce the considered SLP population to reported ranges of only a few hundred caregivers in the ME (Wilson, 1983). This limitation establishes the need for improvement in techniques and procedures to improve both coverage and level of service provided for SLI individuals. Thus, speech, affected by language, can vary with regards to phonetic manifestations, and, consequently, the type of intervention offered by a professional can vary.

Generally, practitioners assess and treat SLI with behavioral and observational interventions. However, SLI can also be evaluated using Electro Encephalo Graphy (EEG) measurements by

Citation Information: Shahin I., Nassif A.B., Elnagar A., Gamal S., Salloum S.A., & Aburayya A. (2021). Neurofeedback interventions for speech and language impairment: A systematic review. *Journal of Management Information and Decision Sciences, 24*(S1), 1-30.

capturing multiple successive EEGs while SLI individuals are performing cognitive exercises. While most investigations associate cognition with the observation of behavioural response, EEG experiments compare their response to an already established cognitive profile for the average nonSLI individual. In contrast to studies that rely solely on behavioral measures, EEG studies can capture cognitive changes in response to learning not seen in time/accuracy measures alone.

In this review, we analyze neurofeedback studies where researchers use EEG or MRI measurements to isolate the effect of a particular behavioral intervention on SLI cognitive profiles. In some ways, this systematic literature review is a pedestal for the future development of Speech or Linguistic Neurofeedback (SLN) studies that target specific brain regions as a focal point for the rehabilitation of individuals with difficulties in linguistics or speech. Cognitive profiles generated by Brain-Computer Interfaces (BCI) can aid in the facilitation and optimization of the learning experience for speech or linguistically challenged individuals.

Problem Statement

Behavioral studies document the progress of SLI and speech or language learning abilities in response to chemical and behavioral interventions. However, uncovering studies that quantitatively examine underlying cognitive changes or improvements in skill-retention in SLI brains in the Middle East was difficult. SLPs generally do not have the resources or tools helping them pinpoint the exact reason why an individual with SLI fails to acquire skill-mastery. Curricular guidelines urge more behaviour-centered training as a solution rather than following a more investigative approach uncovering why a student does not acquire – amongst other types – cognitive skill-sets. Despite attempts to standardize curricular guidelines, the variance in teaching styles, and corresponding variance in SLI learning capacities, knowledge/skill retention is mostly inconsistent. The responsibility for least subjectively assessing SLI falls on the SLP. When individuals with SLI are assessed quantitatively, the odds are that scores will more closely reflect the competence level of the student rather than the SLP's bias towards their method of information transmission/scoring scheme. The goal of the learning process is students performing such tasks or skilled-behaviours independent of the Proctor. Subjective assessments do not inspire confidence in the same way that quantitative measures do. Assessment variations could further affect the plan of tailored skill training for the child as he or she progresses. The actual teaching methodology further impacts the degree of progress. Such variability argues the need for a quantitative approach that can accommodate each student's needs. This review is being conducted to serve three main aims: (1) To study the effects of SLI Neurofeedback on SLI individuals and exhibited changes across cognitive profiles using EEG or MRI; (2) To compare the pre-existing behavioural intervention and assessment methods with those using SLI Neurofeedback; (3) To suggest standardization methodologies and procedural guidelines, and assistive technology solutions using BCI methods targeting SLI cognitive profiles.

It is notable to mention that while we examine the aims above, we maintain a specific interest in Arabic speech research and its relevant literature. To elucidate the nature of this study, a brief overview of the anatomy of the brain follows.

Brain Anatomy

The human nervous system includes the Central Nervous System (CNS) and Peripheral Nervous System (PNS) (Merilainen, 2002), where the CNS is made up of the brain and spinal cord,

Citation Information: Shahin I., Nassif A.B., Elnagar A., Gamal S., Salloum S.A., & Aburayya A. (2021). Neurofeedback interventions for speech and language impairment: A systematic review. *Journal of Management Information and Decision Sciences, 24*(S1), 1-30.

and consequently controls the path between brain and PNS. The CNS consists of three principal components that perform different functions: the cerebrum, the cerebellum, and the brainstem. The cerebrum, or cerebral cortex, controls the majority of bodily functions including intellect, language, visual perception, and visual memory (Ackerman, 1992). The cerebellum is secondary in size as a component of the brain, and it aids the cerebrum in maintaining balance and controlling complex muscular movements. The brainstem, the component located near the periphery of the human's brain, is responsible for critical involuntary functions, including breathing, heart rate, and the diameter of blood vessels (Ackerman, 1992).

Brain Imaging Techniques

Various brain imaging techniques are used to study the structure and function of each region of the brain outlined above. Brain imaging techniques are divided into two categories: 1) those that allow for detailed pictures of the brain's structural anatomy and 2) those that measure the real-time brain activity detected during varying degrees of consciousness. Brain imaging techniques for revealing anatomical structures include Magnetic Resonance Imaging (MRI) and Computed Tomography (CT). These techniques are not in the chosen parameters of this study. The techniques of Electro Encephalo Graphy (EEG), Magneto Encephalo Graphy (MEG), Functional Magnetic Resonance Imaging (fMRI), and optical imaging are relevant to our current experiments since they enable the monitoring of brain activity during the performance of a specific task. The monitored tasks can include a learning paradigm and have been widely used to study SLI brain activity. These techniques vary in their ability to localize an activity based on the method of activity detection and measurement limitation (Merilainen, 2002; Goldman et al., 2000; Matthews & Jezzard, 2004; Jenatton et al., 2012). Due to the EEG's high degree of temporal resolution, researchers prefer to use the EEG for dynamic studies that allow for a greater age-range in research applications. The EEG is a non-invasive and inexpensive option. In addition, researchers have used the EEG extensively in research and practise for many years. EEG signals consist of two broad classes: free-running EEG and Event-Related Potentials (ERP). With the help of these signals and their analyses, researchers have assigned cognitive abilities–or lack thereof–to SLI in a particular form known as a cognitive profile. However, additional studies need to be applied to existing cognitive profiles of individuals with SLIs to correlate or compare the associated brain regions and functions to those of control subjects (either unchallenged by SLI or possessing another unique cognitive profile). Furthermore, such studies may be marginally mimicked by EEG studies that involve the monitoring of the entire spectrum of EEG data, followed by the extraction of cognitive features relevant to a particular event, such as ERP signals. Other studies involve the extraction of features of EEG signals in their entirety to establish a cognitive profile or character of the signals as they are.

Research involving EEG and ERP signals are often associated with the development of BCI applications. The BCI system incorporates the localization of specific brain regions or network that are relevant to a particular cognitive task or state. Such research work would further be used to expand upon using the EEG or ERP signals to enhance robotics or perform automation tasks that are otherwise impossible for physically challenged individuals that have preserved cognitive functions (Ikegami et al., 2012; Farwell & Donchin, 1991; Farwell, 1993; Harley, 2009; Kolev et al., 1997; Rosenfeld et al., 2004). Despite their benefits, researchers criticize EEG and ERP measurement techniques because of their spatial resolution. Researchers typically apply these techniques on the surface of the brain to avoid brain tissue damage. Hence, fMRI studies, which involve monitoring an individual's blood flow

Citation Information: Shahin I., Nassif A.B., Elnagar A., Gamal S., Salloum S.A., & Aburayya A. (2021). Neurofeedback interventions for speech and language impairment: A systematic review. *Journal of Management Information and Decision Sciences, 24*(S1), 1-30.

and oxygenation levels in addition to metabolic changes in nerve cells, are often considered for spatial brain activity measurement in contrast to EEG (Rossi et al., 2009). However, although fMRI provides an accurate spatial resolution, it has limitations that are due to blood changes that coincide with neural changes. Nevertheless, the fMRI apparatus is often affordable only to medical facilities in the UAE that offer medical diagnostic procedures. Another limitation of fMRI is that patients are required to maintain minimal motion during an experiment. Therefore, practitioners only offer fMRI to individuals that are capable of maintaining a particular posture. Hence, taking into consideration the constraints of time, money, the nature of the study, participants ages and behavioural tendencies, we preferred to conduct this research using EEG (Cicchetti & Serafica, 1981; Dumas, 1991; Fidler, 2005). Consequently, in the following paragraphs, we focus more on studies of SLI neurofeedback techniques and cognitive profile targeting that utilize applications of EEG and MRI.

METHOD

The study was planned and conducted following the systematic literature review procedures as specified in (Moher et al., 2009). The adopted SLR method generally consists of a preliminary method of developing a review protocol, where the review process involves planning the review, conducting the investigation and reporting the review. Conducting the review generally involves first identifying the research, selection of primary research, study quality assessment, data extraction, and monitoring, data synthesis and review reporting (AlBayari et al., 2021; Yousuf et al., 2021; Al Mansoori & Salloum, 2021; Al-Maroof et al., 2021; Almazrouei et al., 2020). The study posited that performing a systematic literature review is to ensure effective summarization of existing evidence concerning treatment or technology or other subjects of interest, to identify any breaches in current research to propose areas for further investigation, to provide a framework/background to position new research activities appropriately. Added benefits of performing a systematic literature review are namely to ensure that a well-defined methodology decreases chances of the results of the literature review being biased, even though it does not guard against publication bias in the primary studies arising from several factors which will be discussed later. A systematic literature review can provide information about the effects of some phenomenon across a vast range of settings and empirical methods. In cases where studies give consistent results, the method provides evidence that the observed phenomenon is robust and transferrable; this gives a basis for studying inconsistent results and sources of variation in an investigation. There is a possibility of increasing the likelihood of detecting real effects that smaller scope studies might be unable to identify due to the possibility of data combination through meta-analytic techniques.

A systematic literature review has the significant disadvantage of requiring considerably more effort than traditional literature reviews. Fig. 1 highlights the six stages of the review protocol.

The research question synthesis is an integral part of the SLR approach at it defines at the onset the terms of reference for the study. The next step as outlined in Figure 1 involves integrating a search strategy aimed at determining the primary studies to be included. To accomplish this step, there must be a means of defining the search terms/criteria and the primary studies relevant to the SLR. A pilot study selection which further enhances the level of depth could be employed in the study selection criteria define stage, a quality assessment checklist, data extraction forms, and data synthesis methods as described in (Moher et al., 2009), are all critical processes to be adopted in this research.

Citation Information: Shahin I., Nassif A.B., Elnagar A., Gamal S., Salloum S.A., & Aburayya A. (2021). Neurofeedback interventions for speech and language impairment: A systematic review. *Journal of Management Information and Decision Sciences, 24*(S1), 1-30.

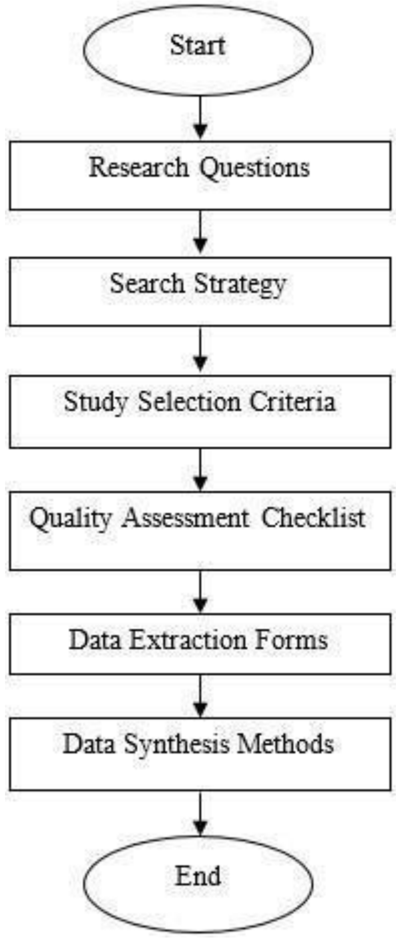

FIGURE 1 PROTOCOL REVIEW STAGES

Research Questions

The systematic literature review adopted in this study aims to summarize and clarify the empirical evidence on the effects of speech and language impairment, and this resulted in three research questions of relevance:

RQ1:

What is the impact of neurofeedback on individuals with SLI and exhibited changes across cognitive profiles using EEG or MRI?

RQ1 aims at investigating the effects of neurofeedback individuals with SLI and the exhibited changes observed through cognitive profiling using the EEG or MRI method.

RQ2:

How are the pre-existing behavioral intervention and assessment methods compared with methods using SLI Neurofeedback?

Citation Information: Shahin I., Nassif A.B., Elnagar A., Gamal S., Salloum S.A., & Aburayya A. (2021). Neurofeedback interventions for speech and language impairment: A systematic review. *Journal of Management Information and Decision Sciences, 24*(S1), 1-30.

RQ2 aims to compare pre-existing behavioral intervention and assessment methods with methods that use SLI Neurofeedback.

RQ3:

What are the suggested standardization methodologies, procedural guidelines, and assistive technology solutions that use BCI methods to target SLI cognitive profiles?

RQ3 aims to propose methodologies and guidelines for handling SLI cognitive profiles with a specific interest in Arabic speech research.

Search Strategy

The search strategy comprises search terms, literature sources, and search process. We describe these components of the search strategy below.

Search Terms

The steps involve deriving significant terms from the research questions, identification of significant spellings for the identified terms, keyword checks in relevant literature and books, the adoption of Boolean OR and functions to enable effective linking and eliminate misspellings.

Literature Sources

The literature sources used to search for relevant primary data are predominantly from Springer Link, ScienceDirect, PLOS One, Taylor and Francis Online, Wiley Online Library, ISNR online, SAGE Publishing, and Google scholar.

We used the search terms above to search relevant journal papers and conference papers. We made adjustments in search terms to account for slight differences in the search databases; the search criteria included the title, abstract, and keywords. The search period was from 1992 to 2020.

Search Process

A comprehensive search of all relevant sources is the key to SLR implementation. The search is accomplished through a series of stages and a subsequent selection phase as shown in Fig. 1. The search phase defines the different databases that were searched separately and the selected papers gathered together to form the primary data for the study, and the search phases include scanning through the references of the selected papers to determine if there are other relevant studies for the SLR. The Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) was adhered to in the search and refinement phases of the review study (Moher et al., 2009). The PRISMA flowchart can be seen in Fig. 2.

Citation Information: Shahin I., Nassif A.B., Elnagar A., Gamal S., Salloum S.A., & Aburayya A. (2021). Neurofeedback interventions for speech and language impairment: A systematic review. *Journal of Management Information and Decision Sciences, 24*(S1), 1-30.

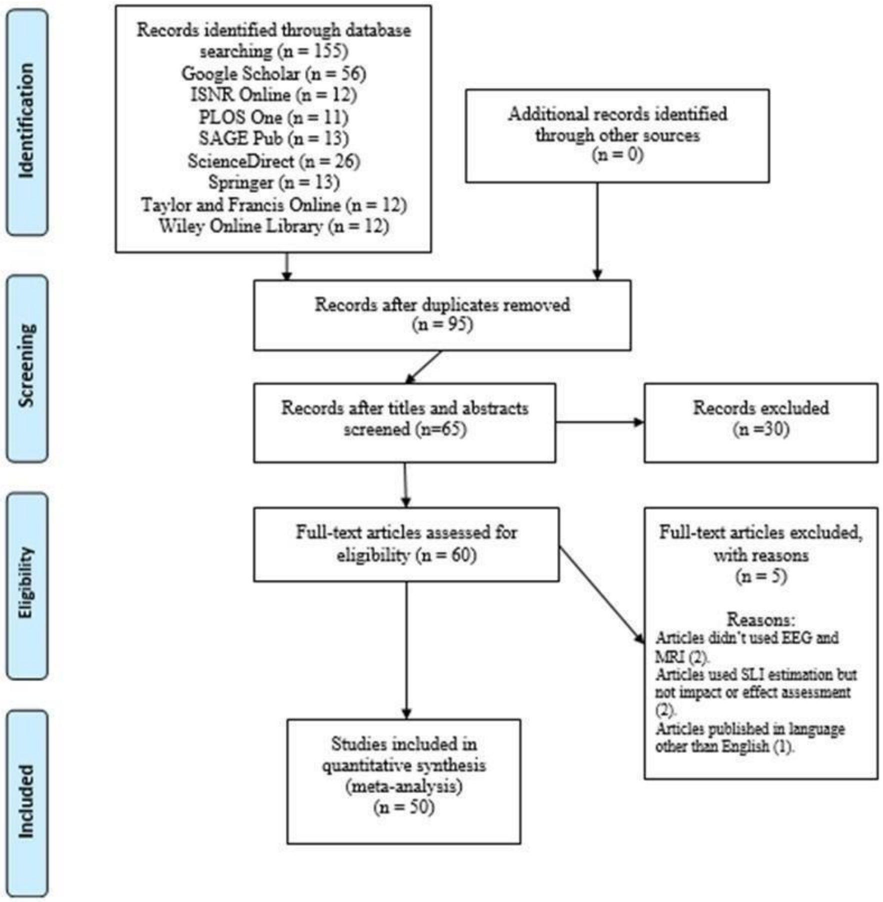

FIGURE 2 PRISMA FLOWCHART FOR THE SELECTED STUDIES

Study Selection

The search phase yielded an initial 155 papers as shown in Figure 2. Out of these, 60 articles were found to be duplicates, and hence, they were removed. Since the majority of the articles gathered offered little information that can be used in the study or in answering the posed research questions, further filtering were required, which in turn reduced the number of papers to 95? Selections were achieved by reading the titles, abstracts, and keywords of the selected papers. We defined the following inclusion and exclusion criteria.

Inclusion Criteria:

- Using EEG and MRI to create cognitive profiles
- Using EEG and MRI applications to change cognitive profiles
- Study about the effects of SLI on individuals
- Using neurofeedback methods for SLI individual assessment and behavioural intervention
- Using BCI methodologies for SLI standardization

Citation Information: Shahin I., Nassif A.B., Elnagar A., Gamal S., Salloum S.A., & Aburayya A. (2021). Neurofeedback interventions for speech and language impairment: A systematic review. *Journal of Management Information and Decision Sciences, 24*(S1), 1-30.

Exclusion Criteria:

- Review papers
- Using SLI estimation but not impact or effect assessment

Thus, the application of the exclusion and inclusion criteria filtered the papers to 65, and further use of selection and quality assessment criteria reduced the documents to 44. After crossreferencing, we found six additional relevant studies. Therefore, the total number of final papers that form the primary data for this systematic literature review is 50. The quality assessment criteria consisted of questions that are not based on meta-analysis due to the subjective nature of the study under consideration. Table 1 shows the quality assessment questions which were applied to the selected papers. The complete list of these 50 selected papers is in Table A.7 in Appendix A.

Study Quality Assessment

We devised a number of quality assessment questions to assess the rigorousness, credibility, and significance of the relevant studies. The list of questions is in Table 1. The responses to the questions have three options: “Yes,” “No,” or “Maybe,” where maybe means partially yes. The values assigned to each response are the following: ‘‘Yes’’=1, ‘‘Maybe’’=0.5, and ‘‘No’’=0. We selected papers with an average score of 50% due to the small sample size and the need to have selections that best matched the sought requirements.

Data Extraction

Data extraction implies the exploitation of the selected studies to collect the data relevant to the investigation as depicted in Table 2. The data extraction card shows the data extracted from the papers with the sole aim of addressing the research questions relating to the study. During the data extraction, we could not derive some data directly from the selected studies. Nevertheless, we obtained them indirectly by processing the available data appropriately. The use of different terminologies to mean the same thing was an obstacle faced during data extraction. Many words are analogous to one another, this posed a great challenge, and thus required concise effort on the part of the researcher to ensure vital information was extracted from the selected papers to form a basis for qualitative analysis. Not every study chosen provides answers to all the five research questions. For ease of tracing the extracted data, we explicitly labeled each study with the IDs of the research questions to which the study can provide the corresponding answers.

Data Synthesis

Data synthesis is used for evidence aggregation of the selected studies for answering the research questions. The extracted data related to this study was qualitative and quantitative. Thus, the use of narrative synthesis method was used along with visualization tools such as relevant charts to demonstrate the interrelationships between the selected studies and their relevance/contribution to answering the research questions.

To provide a systematic overview of the present literature concerning SLI, we created categories for three variables:

Citation Information: Shahin I., Nassif A.B., Elnagar A., Gamal S., Salloum S.A., & Aburayya A. (2021). Neurofeedback interventions for speech and language impairment: A systematic review. *Journal of Management Information and Decision Sciences, 24*(S1), 1-30.

1. Function – The primary human functions influenced by SLI neurofeedback are language, auditory processing, and attention.
2. Electrode type (EEG Label) – Electrode types are labeled with a letter and a number (e.g., F1). The letter refers to the area of the brain underlying the electrode (e.g., F- Frontal lobe). Even numbers indicate the right side of the head and odd numbers the left side of the head.
3. Cortical Projections (Brain Region) – SFG: Superior Frontal Gyrus; BM: Bilateral Medial; MFG: Middle Frontal Gyrus; IFG: Inferior Frontal Gyrus; PrG: Pre-central Gyrus; PoG: Post-central Gyrus; SG: Supramarginal Gyrus; SPL: Superior Parietal lobule; IPL: Inferior Parietal lobule; IPG: Inferior Parietal Gyrus; P: Precuneus; C: Cuneus; T: Tonsile; STG: Superior Temporal Gyrus; MTG: Middle Temporal Gyrus; ITG: Inferior Temporal Gyrus; SOG: Superior Occipital Gyrus; MOG: Middle Occipital Gyrus; IOS: Intra-Occipital Sulcus).

We used the diverse comparative analysis method for the data synthesis, which addresses some research questions that we could not measure using a direct analysis of the selected papers.

Threats to Validity

Study selection bias, publication bias, and possible error in extracted data are primary threats to studies such as the selection of studies depends on the search strategy employed, the literature sources, the selection criteria adopted, and the quality criteria factors. Search terms matching with the research questions to retrieve the relevant studies in the selected electronic databases might not wholly address the issues of concern, and some desired relevant studies may not even use the terms related to the research questions in their titles, abstracts, or keywords. As a result, there is a high risk of leaving out these studies in the automatic search. There is also the threat of falsified results presented in published papers that do not match reality or validity. We checked the documents twice to ensure that we did not exclude papers that did not adequately present their issues in the titles, abstract or in the keyword. The choice of high-quality databases with harsh reviews goes a long way to mitigate the selected low-quality research papers based on falsified results or erroneous results. We detailed the header field in the data extraction card to ensure that each article was well analyzed and their contributions were captured succinctly.

RESULTS AND DISCUSSION

This section discusses the findings of the SLR. First, we present an overview of the findings of the selected studies. Second, we analyze the SLR findings within the context of the research questions. In the discussion, we interpret the review results, not only within the context of the research questions but also within a broader context that connects with the research questions. We also include any related works that justify the findings.

Overview of Selected Studies

We identified 50 studies (see Appendix A) in the field of SLI implementation on the individual. These papers were published between 1992 and 2020. All articles were published in journals. The publication venues and distribution of the studies are depicted in Table 3. The publication venues include Springer Link, Science Direct, PLOS One, Taylor and Francis Online, Wiley Online Library, ISNR online, SAGE Publishing, and Google scholar.

Citation Information: Shahin I., Nassif A.B., Elnagar A., Gamal S., Salloum S.A., & Aburayya A. (2021). Neurofeedback interventions for speech and language impairment: A systematic review. *Journal of Management Information and Decision Sciences, 24*(S1), 1-30.

Impact of Neurofeedback on Individuals with SLI and Exhibited Changes across Cognitive Profiles Using EEG or MRI (RQ1)

Neurofeedback allows individuals to learn voluntarily how to control cortical function. EEG measures the cortical oscillations during neurofeedback training. As shown in Figure 3, 36 out of 50 (72%) selected studies used EEG or MRI to analyze the effects of neurofeedback on individuals with SLI. The rest of the studies (28%) used other applications.

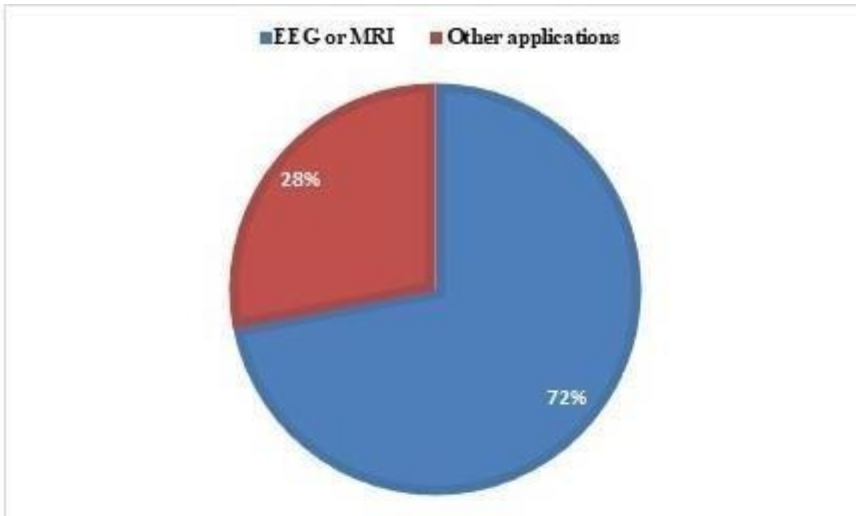

FIGURE 3 DISTRIBUTION OF STUDY FOCUS FROM SELECTED PAPERS

To begin with, a study by Sudirman et al. (2010) classified the different shapes of EEG patterns based on neurological function. Next, a majority of studies that used EEG or MRI for neurofeedback training demonstrated that EEG or MRI activity could influence cognitive profiles. Ros et al. (2013) built upon a previous study that showed that only half an hour of EEG stimulation could significantly change the cognitive profile of the adult cortex, specifically the dorsal anterior cingulate which is involved in intrinsic alertness. Im et al. (2007) used an EEG-based system to induce spatiotemporal changes in the brain at the cortical level. Also, Xiong et al. (2014) showed that EEG neurofeedback could work on the posterior association cortex to improve Working Memory (WM) performance (increase theta-to-alpha rhythm power ratio during WM task), and, ultimately, this improved WM performance has a transfer effect on sustained attention and improved intelligence. In two other similar studies, Enriquez-Geppert et al. (2014); EnriquezGeppert et al. (2017) also showed that neurofeedback training could enhance Frontline Midline (FM)-theta amplitude in the FM cortex, which also holds clinical promise. Kinreich et al. (2014) provided evidence that EEG theta/alpha neurofeedback can induce the transition from the awake to pre-sleep state. Sulzer et al. (2013) focused on Real-Time Functional Magnetic Resonance Imaging (rtfMRI) and discussed its mechanisms and clinical applications. Similarly, Kinreich et al. (2014) used a simultaneous acquisition of fMRI and EEG to produce improved cognitive profiles in patients. (Eroğlu et al., 2020) applied Multi Scale Entropy analysis (MSE) to the EEG data of an experimental group consisting of children with dyslexia and a control group comprised of typically developing children.

Six studies showed that EEG could have specific physiological responses and, hence, may have important clinical applications. Guan et al. (2015) demonstrated that patients with Postherpetic

Citation Information: Shahin I., Nassif A.B., Elnagar A., Gamal S., Salloum S.A., & Aburayya A. (2021). Neurofeedback interventions for speech and language impairment: A systematic review. *Journal of Management Information and Decision Sciences, 24*(S1), 1-30.

Neuralgia (PHN) could self-regulate their pain perception level via fMRI neurofeedback training on the Rostral Anterior Cingulate Cortex (rACC). Similarly, Surmeli et al. (2007) had profound results as all seven children with Down syndrome in the neurofeedback study showed significant improvements. Another study by Breteler et al. (2010) further provides evidence that EEG neurofeedback had benefits when children with dyslexia in the experimental group showed improvements in spelling. Hallman et al. (2012) portrayed an important case study of an adolescent diagnosed with Fetal Alcohol Spectrum Disorders (FASD) with and attention deficit hyperactivity disorder, and how neurofeedback treatment (80 sessions over 14 months) significantly resolved neural dysregulation almost entirely. Gruzelier (2014) demonstrated improved cognitive skills such as sustained attention and improved memory in healthy and elderly participants. A study by Thompson et al. (2010) was particularly strong as patients with Asperger's syndrome, and Autistic Spectrum Disorder improved their symptoms throughout 15 years via neurofeedback training. Marzbani et al. (2016) compared various neurofeedback treatments and demonstrated the effects of various EEG frequencies on different physiological functions. Keizer et al. (2010) were more specific in the type of neurofeedback training they used; the authors demonstrated that Gamma Band Activity (GBA)-enhanced and Beta Band Activity (BBA) enhanced neurofeedback had some differences. The authors observed that GBA-targeted training improved both short-term and long-term memory, while BBA-targeted training only improved familiarity memory. Another similar specific study by Surmeli and Ertem (2010) included significant improvement in quantitative scores such as the WISC-R (Wechsler Intelligence Scale for Children-Revised) IQ test and TOVA (Test of Variables of Attention) tests.

A few studies showed an overall improvement in children after quantitative EEG (QEEG) treatments; Sürmeli et al. (2007) demonstrated QEEG treatments improved overall outcome measures, including speech development and improved learning, and (Breteler et al., 2010) showed improvements in spelling in children with dyslexia after QEEG-based neurofeedback. Legarda et al. (2011) provided three case study profiles of a 6-year-old, 16-year-old, and 19-year-old, respectively, who went through various EEG neurofeedback training and experienced better cognitive profiles. Pineda et al. (2008) showed improvements in behavior in children with autism spectrum disorders after neurofeedback training; however, this study did not focus on SLI and was not included in our distribution calculation.

One study discussed the need for a more efficient EEG neurofeedback technology. Meir-Hasson et al. (2016) suggested that an EEG prediction model (EEG fingerprint; EFP) can replace the need for fMRI neurofeedback applications, and concluded that EEG is the less expensive option for learned self-regulation of localized brain activity. Figure 4 depicts the distribution of studies that measure SLI neurofeedback effects. To know if a study focuses on effect estimation, we examined its cases of application. Thus, case-based studies reflected papers relevant to the research question, while non-case-based studies highlighted other research foci for SLI neurofeedback applications.

Citation Information: Shahin I., Nassif A.B., Elnagar A., Gamal S., Salloum S.A., & Aburayya A. (2021). Neurofeedback interventions for speech and language impairment: A systematic review. *Journal of Management Information and Decision Sciences, 24*(S1), 1-30.

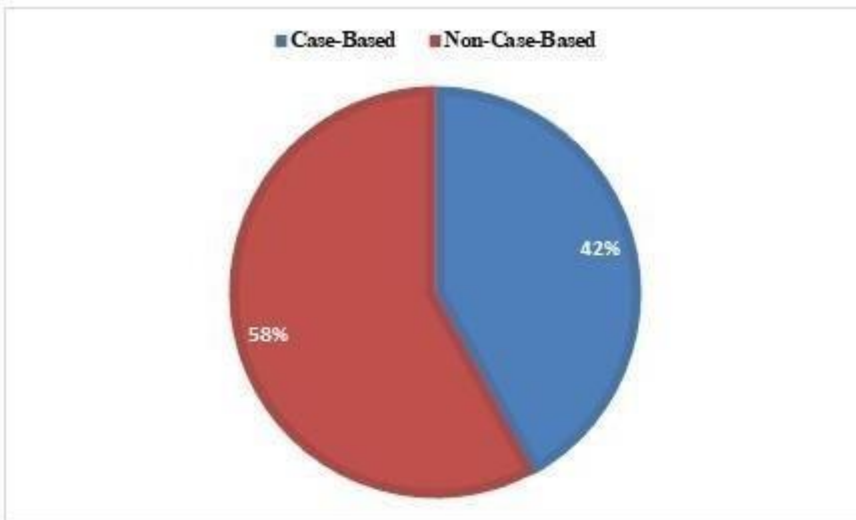

FIGURE 4 CASE-BASED VERSUS NON-CASE-BASED STUDIES

The sample size of each study significantly affects a wide range of applicability in understanding its efficacy and coverage. Figure 5 depicts the sample size distribution for each case-based and non-case-based paper.

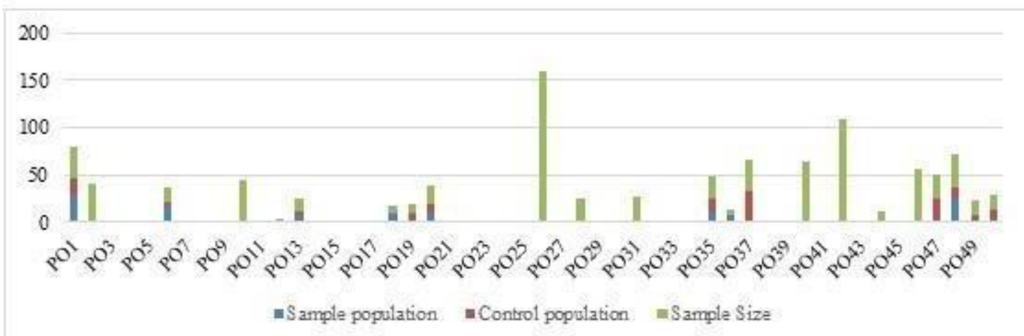

FIGURE 5 SAMPLE POPULATION DISTRIBUTION FOR STUDY

The proportion of authors who implemented quality controls on their data collection methods and whose results showed better research quality are shown in Figure 6.

Citation Information: Shahin I., Nassif A.B., Elnagar A., Gamal S., Salloum S.A., & Aburayya A. (2021). Neurofeedback interventions for speech and language impairment: A systematic review. *Journal of Management Information and Decision Sciences, 24*(S1), 1-30.

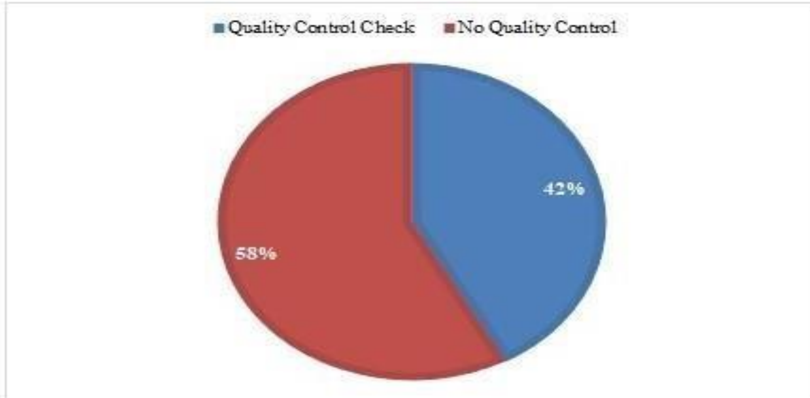

FIGURE 6 DATA COLLECTION QUALITY CONTROL

Only 42% of the authors performed a quality control check of their results, and only 58% of studies used a case-based methodology. These percentages are indicative of effect estimation studies, which show that there is room for research in the area of determining the effects of neurofeedback on individuals with SLI.

Comparison of Pre-Existing Behavioral Intervention and Assessment Methods with Those Using SLI Neurofeedback (RQ2)

Several of the selected studies performed a comparative analysis to validate their results, and this is shown in Table 4 below. Out of the selected studies, 62% performed comparative analysis and hence improved the quality of their studies. The percentage of selected papers with a comparative analysis section is depicted in Figure 7. Ros et al. (2013) built on a previous study to show that the plasticity of the brain can be increased with neurofeedback training. At around 30 minutes after training, the neurofeedback method induced a significant up-regulation of functional connectivity in the salience network, demonstrating that even half an hour can further affect cognitive response. Xiong et al. (2014) improved on previous studies by up-regulating the theta-to-alpha rhythm of EEG that projects to the anterior-parietal region. This up-regulation significantly improved the working memory of the study participants. In a similar study, Enriquez-Geppert et al. (2014) also upregulated Fm-theta power and reported that the participants in the experimental group experienced an increased difficulty than in the control group. More studies extended previous studies as well, including (Kinreich et al., 2012; Eroğlu et al., 2020; Guan et al., 2015; Breteler et al., 2010; Surmeli & Ertem, 2010; Myers & Young, 2012; Mayer et al., 2013; Angelakis et al., 2007; Jarusiewicz, 2002; Koush et al., 2013; Zweerings et al., 2019; Zotev et al., 2014; Choi, 2013; Rubí, 2007; Todder et al., 2010; Ninaus et al., 2015; Fahrion et al., 1992).

Citation Information: Shahin I., Nassif A.B., Elnagar A., Gamal S., Salloum S.A., & Aburayya A. (2021). Neurofeedback interventions for speech and language impairment: A systematic review. *Journal of Management Information and Decision Sciences, 24*(S1), 1-30.

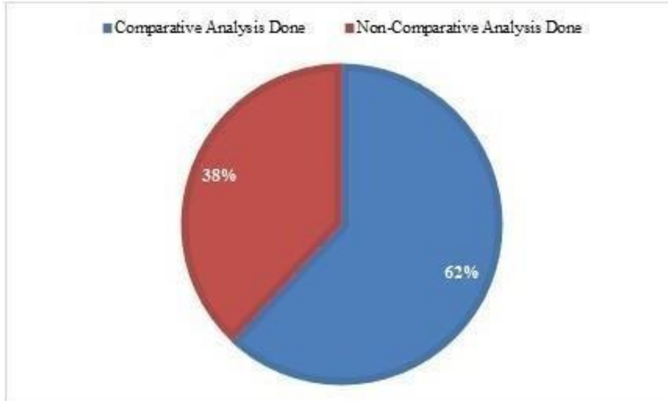

FIGURE 7 COMPARATIVE ANALYSIS DISTRIBUTION AMONGST SELECTED PAPERS

One of the studies Rubí (2007) included in our review simply surveyed neurofeedback practices from 47 practitioners in 27 countries and confirmed the shifting demographics of practitioners. Although Ochs et al. (2006) reported a significant flaw in the thickness of the tape and the excessive strength of stimulation used in Kravitz et al. (2006). Flexyx neurofeedback study, we observed a lack of quality controls in the authors' data. Another study by Thompson and Thompson (1998) provided evidence built on previous studies that children with Attention Deficit Disorder (ADD) can benefit from neurofeedback training; however, their study was not a controlled scientific study, so we have not included it in our comparative analysis distribution.

Suggestion of Standardization Methodologies and Procedural Guidelines, and Assistive Technology Solutions Using BCI Methods Targeting SLI Cognitive Profiles (RQ3)

Only 7 out of 50 studies (14%) suggested that BCI methods could be standardized and used to improve SLI cognitive profiles. Ros et al. (2013) showcased a novel protocol using BCI technology. Using their protocol, participants in the authors' study were able to reduce alpha (8–12 Hz), the dominant rhythm of the human brain, voluntarily via EEG neurofeedback. The authors suggested that their BCI protocol might be applicable in patients with ADHD and PTSD. Choi (2013) goes even further to address the practical limitations of BCIs by suggesting a significant modification to these interfaces. Other studies indicated the feasibility of EEG studies for therapeutic applications (Zaehle et al., 2010; Hammond, 2011; Kober et al., 2015; Naas et al., 2019; Jirayucharoensak et al., 2019; Varsehi & Firoozabadi, 2020; Jeunet et al., 2019; Bauer et al., 2020) and counseling (Myers & Young, 2012), but they were not focused only on BCI methods and, hence, were not included in our distribution calculation. Table 5 below depicts studies with standardized methodologies and procedural guidelines using BCI methods. The percentage of the selected studies that suggested or used BCI methods from the selected papers are highlighted in Figure 8.

Citation Information: Shahin I., Nassif A.B., Elnagar A., Gamal S., Salloum S.A., & Aburayya A. (2021). Neurofeedback interventions for speech and language impairment: A systematic review. *Journal of Management Information and Decision Sciences, 24*(S1), 1-30.

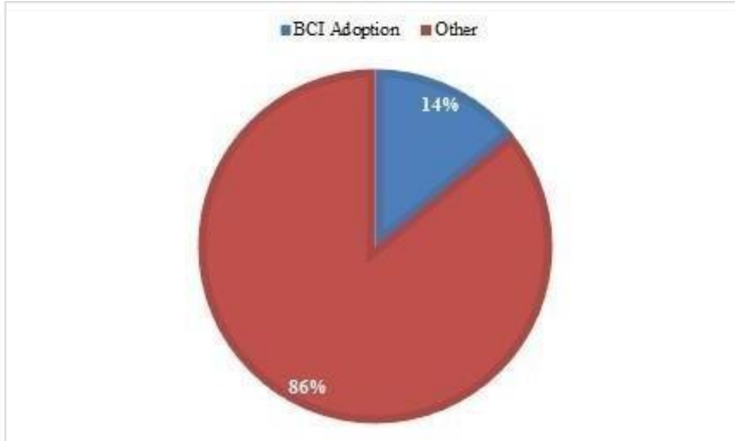

FIGURE 8 BCI ADOPTION DISTRIBUTION AMONG SELECTED PAPERS

Synthesis of Results

The synthesis offers an overview and comparison of qualitative evidence derived from these multiple selected studies. Based on electrode type and cortical projections, we identified five major themes specific to EEG and fMRI neurofeedback across the studies: STG controls phonological processing (speech), particularly the priming of articulatory planning; MTG influences auditory comprehension; ATL controls semantic processing; SFG affects executive functions (e.g., left SFG affects working memory, and task shifting and right SFG affects emotional self-regulation); and STG (Wernicke's area) controls phonological processing (sound perception). We isolated our synthesis analysis only to cortical projections shown by our selected studies to respond to EEG and fMRI. We observed overlap in the electrodes used to test language and auditory processing; two electrodes, FT7 and FT8, were projected to the temporal lobe, which controls both functions (Hickok, 2009; Di Salle et al., 2003). Different electrodes are projected to the posterior parietal and prefrontal cortices, both of which control attention (Petersen & Posner, 2012). Table 6 shows the full list of electrodes for these regions. The STG is in control of the spoken word, but, surprisingly, the left prefrontal cortex is sometimes activated during spoken word, in addition to written word (Zaidel, 2001). This poses a possible connection between these three functional areas of the brain.

IMPLICATIONS FOR RESEARCH AND PRACTICE

This systematic literature review has found that EEG and MRI neurofeedback may have significant clinical applications in positively influencing the cognitive, physiological profiles of individuals with SLI. Unfortunately, in previous studies, only a few authors performed quality control checks of their results or used case-based methodologies. Therefore, researchers are encouraged to perform more studies using EEG and MRI neurofeedback methodologies with strong quality checks and case-based methodologies to strengthen the empirical evidence. As to the implication for practitioners, this review has found that very few of the selected studies focus on standardization of BCI methods in clinical practice (only seven studies were found). Therefore, researchers are encouraged to suggest standardization methodologies and procedural guidelines using BCI Methods. This review is a pedestal for the future development of Speech or Linguistic Neurofeedback (SLN)

Citation Information: Shahin I., Nassif A.B., Elnagar A., Gamal S., Salloum S.A., & Aburayya A. (2021). Neurofeedback interventions for speech and language impairment: A systematic review. *Journal of Management Information and Decision Sciences, 24*(S1), 1-30.

studies that target specific brain regions as a focal point for the rehabilitation of individuals with SLI. Researchers can improve the BCI technology further to aid in the facilitation and optimization of the learning experience for individuals with SLI.

LIMITATIONS OF THIS REVIEW

This systematic review had several limitations. One limitation was the lack of Middle-Eastern studies on neurofeedback, as the focus of this SLR was the impact of such studies in this region. Another limitation is that the studies included in this SLR employed various applications of neurofeedback. Therefore, it was a challenge to compare them, and there were inconsistencies between comparisons. The insufficient number of the studies in this field may have contributed to these inconsistencies. Moreover, this research focuses on the available literature, and the lack of relevant curriculum-based neurofeedback studies necessitates future research in this field. Another limitation of this study is the study period itself. As new research emerges, our findings will require further updates. However, we have applied a rigorous systematic literature review for the included studies to aid in creating a predictive context for pending and future research. Another limitation of this study is the possible biases found within the studies included. However, we have conducted our SLR solely for the purpose of science and it has no corporate or government-based beneficiary. Lastly, this review did not consider studies published in other languages due to a language barrier. Therefore, we recommend that more researchers should perform further studies on neurofeedback interventions for SLI in the Middle-Eastern region and/or using the Arabic language.

CONCLUSION

Evidence from 50 studies demonstrates that EEG and MRI neurofeedback may have significant clinical applications in positively influencing the cognitive, physiological profiles of individuals with SLI. For researchers, we recommend more studies that have quality controls and are case-based. We also recommend that researchers use modern BCI systems for their studies. For future clinical applications, we recommend the standardization EEG and MRI neurofeedback training using BCI systems. EEG and MRI neurofeedback training methods are less expensive and yet more potent compared with pre-existing behavioral intervention and assessment methods that use SLI Neurofeedback. In addition, we recommend the integration of EEG neurofeedback methods into mainstream education for assistive technology, including those that are BCI-based. Finally, a meta-analysis is suggested for each SLI related brain function for a trend map of Neurofeedback study approaches, design improvement, and forecast.

ACKNOWLEDGMENT

The authors of this work would like to thank "University of Sharjah" for funding their work through the Machine Learning and Arabic Language Processing Research Group.

CONFLICT OF INTEREST

The authors declare that they have no competing interests.

Citation Information: Shahin I., Nassif A.B., Elnagar A., Gamal S., Salloum S.A., & Aburayya A. (2021). Neurofeedback interventions for speech and language impairment: A systematic review. *Journal of Management Information and Decision Sciences, 24*(S1), 1-30.

REFERENCES

Ackerman, S. (1992). Major structures and functions of the brain in Discovering the Brain Washington (DC): National Academies Press (US).

Al Kurdi, B., Alsurideh, M., Nuseir, M., Aburayya, A., & Salloum, S.A. (2021). The effects of subjective norm on the intention to use social media networks: An exploratory study using PLS-SME and machine learning approach. In A. Hassanien & K. Chang. Advanced Machine Learning Technologies and Applications, 324-334. Springer..

Al-Khayyal, A., Alshurideh, M., Al Kurdi, B., & Aburayya, A. (2020). The impact of electronic service quality dimensions on customers' e-shopping and e-loyalty via the impact of e-satisfaction and e-trust: A qualitative approach. International Journal of Innovation, Creativity and Change, *14*(9), 257-281.

Al-Maroof, R., Alhumaid, K., Alhamad, A.Q., Aburayya, A., & Salloum, S.A. (2021). User acceptance of smart watch for medical purposes: An empirical study. Future Internet, *13*(5), 127.

Angelakis, E., Stathopoulou, S., Frymiare, J.L., Green, D.L., Lubar, J.F., & Kounios, J. (2007). EEG neurofeedback: A brief overview and an example of peak alpha frequency training for cognitive enhancement in the elderly. *The Clinical Neuropsychologist, 21*(1), 110–129.

Battle, D. E. (2012). *Communication disorders in multicultural populations-e-book.* Elsevier Health Sciences.

Bauer, C.C.C. (2020). Real-time fMRI neurofeedback reduces auditory hallucinations and modulates resting state connectivity of involved brain regions: Part 2: Default mode network-preliminary evidence. *Psychiatry Research, 284,* 112770.

Breteler, M.H.M., Arns, M., Peters, S., Giepmans, I., & Verhoeven, L. (2010). Improvements in spelling after QEEGbased Neurofeedback in dyslexia: A randomized controlled treatment study. *Applied Psychophysiology and Biofeedback, 35*(1), 5–11.

Brinkman, S., Sayers, M., Goldfeld, S., & Kline, J. (2009). Population monitoring of language and cognitive development in Australia: The Australian early development index. *International Journal of Speech-Language Pathology, 11*(5), 419–430.

Capuyan, D.L., Capuno, R.G., Suson, R., Malabago, N.K., Ermac, E.A., …& Lumantas, B.C. (2021). Adaptation of innovative edge banding trimmer for technology instruction: A university case. World Journal on Educational Technology, *13*(1), 31-41.

Choi, K. (2013). Electroencephalography (EEG)-based neurofeedback training for Brain–Computer Interface (BCI). *Experimental brain research, 231*(3), 351–365.

Cicchetti, D., & Serafica, F.C. (1981). Interplay among behavioral systems: Illustrations from the study of attachment, affiliation, and wariness in young children with Down's syndrome. *Developmental Psychology, 17*(1), 36–49.

Di Salle, F. (2003). fMRI of the auditory system: understanding the neural basis of auditory gestalt. *Magnetic Resonance Imaging,* 21(10), 1213–24.

Dumas, J.E., Wolf, L.C., Fisman, S.N., & Culligan, A. Parenting stress, child behavior problems, and dysphoria in parents of children with autism, down syndrome, behavior disorders, and normal development. *Exceptionality, 2*(2), 97–110.

Elnagar, A., Yagi, S.M., Nassif, A.B., Shahin, I., & Salloum, S.A. (2021). Systematic Literature Review of Dialectal Arabic: Identification and Detection. *IEEE Access, 9,* 31010–31042.

Engelbregt, H.J. (2016). Short and long-term effects of sham-controlled prefrontal EEG-neurofeedback training in healthy subjects. *Clinical Neurophysiology, 127*(4), 1931–1937.

Enriquez-Geppert, S., Huster, R.J., & Herrmann, C.S. EEG-Neurofeedback as a tool to modulate cognition and behavior: A review tutorial. *Frontiers in Human Neuroscience, 11,* 5.

Enriquez-Geppert, S., Huster, R.J., Scharfenort, R., Mokom, Z.N., Zimmermann, J., & Herrmann, C.S. (2014). Modulation of frontal-midline theta by neurofeedback. *Biological Psychology, 95*(3), 59–69.

Eroğlu, G. (2020). Changes in EEG complexity with neurofeedback and multi-sensory learning in children with dyslexia: A multiscale entropy analysis. *Applied Neuropsychology: Child,* 1–12.

Fahrion, S.L., Walters, E.D., Coyne, L., & Allen, T. (1992). Alterations in EEG amplitude, personality factors, and brain electrical mapping after alpha-theta brainwave training: A controlled case study of an alcoholic in recovery. *Alcoholism: Clinical and Experimental Research, 16*(3), 547–552.

Farwell, L.A. (1993). Method and apparatus for Multifaceted Electroencephalographic Response Analysis (MERA).

Farwell, L.A., & Donchin, E. (1991). The truth will out: Interrogative polygraphy ("lie detection") with event-brain potentials. *Psychophysiology, 28*(5), 531–47.

Citation Information: Shahin I., Nassif A.B., Elnagar A., Gamal S., Salloum S.A., & Aburayya A. (2021). Neurofeedback interventions for speech and language impairment: A systematic review. *Journal of Management Information and Decision Sciences, 24*(S1), 1-30.

Fidler, D.J. The emerging Down syndrome behavioral phenotype in early childhood. *Infants & Young Children, 18*(2), 86-103.

Fielenbach, S., Donkers, F.C.L., Spreen, M., Smit, A., & Bogaerts, S. (2019). Theta/SMR neurofeedback training works well for some forensic psychiatric patients, but not for others: A sham-controlled clinical case series. *International Journal of Offender Therapy and Comparative Criminology*, *63*(14), 2422–2439.

Goldbart, J., & Sen, R. (2013). The world report on disability and communication disability: Some considerations from an Indian context. *The International Journal of Language & Communication Disorders, 15*(1), 21–26.

Goldman, R.I., Stern, J.M., Engel, J., & Cohen, M.S. (2000). Acquiring simultaneous EEG and functional MRI. *Clinical Neurophysiology, 111*(11), 1974–1980.

Gruzelier, J.H. (2014). "EEG-neurofeedback for optimising performance : A review of cognitive and affective outcome in healthy participants. *Neuroscience & Biobehavioral Reviews, 44*, 124–141.

Guan, M. Self-regulation of brain activity in patients with postherpetic neuralgia: A double-blind randomized study using real-time fMRI Neurofeedback. *PLoS One, 10*(4), e0123675.

Hallman, D.W. (2012). 19-Channel neurofeedback in an adolescent with fasd. *Expert Review of Neurotherapeutics,* 16(2), 150–154.

Hammond, D. C. (2011). What is neurofeedback: An update. *International Journal of Neurology and Neurotherapy* 15(4), 305–336.

Harley, A. (2014). *Neuroimaging as lie detection: Detecting retrieval of individual memories using EEG recordings*. Psyence blog.

Hickok, G. (2009). The functional neuroanatomy of language. Physics of Life Reviews, 6(3), 121–43.

Hoffman, L.M., & Gillam R.B. (2004). Verbal and spatial information processing constraints in children with specific language impairment. *Journal of Speech, Language, and Hearing Research*, *47*(1), 114–125.

Humpston, C. (2020). Real-time functional magnetic resonance imaging neurofeedback for the relief of distressing auditory-verbal hallucinations: methodological and empirical advances. Schizophrenia Bulletin, 46(6), 1409–1417.

Ikegami, S., Takano, K., Wada, M., Saeki, N., & Kansaku, K. (2012). Effect of the green/blue flicker matrix for P300based brain-computer interface: An EEG-fMRI Study. *Frontiers in Neurology, 3*(113).

Im, C.H., Hwang, H.J., Che, H., & Lee, S. (2007). An EEG-based real-time cortical rhythmic activity monitoring system. *Physiological Measurement*, *28*(9), 1101–1113.

Jarusiewicz, B. (2002). Efficacy of neurofeedback for children in the autistic spectrum: A pilot study. International *Journal of Neurology and Neurotherapy*, *6*(4), 39–49.

Jenatton, R. (2012). Multiscale mining of fMRI data with hierarchical structured sparsity. *SIAM Journal on Imaging Sciences, 5*(3), 835–856.

Jeunet, C., Glize, B., McGonigal, A., Batail, J.M., & Micoulaud-Franchi, J.A. (2019). Using EEG-based brain computer interface and neurofeedback targeting sensorimotor rhythms to improve motor skills: Theoretical background, applications and prospects. Clinical Neurophysiology, 49(2), 125–136.

Jirayucharoensak, S., Israsena, P., Pan-ngum, S., Hemrungrojn, S., & Maes, M. (2019). A game-based neurofeedback training system to enhance cognitive performance in healthy elderly subjects and in patients with amnestic mild cognitive impairment. *Clinical Interventions in Aging, 14,* 347.

Keizer, A.W., Verment, R.S., & Hommel, B. Enhancing cognitive control through neurofeedback: A role of gammaband activity in managing episodic retrieval. *Neuroimage, 49*(4), 3404–3413.

Kinreich, S., Podlipsky, I., Intrator, N., & Hendler, T. (2012). Categorized EEG neurofeedback performance unveils simultaneous fMRI deep brain activation. *Springer, 10*(3), 108–115.

Kinreich, S., Podlipsky, I., Jamshy, S., Intrator, N., & Hendler, T. (2014). Neural dynamics necessary and sufficient for transition into pre-sleep induced by EEG NeuroFeedback. *Neuroimage, 97,* 19–28.

Kober, S.E., Witte, M., Stangl, M., Väljamäe, A., Neuper, C., & Wood, G. (2015). Shutting down sensorimotor interference unblocks the networks for stimulus processing: An SMR neurofeedback training study. *Clinical Neurophysiology, 126*(1), 82–95.

Kolev, V., Demiralp, T., Yordanova, J., Ademoglu, A., & Isoglu-Alkaç, U. (1997). Time-frequency analysis reveals multiple functional components during oddball P300. *Neuro report, 8*(8), 2061–5.

Koush, Y. (2013). Connectivity-based neurofeedback: Dynamic causal modeling for real-time fMRI. *Neuroimage, 81,* 422–430.

Kravitz, H.M., Esty, M L., Katz, R.S., & Fawcett, J. (2006). Treatment of fibromyalgia syndrome using low-intensity neurofeedback with the flexyx neurotherapy system: A randomized controlled clinical trial. *International*

Citation Information: Shahin I., Nassif A.B., Elnagar A., Gamal S., Salloum S.A., & Aburayya A. (2021). Neurofeedback interventions for speech and language impairment: A systematic review. *Journal of Management Information and Decision Sciences, 24*(S1), 1-30.

Journal of Neurology and Neurotherapy, 10(2–3), 41–58.

Legarda, S.B., McMahon, D., Othmer, S., & Othmer, S. Clinical neurofeedback: Case studies, proposed mechanism, and implications for pediatric neurology practice. *The Journal of Child Neurology, 26*(8), 1045–1051.

Marzbani, H., Marateb, H.R., & Mansourian, M. Neurofeedback: A comprehensive review on system design, methodology and clinical applications. *Basic and Clinical Neuroscience, 7*(2), 143–58.

Matthews, P.M., & Jezzard, P. (2004). Functional magnetic resonance imaging. *Journal of Neurology, Neurosurgery, and Psychiatry, 75*(1), 6–12.

Mayer, K., Wyckoff, S.N., & Strehl, U. One size fits all? Slow cortical potentials neurofeedback. *Journal of Attention Disorders, 17*(5), 393–409.

Meir-Hasson, Y. (2016). One-class FMRI-inspired EEG model for self-regulation training. *PLoS One,11*(5), e0154968.

Merilainen, V. (2002). Magnetic resonance imaging with simultaneous electroencephalography recording: Safety issues. 2002.

Misaki, M. (2019). Brain activity mediators of PTSD symptom reduction during real-time fMRI amygdala neurofeedback emotional training. *NeuroImage: Clinical, 24*, 102047.

Moher, D., Liberati, A., Tetzlaff, J., & Altman, D.G. (2009). Preferred reporting items for systematic reviews and metaanalyses: the PRISMA statement. *Annals of internal medicine, 151*(4), 264–269.

Mustafa, M.W. (2004). Prevalence of the connexin-26 mutation 35delG in non-syndromic hearing loss in Egypt. *International Journal of Pediatric Otorhinolaryngology, 3*(1), 2004.

Myers, J.E., & Young, J.S. (2012). Brain wave biofeedback: Benefits of integrating neurofeedback in counseling. *Journal of Counseling & Development, 90*(1), 20–28.

Naas, A., Rodrigues, J., Knirsch, J.P., & Sonderegger, A. (2019). Neurofeedback training with a low-priced EEG device leads to faster alpha enhancement but shows no effect on cognitive performance: A single-blind, shamfeedback study. *PLoS One, 14*(9), e0211668.

Nassif, A.B., Shahin, I., Attili, I., Azzeh, M., & Shaalan, K. (2019). Speech recognition using deep neural networks: A systematic review. *IEEE Access*, *7*, 19143–19165.

Ninaus, M., Kober, S.E., Witte, M., Koschutnig, K., Neuper, C., & Wood, G. (2015). Brain volumetry and selfregulation of brain activity relevant for neurofeedback. *Biological Psychology, 110*, 126–133.

Ochs, L. (2006). Comment on the treatment of fibromyalgia syndrome using low-intensity neurofeedback with the flexyx neurotherapy system: A randomized controlled clinical trial, or how to go crazy over nearly nothing. *International Journal of Neurology and Neurotherapy, 10*(2–3), 59–61.

Office of the Registrar General & Census Commissioner. (2001).*Census of India: Disabled population*.

Petersen, S.E., & Posner, M.I. (2012). The attention system of the human brain: 20 years after. *Annual Review of Neuroscience, 35*, 73–89.

Pineda, J.A. (2008). Positive behavioral and electrophysiological changes following neurofeedback training in children with autism. *Research in Autism Spectrum Disorders*, *2*(3), 557–581.

Reilly, S., Bishop, D.V.M., & Tomblin, B. (2014). Terminological debate over language impairment in children: forward movement and sticking points. *International Journal of Speech-Language Pathology, 49*(4), 452–462.

Ros, T. (2013). Mind over chatter: Plastic up-regulation of the fMRI salience network directly after EEG neurofeedback. *Neuroimage, 65*, 324–335.

Rosenfeld, J.P., Soskins, M., Bosh, G., & Ryan, A. (2004). Simple, effective countermeasures to P300-based tests of detection of concealed information. *Psychophysiology, 41*(2), 205–219.

Rossi, S., Hallett, M., Rossin, P.M., Pascual-Leone, A., & Safety of TMS Consensus Group. (2009). Safety, ethical considerations, and application guidelines for the use of transcranial magnetic stimulation in clinical practice and research. *Clinical Neurophysiology, 120*(12), 2008–2039.

Rubí, M.C.M. (2007). Neurofeedback around the world. *International Journal of Neurology and Neurotherapy,10*(4), 63-73.

Salloum, S.A., Al Ahbabi, N., Habes, M., Aburayya, A., & Akour, I. (2021). Predicting the intention to use social media sites: A hybrid SME- machine learning approach. In A. Hassanien & K. Chang (Eds.), Advanced Machine Learning Technologies and Applications, 324-334.

Sattar, A.M.A., Ertuğrul, O.F., Gharabaghi, B., McBean, E.A., & Cao, J. (2019). Extreme learning machine model for water network management. *Neural Comput. Appl, 31*(1), 157–169.

Shahin, I., Nassif, A.B., & Hamsa, S. (2020). Novel cascaded Gaussian mixture model-deep neural network classifier for speaker identification in emotional talking environments. *Neural Comput. Appl, 32*(7), 2575–2587.

Sudirman, R., Saidin, S., & Safri, N.M. (2010). Study of Electroencephalography signal of autism and Down syndrome

Citation Information: Shahin I., Nassif A.B., Elnagar A., Gamal S., Salloum S.A., & Aburayya A. (2021). Neurofeedback interventions for speech and language impairment: A systematic review. *Journal of Management Information and Decision Sciences, 24*(S1), 1-30.

children using FFT. *2010 IEEE Symposium on Industrial Electronics and Applications (ISIEA)*, 401–406.

Sulzer, J. (2013). Real-time fMRI neurofeedback: Progress and challenges. *Neuroimage, 76,* 386–399.

Sürmeli, T., & Ertem, A. (2007). EEG neurofeedback treatment of patients with Down syndrome. *Expert Review of Neurotherapeutics, 11*(1), 63–68.

Surmeli, T., & Ertem, A. Post WISC-R and TOVA improvement with qeeg guided neurofeedback training in mentally retarded: A clinical case series of behavioral problems. *Clinical EEG and Neuroscience, 41*(1), 32–41.

Thompson, L., & Thompson, M. (1998). Neurofeedback combined with training in metacognitive strategies: Effectiveness in students with ADD. *Applied Psychophysiology and Biofeedback,* 23(4), 243–263.

Thompson, L., Thompson, M., & Reid, A. Neurofeedback outcomes in clients with Asperger's syndrome. *Applied Psychophysiology and Biofeedback, 35*(1), 63–81.

Todder, D., Levine, J., Dwolatzky, T., & Kaplan, Z. (2010). Case report: Impaired memory and disorientation induced by delta band down-training over the temporal brain regions by neurofeedback treatment. *International Journal of Neurology and Neurotherapy, 14*(2), 153–155.

Tomblin, J.B., Records, N.L., Buckwalter, P., Zhang, X., Smith, E., & O'Brien, M. (1997). Prevalence of specific language impairment in kindergarten children. *Journal of Speech, Language, and Hearing Research, 40*(6), 1245-60.

Varsehi, H., & Firoozabadi, S.M.P. (2020). An EEG channel selection method for motor imagery based brain–computer interface and neurofeedback using Granger causality. *Neural Networks, 133,*193–206.

Vickers, N.J. (2017). Animal communication: when i'm calling you, will you answer too?. *Curr. Biol, 27*(14), 713–715.

Wilson, W. (1993). The role of speech-language pathology and audiology in the management of handicapped children in Saudi Arabia, in *First International Conference of the Saudi Benevolent Association for Handicapped Children.*

Xiong, S., Cheng, C., Wu, X., Guo, X., Yao, L., & Zhang, J. Working memory training using EEG neurofeedback in normal young adults. *Bio-Medical Materials and Engineering, 24*(6), 3637–3644.

Zaehle, T., Rach, S., & Herrmann, C.S. (2010). Transcranial alternating current stimulation enhances individual alpha activity in human EEG. *PLoS One, 5*(11), e13766.

Zaidel, E. (2001). Brain Asymmetry. *International Encyclopedia of the Social & Behavioral Sciences,* 1321–1329.

Zhu, H., Cao, Y., & Zhang, Z. (2019). A training scheme for autism rehabilitation based on language comprehension using real-time fMRI neurofeedback. *Journal of Physics: Conference Series,* 1176(3), 32002.

Zotev, V., Mayeli, A., Misaki, M., & Bodurka, J. Emotion self-regulation training in major depressive disorder using simultaneous real-time fMRI and EEG neurofeedback. *NeuroImage: Clinical,* 27, 102331.

Zotev, V., Phillips, R., Yuan, H., Misaki, M., & Bodurka, J. (2014). Self-regulation of human brain activity using simultaneous real-time fMRI and EEG neurofeedback. *Neuroimage, 85,* 985–995.

Zweerings, J. (2019). Neurofeedback of core language network nodes modulates connectivity with the default-mode network: a double-blind fMRI neurofeedback study on auditory verbal hallucinations. *Neuroimage, 189,* 533–542.

Citation Information: Shahin I., Nassif A.B., Elnagar A., Gamal S., Salloum S.A., & Aburayya A. (2021). Neurofeedback interventions for speech and language impairment: A systematic review. *Journal of Management Information and Decision Sciences, 24*(S1), 1-30.