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A SYSTEMATIC REVIEW OF AUDITORY PROCESSING ABILITIES IN CHILDREN WITH SPEECH SOUND DISORDERS

Contributions:
A Study design/planning
B Data collection/entry
C Data analysis/statistics
D Data interpretation
E Preparation of manuscript
F Literature analysis/search
G Funds collection

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Abstract

Children with speech sound disorder (SSD) have incomplete phonological acquisition without organic alteration. These children's speech exhibits multiple phoneme omission, substitution, and distortion errors. Auditory processing disorders (APD) are associated with speech sound disorders. Since APD prevents the development of a stable representation of phonemes in the brain, it may cause speech issues and make semantics, syntax, and phonology challenging to acquire. The review summarises behavioral findings of auditory processing abilities in children with SSD. The study used a literature search of electronic databases (Google Scholar, Science Direct, Research Gate, PubMed) from 2007 to 2022. The retrieved articles were assessed in two stages: title and abstract screening, followed by a full-length article review. Six articles were selected after the full-length review of 12 shortlisted articles. The review of the articles showed that temporal processing abilities are affected in children with SSD. Thus, temporal processing is critical for developing phonological awareness because it is vital for perceiving and rapidly changing acoustic cues in speech. The close relationship between temporal processing and phonological awareness in children with SSD highlights the importance of including temporal processing assessment in these children. Appropriate auditory training which taps into temporal processing skills may improve phonological awareness in these children. The effect of auditory processing training on phonological skills in SSD children needs further study.

Key words: CAPD • auditory processing • speech sound disorder • phonological disorder

ZDOLNOŚCI PRZETWARZANIA SŁUCHOWEGO DZIECI Z DYSLALIĄ GŁOSKOWĄ – PRZEGLĄD SYSTEMATYCZNY

Streszczenie

Dzieci z dyslalią głoskową nie nabywają w pełni kompetencji fonologicznych pomimo braku nieprawidłowości organicznych. W mowie tych dzieci występują liczne błędy polegające na opuszczaniu, zastępowaniu lub zniekształcaniu głosek. Z dyslalią głoskową związane są zaburzenia przetwarzania słuchowego (APD). Ponieważ APD uniemożliwia utworzenie stabilnej reprezentacji głosek w mózgu, może powodować problemy z mówieniem i stwarzać problemy w nabywaniu umiejętności semantycznych, składniowych i fonologicznych. Przegląd ten podsumowuje wyniki badań behawioralnych w zakresie zdolności przetwarzania słuchowego dzieci z dyslalią głoskową. W badaniu wykorzystano przegląd literatury w elektronicznych bazach danych (Google Scholar, Science Direct, Research Gate, PubMed) z lat 2007–2022. Wyszukane artykuły poddano dwuetapowej ocenie: przesiewowej ocenie tytułu i streszczenia, a następnie analizie pełnego tekstu artykułu. Następnie wybrano sześć artykułów z krótkiej listy obejmującej 12 artykułów. Ich analiza wykazała, że u dzieci z dyslalią głoskową występują zaburzenia przetwarzania czasowego. Wynika z tego, że przetwarzanie czasowe ma zasadnicze znaczenie w rozwoju świadomości fonologicznej, ponieważ jest niezbędne do postrzegania i szybkiej zmiany wskazówek akustycznych w mowie. Ścisły związek pomiędzy przetwarzaniem czasowym i świadomością fonologiczną dzieci z dyslalią głoskową podkreśla znaczenie uwzględnienia oceny przetwarzania czasowego u tych dzieci. Odpowiedni trening słuchowy, uwzględniający rozwój zdolności przetwarzania słuchowego, może poprawić świadomość fonologiczną u tych dzieci. Wpływ treningu przetwarzania słuchowego na zdolności fonologiczne dzieci z dyslalią głoskową wymaga dalszych badań.

Słowa kluczowe: CAPD • przetwarzanie słuchowe • dyslalia głoskowa • zaburzenia fonologiczne

Key for abbreviations	
APA	auditory processing abilities
APD	auditory processing disorders
CAPD	central auditory processing disorders
CSD	consistent speech disorder
DD	dichotic digit

Key for abbreviations	
DEAP	diagnostic evaluation of articulation and phonology (test)
DPS	duration pattern sequence
DPT	duration pattern test
FI	figure identification
GDT	gap detection test
GIN	gap in noise
ISD	inconsistent speech disorder
MLD	masking level difference
NA	not applicable
NIH	National Institute of Health
PA	phonological ability
PCC-R	percentage consonants correct – revised
PhoST-K	phonological sensitivity training kit in Kannada
PPS	pitch pattern sequence
PTAT	protocol task awareness test
QCRI	Qatar Computing Research Institute
SPIN	speech perception in noise
SSD	speech sound disorder
SSW	staggered spondaic word test
U-TAP	Urimal test of articulation and phonology

Introduction

Children with speech sound disorder (SSD) exhibit delays in the age-appropriate production of speech sounds [1]. SSD children have incomplete phonological acquisition without any organic alteration; thus the speech of such children exhibits omission of multiple phonemes, substitution, and distortion errors. Communication with their family, teachers, and peers is hampered by sometimes unintelligible speech [2]. The prevalence of speech sound problems in children is about 8 to 9% [3].

SSDs are divided into two categories: articulation difficulties and phonological disorders. Articulation problems have an effect at the phonetic level, which is the muscular act of making speech sounds, whereas phonological process disorders involve the phonemic level, which is the cognitive activity involved in structuring speech sound contrasts. Sounds are distinguished from one another using these contrasts [4].

A functional hearing system is essential for speech sound acquisition. Hearing is involved from sound detection through speech sound processing in the auditory cortex [5]. The auditory system controls intricate behavioral processes such as auditory discrimination, sound lateralisation, sound localisation, temporal ordering and resolution, auditory recognition, and speech understanding in noise, all of which are referred to as auditory processing abilities [6]. Speech and language issues, such as phonological awareness deficits, are associated with auditory processing disorders (APD) [7,8]

Since APD prevents the development of a stable representation of phonemes in the brain, it may cause speech issues and make it difficult to acquire semantics, syntax, and phonology [9]. An inability or interference in the auditory information processing in the cortex is likely to impact the integration, comprehension, and interpretation of sound stimuli [10]. Studies have shown that children with SSD have auditory processing difficulties [11–13].

Even though the association between speech sound disorders and auditory processing has been extensively studied, the results are still unclear, and so too is the effect of auditory perception deficit on precise speech production. According to [14], there is no link between speech production and perception in children with SSD. Children with SSD could differentiate the sorts of sounds they cannot produce [15]. However, several studies have found that children with SSD have difficulty discriminating the sort of speech sounds that they produce with errors [16,17].

From this puzzling perspective, a systematic review may help in understanding auditory processing abilities in children with SSD. This review aims to summarise the existing findings on auditory processing abilities in children with SSD. This review might help underline the importance of including auditory processing assessments in managing children with SSD.

Material and methods

The research design of this systematic review used the Preferred Reporting Items for Systematic Review and Meta-analyses Statement (PRISMA) standards to guide the selection of what is suitable for inclusion in the review.

Inclusion criteria

Articles published in peer-reviewed publications within the last 12 years (2010–22) were considered. Studies were chosen based on the technique, data, and quality of results. Studies with at least 10 participants were included. Only original publications involving human subjects, suitable samples, and relevant data were considered. Only manuscripts available in the English language were examined. Selection of articles was based on the PECOS criteria (population, exposure, comparison, outcome, study design) [18]. Population: participant children with speech sound disorder. Exposure: APD tests (the only behavioral test). Comparison: typically developing peers / no control group. Outcome: the results of the behavioral APD tests. Study design: cohort, case-control, retrospective, and prospective studies.

Exclusion criteria

Articles with a poor methodology and manuscripts available in a language other than English were rejected. Studies using electrophysiological assessment for assessing processing ability, case studies, letters to the editor, systematic reviews, and editorials were excluded. The review did not include articles involving children with associated language and cognitive abnormalities.

Search strategy

Two researchers used the following electronic databases to conduct the literature search: PubMed, Google Scholar, J-Stage, Research Gate, and Science Direct. Articles published from 2007 to 2022 were included. Boolean operators AND, OR, and NOT were used during the search strategy. Relevant papers were found by scanning databases that included audiology, otolaryngology, and speech and language journals.

The keywords used for the search string for all databases were: speech sound disorder; phonological disorder; deviant speech auditory processing; misarticulation; central auditory processing disorders (CAPD); auditory processing; temporal processing; gap in noise; gap detection; binaural interaction; binaural integration; auditory closure; monoaural low redundancy; binaural separation; speech perception in noise; and SPIN.

Study selection

The studies for systematic review were selected in two stages. The two investigators were involved in the literature search. The shortlisted studies were assembled using the Rayyan QCRI (Qatar Computing Research Institute) systematic review online software, and duplicates were removed. The first stage involved reviewing all the selected articles for eligibility based on the title and abstract. Studies were chosen based on the technique, data, intervention, result quality, and if they satisfied all inclusion criteria. The selection in the second stage was based on the full-length article.

Quality assessment

The studies that were a part of the systematic review were evaluated for methodological quality. We used the National Institute of Health (NIH) quality assessment tool for the case–control study of the chosen studies. This checklist for case–control studies includes design, target population, selection bias, information gathering, information on the case and control separately, blinding, and key potential confounding variables. Based on the above parameters, an overall rating of poor, fair, or good was given. Both authors conducted the quality analysis, and there were no cases of disagreement. The methodological quality of the articles chosen ranged from good to fair.

Results

The present study systematically reviewed the auditory processing abilities of children with speech sound disorder. A total of 3,452 articles were obtained after reviewing all the databases, of which 152 duplicates were eliminated. The abstracts and titles of the remaining 3,300 articles were reviewed, and 3,288 articles were excluded as not fulfilling the review objectives. Full-text articles were retrieved for the 12 shortlisted abstracts. Based on the full-text review, 6 articles were eliminated: 3 of them did not have a full text in English, 2 studies used irrelevant methods and outcomes, and 1 article had less than 10 participants. Thus, 6 articles altogether were included in the review. A detailed PRISMA flow chart for the study selection is shown in **Figure 1**.

General features of the selected articles

All articles included in the study recruited children aged 5 to 11 years who had been diagnosed with a speech sound disorder using a standardised test. Children with normal peripheral hearing were considered in all the selected articles, and children with sensory, neurological, behavioral, cognitive, or craniofacial problems were excluded. Exactly 4 of the 6 studies included typical normal developing children in the control group [12,19–21]. In contrast, the remaining two studies [22,23] had no control group. All selected studies utilised behavioral APD tests to assess temporal processing, binaural interaction, integration, and auditory closure. There were 5 selected studies which reported a correlation between auditory processing and phonological skill. The study characteristics of all selected articles are summarised in **Table 1**.

Discussion

This review aims to provide understanding of auditory processing abilities in children with SSD. From 3452 articles, 6 were chosen for the systematic review, and their findings are summarised in **Table 1**. Children with SSD have impaired phonological acquisition, and their speech

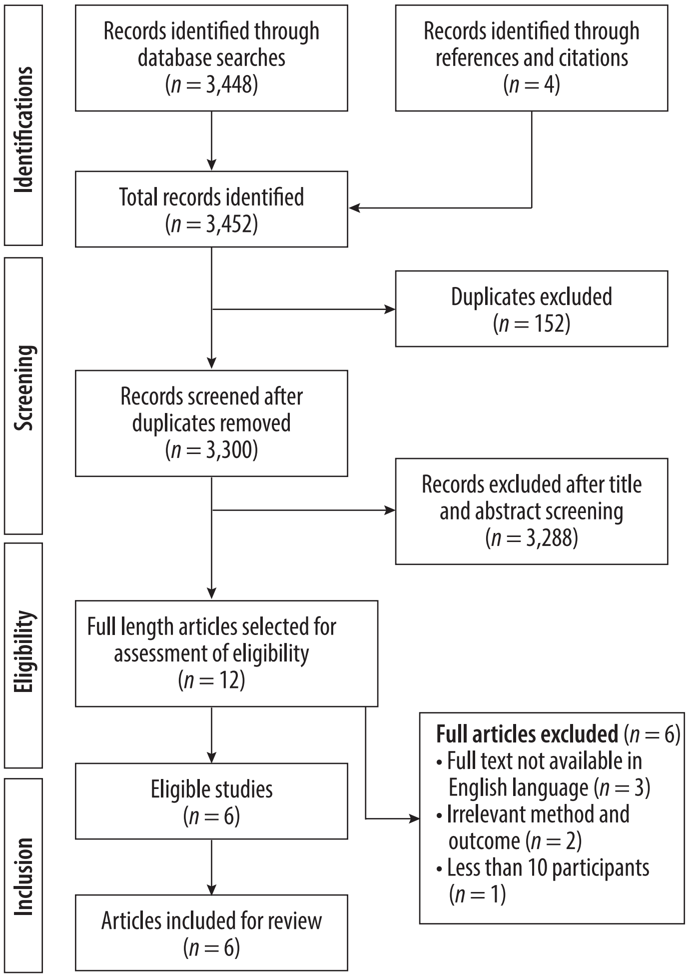

Figure 1. PRISMA flow chart for the selection of studies for this systematic review

is characterised by substitution, omission, and distortion errors. Auditory processing abnormalities are seen in children who have speech sound problems. Auditory processing deficiencies can lead to erroneous speech output by interfering with the perceptual knowledge of speech sounds and disrupting the mapping between the perception of acoustic patterns of speech sounds and productive speech gestures [10].

Bartz et al. (2015) examined binaural interaction in children with SSD by administering masking level difference, and the results showed that MLD was impaired in 54% of the children with SSD [22]. Binaural interaction is mainly responsible for speech recognition in the presence of competing signals by detecting differences in the intensity and timing of signals received in both ears [8]. However, this study showed no correlation between phonological ability

Table 1. Details of the participants, phonological and auditory processing assessment, and outcomes in children with SSD from the selected review articles

Author and year [ref nr]	Number of participants		Age range (years)	Phonological/ speech sound assessment	Language of phonological assessment	Behavioral test for auditory processing assessment	Result	Correlation between phonological and auditory processing abilities
	Control group (typical normal)	Study group (SSD children)						
Jung & Lee (2020) [19]	10	10	8–10	U-TAP	Korean	GIN	Normal group had significantly better (shorter) GIN thresholds compared to children with SSD ($p < 0.01$)	Percentage correct score in GIN test had significant positive corelation with U-TAP performance ($\rho = -0.44$, $p < 0.05$)

Table 1 continued. Details of the participants, phonological and auditory processing assessment, and outcomes in children with SSD from the selected review articles

Author and year [ref nr]	Number of participants		Age range (years)	Phonological/ speech sound assessment	Language of phonological assessment	Behavioral test for auditory processing assessment	Result	Correlation between phonological and auditory processing abilities
	Control group (typical normal)	Study group (SSD children)						
Jain et al. (2020) [12]	16	16	6–11	PhoST-K	Kannada (Indian language)	GDT DPT	Children with SSD showed significant poorer scores in GDT ($U = 39.5$, $p = 0.001$) and DPT ($U = 49.5$, $p = 0.003$)	There was a significant negative correlation between GDT and the syllable deletion task ($\rho = -0.520$, $p < 0.05$) and the phoneme deletion test ($\rho = -0.519$, $p < 0.05$). DPT showed a significant positive correlation with the syllable oddity test ($\rho = 0.537$, $p < 0.05$) and the phoneme oddity task ($\rho = 0.521$, $p < 0.05$)
Sayyahi et al. (2017) [21]	43	Total 52 22 = inconsistent speech disorder (ISD); 30 = consistent speech disorder (CSD)	5–6	DEAP	English	Phonetic gap detection	There was no significant difference ($p = 0.55$) between the normal and CSD groups. However, ISD children performed significantly poorer than normal and CSD children ($p < 0.01$)	NA
Bartz et al. (2015) [22]	–	57	5–10	Phonological assessment protocol	Portuguese	MLD	MLD was affected in 34 children (54%) with phonological disorder	There was no statistical correlation between MLD and speech intelligibility ($p = 0.199$)
Vilela et al. (2016) [23]	–	27 G-I: 13 children with SSD and without CAPD; G-II: 14 children with SSD and CAPD	7–10	Phonological test derived from infantile language test-ABFB PCC-R	Portuguese	FI DD PPS DPS	APD test was used to divide SSD children into, with, and without CAPD	A significant difference in PCC-R score was observed between G-I and G-II. SSD children with CAPD had greater severity of speech disorder compared to SSD children without CAPD ($p = 0.023$)
Quintas et al. (2010) [20]	22	22	5–7	PTAT	Portuguese	SSW Dichotic listening test Binaural fusion test	Children with a phonological disorder had a poorer score on all phonological and auditory processing tests compared to normal (but no statistical test for group comparison)	Both groups showed a strong negative correlation between phonological and auditory processing scores. An indication that the larger the deviation in auditory performance scores, the poorer the performance on the phonological test

Note: CSD, consistent speech disorder; DD, dichotic digit; DEAP, diagnostic evaluation of articulation and phonology test; DPS, duration pattern sequence; DPT, duration pattern test; FI, figure identification; GDT, gap detection test; GIN, gap in noise; G-I, group 1; G-II, group 2; ISD, inconsistent speech disorder; MLD, masking level difference; NA, not applicable; PhoST-K, phonological sensitivity training kit in Kannada; PCC-R, percentage consonants correct-revised; PPS, pitch pattern sequence; PTAT, protocol task awareness test; SSW, staggered spondaic word test; U-TAP, Urimal test of articulation and phonology

(PA) and auditory processing abilities (APA), hinting that other processes may be involved in children with SSD.

Temporal processing is the most significant auditory processing ability in developing speech perception. As natural speech fluctuates rapidly over time, the ability to perceive rapid temporal acoustic cues may be crucial for speech perception [24]. Temporal processing has been studied in children with SSD using tests such as the gap in noise test, gap detection test, duration pattern test, and pitch pattern test. The results show that these children's temporal processing is significantly impaired [12,19,21]. SSD children had poor ability in discrimination, remembering brief stimuli in rapid succession, and sequencing [25]. According to Sayyahi and colleagues [21], the consistency of speech sound errors in SSD children is affected by the gap detection threshold for speech sounds. There was a significant correlation between the consistency of speech problems and gap detection threshold in children with SSD. Children with inconsistent speech sound problems performed considerably worse in the gap detection test. The gap detection threshold may be too high for a small temporal window of phonetic discrimination, resulting in unpredictability in speech production. Thus, a strong correlation exists between phonological and temporal processing abilities [12,19]. Temporal processing is essential for discriminating consonants and other speech sounds and percepts. It is important for phonological awareness, as it recognises, isolates, and manipulates specific phonemes in words [25]. It has also been reported that auditory processing problems affect the severity of SSD in children. When an auditory processing impairment coexists with a speech sound disorder, children score lower on phonological evaluations [12,19,21], and we believe that SSD children's temporal processing is also significantly affected. Thus, we conclude that temporal processing plays a critical role in developing phonological awareness and is vital in perceiving rapidly changing acoustic cues in speech. The close relationship between phonological awareness and temporal processing in children with SSD highlights the importance of including temporal processing when assessing these children. Providing appropriate auditory training centering around temporal processing skills may improve these children's phonological awareness.

Future studies on profiling auditory processes in children with SSD are required, and the effect of auditory processing interventions on phonological awareness needs to be studied.

Conclusion

Based on various behavioral test findings, children with SSD exhibit deficits in temporal processing abilities. Temporal processing is vital in developing phonological awareness and accurate speech production. Thus, it is essential to include temporal processing in assessing and managing these children. However, there is a need for studies profiling complete auditory processes in these children. The effect of auditory processing interventions on phonological awareness also needs to be studied in future.

Statement of tnterest

The authors state there is no conflict of interest.

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