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EVALUATION OF ENDOGENOUS AUDITORY EVOKED POTENTIALS IN CHILDREN WITH SPECIFIC LANGUAGE IMPAIRMENT: A REVIEW

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

Introduction: Children with specific language impairment (SLI) have poorer language ability and have difficulties understanding complex sentences even though they have no clear sensory, motor, or neurological abnormalities. Nevertheless, they may exhibit auditory processing deficits. Hence the present study was conducted to provide an overview of endogenous auditory evoked potentials in this population, potentials which may help in early identification of subtle auditory processing deficits.

Material and methods: Relevant articles were included from searches of two electronic data sources, Google Scholar and PubMed. Articles on endogenous potentials in children with SLI were included, but studies on exogenous potentials in children with SLI were excluded.

Results: The results of the review showed contradictory findings in terms of mismatch negativity. Some studies report a statistically significant difference in waveform morphology, latency, and amplitude of mismatch negativity between children with SLI and a control group. This suggests that these children might have auditory processing problems at higher auditory centers. A few other studies find no difference in evoked potentials, pointing to intact auditory processing abilities in children with SLI.

Conclusion: The study helps us understand auditory processing abilities at the level of the higher auditory areas. Endogenous potentials may be included in a battery of tests for identifying children with SLI.

Key words: P300 • specific language impairment • N400 • mismatch negativity • endogenous auditory evoked potentials • P600

OCENA ENDOGENNYCH SŁUCHOWYCH POTENCJAŁÓW WYWOŁANYCH U DZIECI ZE SPECYFICZNYMI ZABURZENIAMI JĘZYKOWYMI – PRZEGLĄD

Streszczenie

Wprowadzenie: Dzieci ze specyficznymi zaburzeniami językowymi (SLI) mają słabsze zdolności językowe i trudności w rozumieniu złożonych zdań pomimo braku widocznych nieprawidłowości sensorycznych, ruchowych czy neurologicznych. Niemniej mogą przejawiać deficyty przetwarzania słuchowego. Celem niniejszej pracy jest przedstawienie przeglądu piśmiennictwa dotyczącego endogennych słuchowych potencjałów wywołanych dla tej populacji. Badanie tych potencjałów może pomóc we wczesnej identyfikacji niewielkich deficytów przetwarzania słuchowego.

Materiał i metoda: W przeglądzie uwzględniono artykuły dotyczące omawianego tematu pozyskane z kwerendy dwóch elektronicznych baz danych: Google Scholar i PubMed. Włączono także artykuły na temat endogennych potencjałów u dzieci z SLI, a wyłączono artykuły na temat egzogennych potencjałów u dzieci z SLI.

Wyniki: Wyniki przeglądu literatury wykazały istnienie sprzecznych ustaleń odnośnie fali niezgodności. W niektórych badaniach stwierdzono statystycznie istotne różnice w morfologii, latencji i amplitudzie fali niezgodności pomiędzy dziećmi z SLI a grupą kontrolną. Wynik ten sugeruje, że u dzieci z SLI mogą występować problemy z przetwarzaniem słuchowym na poziomie wyższych ośrodków słuchowych. W kilku badaniach nie znaleziono różnic w potencjałach wywołanych, co wskazuje na nienaruszoną zdolność przetwarzania słuchowego u dzieci z SLI.

Wnioski: Niniejszy przegląd pomaga zrozumieć zdolności przetwarzania słuchowego na wyższych poziomach drogi słuchowej. Badanie potencjałów endogennych może zostać włączone do baterii testów diagnostycznych dla dzieci ze SLI.

Słowa kluczowe: P300 • specyficzne zaburzenia językowe • N400 • fala niezgodności • endogenne słuchowe potencjały wywołane • P600

Introduction

Specific language impairment (SLI) is a developmental language disorder which affects 3–10% of children [1] and which impacts the child's educational and psychosocial development and overall outcome [2]. A child with SLI has normal intelligence and no sensory disorder, serious emotional or physiological problem, or environmental deprivation [3]. The cause of SLI is unknown, but recent discoveries suggest there is a strong genetic link. Children with SLI are more likely than those without to have parents and siblings who also have had difficulties and delays in speaking (NIDCD, 2019) [4]. Significant difficulties in language acquisition and receptive or expressive language can be observed in about 6–8% of this population [1,3]. Approximately 5% of primary school children (6–11 years) are estimated to have SLI, also known as developmental language disorder, DLD [5]. On average, children with

SLI exhibit a delay in learning new words, have difficulties understanding complex sentences, and often produce poorer language than typically developing children [6]. In some children with SLI, cognitive impairments in SLI include deficits in speech perception, working memory, and phonological short-term memory [7].

For several decades it has been observed that many children with SLI have associated auditory processing deficits [8]. Previous research has shown that a few patients with auditory processing deficits have difficulty perceiving small acoustic differences [9]. They might also exhibit subtle auditory perceptual problems or auditory agnosia [10], low-level abnormalities in auditory perception [11], and deficits in the ability to process rapidly changing acoustic information [12]. Lowe and Campbell [13] were the first to find auditory temporal discrimination deficits in children with SLI. All these studies suggest that there might be a specific disturbance in the perception of the sequence of auditory events in children with SLI. Speech perception and language learning involving phonology, syntax, or semantics can be affected due to the unstable representation of phonemes [14]. Children with SLI are at a higher risk of struggling academically due to their linguistic difficulties, preventing them from learning as easily as their peers from spoken language in the classroom or from the reading material provided to supplement class instruction [15].

The studies mentioned above suggest there might be an underlying neurobiological cause for SLI that lead to subtle deficits in information processing. The difficulties faced by children with SLI might be similar to those seen in individuals with neuro-audiological abnormalities [10]. Thus, in children with SLI electrophysiological tests could be very useful in assessing the auditory structures for possible functional abnormality. It is possible that these tests could identify subtle auditory neural deficits, which in turn might help us understand why expressive and receptive language is affected in children with SLI.

A systemic review on obligatory eleoctro-physiological test results is reported in our earlier review article [16]. The present article focuses on test results of non-obligatory or endogenous potentials in children with SLI. The endogenous potentials which are recorded from the human scalp-provide us the information regarding some of the cerebral mechanisms that underlie attention, memory, language processing and information processing [17]. They also help us to understand the mechanisms in normal subjects which in turn suggest the possible abnormal processes that may occur in patients with disorders of higher neural function [17]. Endogenous potentials enable neurophysiological evaluation of cognitive processes; in children, they also reflect lexical–semantic, morpho–syntactic, and syntactic processing [18].

Endogenous auditory evoked potentials (AEPs)

Endogenous potentials are related to the psychological significance of the stimulus to the subject [17]. These event-related potentials are triggered by external events; however, their variance is primarily dependent on variations in the task assigned to the subject. Mismatch negativity (MMN) potentials – P300, N400, and P600 – are important endogenous potentials which, given an appropriately structured task, follow the exogenous P1, N1, and P2 components. These components are typically elicited in an oddball paradigm in which a relevant task – an oddball (target) stimulus – occurs randomly within a series of repeating (non-target) stimuli that occur more frequently. Parameters of recordings include morphology, wave latency (conduction time), and amplitude (voltage) of the potentials. Diagnostic inferences from AEPs are derived by comparing these parameters. The findings of studies on endogenous auditory evoked potentials in children with SLI are discussed in terms of these parameters.

The main aim of the present study was to understand the range of findings about endogenous AEPs studied in children with SLI. This review aims to throw light on understanding auditory processing abilities in children with SLI based on endogenous AEPs. It should also help clinicians and new researchers to the field understand the relevance of including these potentials in a test battery assessing auditory processing in children with SLI. We focus on a review of the literature concerning four endogenous potentials – MMN, P300, N400, and P600 – in children with SLI.

Material and methods

The method used for reviewing the various research studies from the past years involved searching databases using different combination of keywords. A PICOS design (participant, intervention, control, observation, and study) proposed by Moher et al. [19] was used for selecting articles suitable for the study. According to Considine et al. (2017) [20], the PICO framework should also be used to develop search terms along with Medical Subject Headings (MeSH) and any other terms found to be relevant. Google Scholar and PubMed were the databases used for the search. A total of 210 articles were selected for abstract screening; out of these, 52 were retained for full length screening. Exactly 12 articles met the inclusion criteria and were included in the present review; the remaining 40 articles were rejected.

Inclusion criteria: Studies were included based on the PICOS system. Non-invasive endogenous potentials in language impaired children were included. Children aged 3–15 years with bilateral normal hearing sensitivity were included. Studies having a control group consisting of typically developing children in the same age range for comparison with children with SLI were included. The results obtained in these two groups were analyzed and observations were made based on these results.

Exclusion criteria: Invasive potentials and the endogenous potentials in adults were excluded. Studies on exogenous potentials were not included. Studies which focused on behavioral tests to assess auditory processing abilities were also excluded.

Search strategy: The articles were included from the results of the searches from the electronic data bases and included the articles on the endogenous potentials studied in children with SLI. Two databases were searched, PubMed and Google Scholar.

Search terms: Endogenous auditory evoked potentials in children with SLI or language impairment; MMN/P300/N400/P600 in children with SLI or language impairment.

Data extraction: The data was extracted based on the subjects, tests used, and the methodology.

Selecting relevant articles: Articles relevant to the present study were selected through screening them at different levels. All the titles and abstracts of the articles were screened to determine the eligibility for inclusion in the review. Selected articles were summarized under the respective endogenous potentials.

Results

A total of 849 articles were obtained from two databases, Google Scholar (n = 360) and PubMed (n = 489). After excluding the duplicates among these articles, 594 articles were retained for title screening. 210 articles met the inclusion criteria for abstract screening. The remaining 384 articles were rejected after title screening. After an intensive and exhaustive review among 210 articles, 52 articles were retained for full length article screening. These articles were further scrutinized based on the inclusion criteria of the present study. In order to select the articles systematically, PICOS (participant, intervention, control, outcome and study) design was used, proposed by Moher et al. [19]. A thorough review of the 52 articles led to the selection of 12 articles. The other 40 articles were rejected as they did not meet the inclusion criteria. The process followed has been presented in the form of flow chart in Figure1. The results from the selected articles will be explained under each endogenous auditory evoked potential.

Mismatch negativity (MMN)

After a detailed review, 5 MMN based articles were selected. Mismatch negativity is an electrophysiological measure that evaluates the brain's capacity to discriminate sounds, regardless of attention and behavioral capacity. It also enables the evaluation of phonemes of a particular language. Mismatch negativity has been studied extensively in various populations such as children with dyslexia [21], children with learning disabilities [22], children with dysphasia [23], developmental language and literacy impairments [24], autism [25], and auditory processing disorder [26]. So far there have been only a few studies of MMN in children with SLI [26]. A summary of the 5 articles on MMN in children with SLI is shown in Table 1.

Figure 1. Flow chart illustrating the procedure followed for selection of articles for review

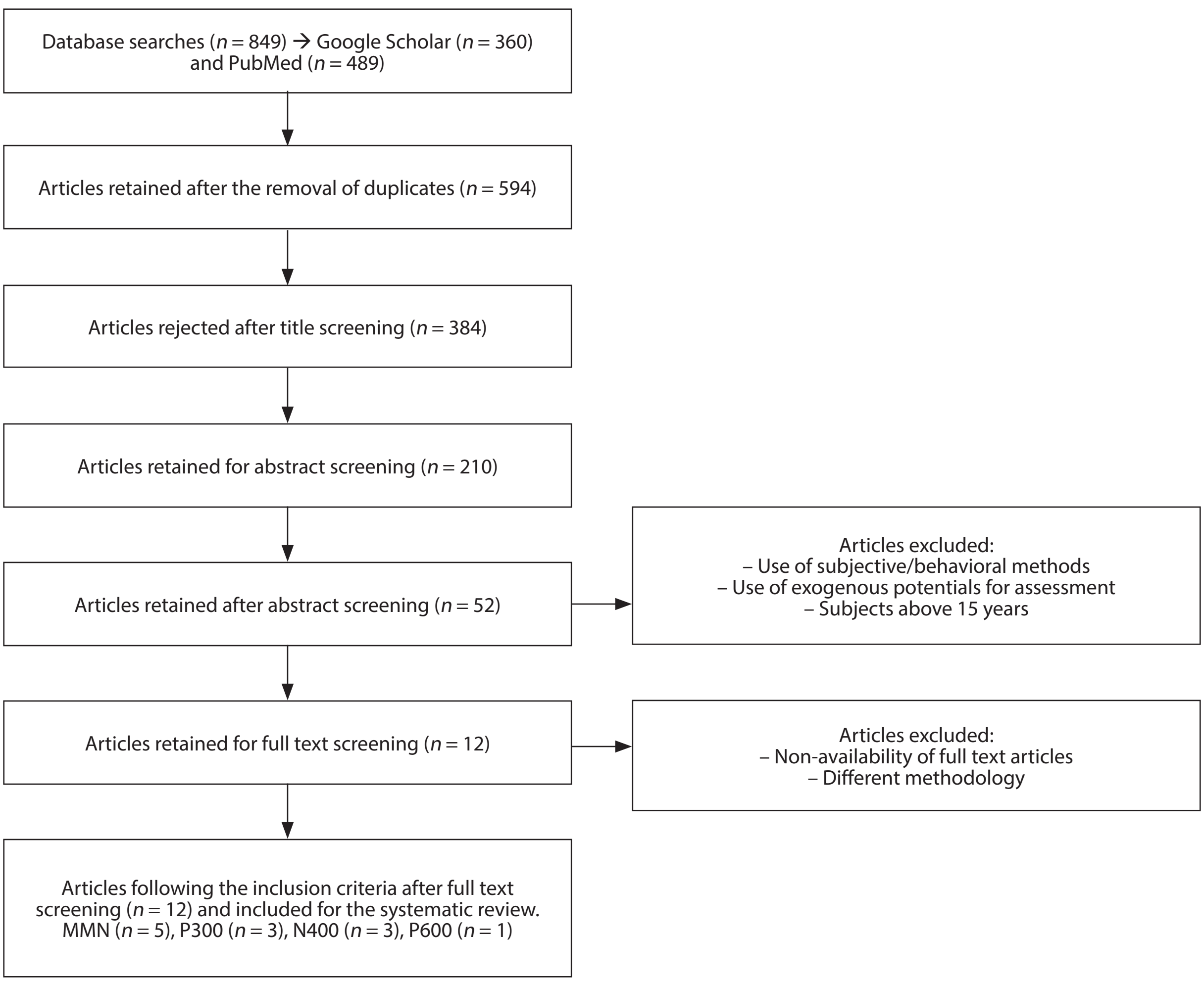

Table 1. Summary of 5 identified MMN articles. TD, Typically Developing children; SLI, Specific Language Impairment

S/N	Study	Age range	No of subjects	Material and methods
1.	Rocha-Muniz, Befi-Lopes & Schochat, 2015 [27]	6–12 years	SLI: 25 TD: 25	Children with bilateral normal hearing were included. MMN was obtained by presenting acoustic speech stimuli (plosive consonants /da/ and /ga/). 1600 stimuli were used, out of which 1400 (86%) were common (/ga/) and 200 (14%) were rare (/da/). Stimuli were presented in 8 sets of 200 stimuli (175 frequent and 25 rare), with a 4-s interval between the sets. The stimuli were randomly presented in an oddball paradigm to trigger MMN at a rate of 1.5 per s.
2.	Davids, Segers, van den Brink, Mitterer, van Balkom, Hagoort, et al., 2011 [28]	5 years	SLI: 25 TD: 25	IQ and language tests were conducted. The SLI group scored significantly lower on all the language tests of receptive language, productive language, auditory discrimination, rhyme and grapheme knowledge, attention task, and on both linguistic identification and discrimination tasks. MMN was conducted using linguistic stimuli – Dutch words /kɑn/and/pɑn/. Non-linguistic stimuli created by spectral rotation of the average linguistic stimuli were also used. Oddball paradigm was used to elicit MMN responses in which the occurrence of deviants was 12%. Each linguistic and nonlinguistic contrast were presented in 4 blocks. The standard stimuli were presented in 2 blocks and the deviant stimuli were presented in 2 blocks within each contrast. 80 deviant and 587 standard stimuli were presented for each unique stimulus.
3.	Shafer, Morr & Datta, 2005 [29]	SLI – 9.3 years TD – 8.11 years	SLI: 8 TD: 11	IQ and language tests were conducted. Significantly lower scores were obtained for children with SLI on language test, but not on IQ test. There were 4 stimuli used in the study: stimuli 1 and 2 were the vowel [I] and stimuli 3 and 4 were the vowel [e]. Passive and attend tasks were used. In both tasks, stimulus 4 occurred on 79% of trials and stimulus 1 on 21% of trials (with a total of 400 deviant trials).
4.	Rinker, Kohls, Richter, Maas, Schulz & Schecker, 2007 [30]	7–11 years	SLI: 13 TD: 13	Children with normal hearing with a non-verbal IQ>85 were included. Language tests were conducted. The language-impaired group scored at least 2 standard deviations below the norm on either receptive or expressive language. A significant difference was obtained between children with SLI and controls: expressive subtest: $p = 0.001$ and receptive subtest: $p < 0.001$. Stimuli were sine tones of 700 Hz (standard) and 750 Hz (deviant). The deviant tone occurred with $p = 0.15$. A total of 1200 tones were presented. Two time windows were employed: 140–280 ms (MMN1) and 420–620 ms (MMN2).
5.	Abou-Elsaad & Abdel Tawwab, 2009 [26]	SLI: 3–11 years TD: 3–10 years	SLI: 39 TD: 33	IQ test, language, and audiological evaluation were done to include children who met the inclusion criteria based on these test results. MMN was calculated by subtracting the waveform obtained from the standard stimulus from the deviant stimulus. A standard tone burst of 750 Hz ($p = 0.8$) and a deviant 1000 Hz tone burst ($p = 0.2$) were used as stimuli. Surface electrodes were used for recording MMN.

Results	Comments
1. Waves were present in 76% (21 of 25) in the SLI group. 2. Waves had longer latencies and lower amplitudes compared to the control group. 3. Waves were present in all (25/25) TD children. 4. The mean MMN latency in the TD group was shorter than in the SLI group.	This indicates that the SLI group had some hindrance at neural levels to accurately discriminate the contrasts from the stimuli. MMN also indicated that phonological deficits can coexist with difficulties in processing acoustic differences between stimuli. This may lead to poor auditory perception.
1. Significant MMNs were not elicited for both linguistic and non-linguistic stimuli conditions in the SLI group. 2. Smaller response amplitudes and longer latencies for speech and non-speech sound changes were observed in children with SLI. 3. Absent MMN in response to either the linguistic or non-linguistic contrast was obtained in children with SLI.	This implies that children with SLI have impaired processing of linguistic as well as non-linguistic information compared to the control group.
1. MMN obtained for the deviant stimulus was more negative than that of the standard stimulus beginning around 100 ms and extending almost to 300 ms in children with TLD. 2. Greater negativity of the ERP to the deviant was also observed for children with SLI. 3. A clear MMN was observed in 2 of 8 children with SLI in the passive task, and in 1 of 8 children in the attend task. 4. In contrast, 7 of 11 and 9 of 11 TLD children showed a robust MMN in the passive task and in the attend task respectively. 5. Significant difference was seen in the proportion of children showing a robust MMN in the attend task but not in the passive task for the two groups. 6. Greater negativity was observed for the deviant compared with standard stimulus in a later time frame in both the groups. This late negativity (LN) peaked at fronto-central sites between 300 and 500 ms. 7. For the TLD children, two neurophysiological measures (MMN and LN) indexed discrimination of the vowels in both tasks. In contrast, only LN was elicited in either task for the SLI group. LN was present, but no early MMN or absence of MMN was observed in children with SLI. 8. Robust MMN and LN were present in TD group.	Children with SLI showed no MMN either in passive or attend task and most of them had poor behavioral identification. Both groups of children showed an LN component in both ERP tasks and good behavioral discrimination. The findings suggest that children with SLI have speech perception deficiencies reflected in the absence of MMN and in poor behavioral identification, although the underlying cause may vary.
1. Area measurements revealed that a significant MMN1 was present for controls at Fz and Cz. But for children with SLI, a significant MMN1 was observed at Fz but not at Cz. 2. MMN2 was significantly seen in the control group at Fz and Cz, whereas it was found to be absent in the SLI group at both placements. 3. Significant hemispheric differences were observed for both MMN1 and MMN2. A significant fronto-central MMN1 and MMN2 were observed in controls with more left-localized activity for the second negativity. For children with SLI, MMN1 was elicited only at Fz but not at Cz with a slightly right-localized focus. 4. The area of MMN2 was not significant in children with SLI. 5. MMN was absent in children with SLI in the second time window.	The results suggest a frequency discrimination deficit in children with SLI. This deficit may become apparent for small frequency changes (e.g. about 50 Hz or less). The language impairments in children with SLI might be strongly influenced by weaker auditory discrimination ability rather than lower IQ.
1. Statistically non-significant differences were detected. 2. A clear and a robust MMN was obtained in the control group with a latency ranging from 105 to 215 ms with a mean latency of 151 ± 31 ms. 3. Amplitude ranged from 10 to 22 µV with mean of 16 ± 3.5 µV. 4. A clear and robust MMN was obtained in the SLI group also. 5. Latency ranged from 100 to 210 ms with mean of 152 ± 33 ms. 6. Amplitude of MMN in this group ranged from 9.8 to 22.4 µV with a mean of 14.6 ± 3.8 µV. 7. There was no significant difference in the latency and amplitude of MMN between the two groups.	It was concluded that children with SLI have intact neurophysiological measures of auditory processing that reflect their pre-attentive process. Some other factors rather than the auditory processing might be the cause for delayed language development in this population.

Table 2. Summary of 3 identified P300 articles. TD, Typically Developing children; SLI, Specific Language Impairment

S/N	Study	Age range	No of subjects	Material and methods
1.	Shaheen, Shohdy, Raouf, Abd & Elhamid, 2011 [34]	4–6 years	SLI: 40 TD: 20	Psychometric evaluation, language assessment, and audiological assessment. The SLI group obtained poorer scores than the control group in language domains (receptive, expressive, and total language age). Event-related potentials ERPs (P300) were recorded. P300 responses were recorded for target stimulus (a tone). Frequent tones were ignored. P300 amplitude and latency were measured.
2.	Evans & Pollak, 2011 [35]	11.9–14.1 years	SLI: 10 TD: 10	IQ test, speech and language evaluation, audiological assessment, visual and motor skill assessment, and cognitive assessment. Auditory and visual modality with working memory task (memory load) was used to elicit P300 responses. Auditory stimuli consisted of 24 words (12 monosyllabic common nouns and verbs). Visual stimuli consisted of 24 faces (12 males, 12 females, 16 Caucasian, 8 Asian). All stimuli were 800 ms with an ISI of 1.6 s.
3.	Włodarczyk, Szkiełkowska, Pilka & Skarżyński, 2017 [36]	7–10 years	SLI: 100 TD: 100	All children underwent phoniatric examination and evaluation of peripheral organs of speech, audiological evaluation, psychological examination, speech and language evaluation, and cortical auditory evoked potentials (P300). Oddball paradigm was used with 0.5 kHz as standard stimulus and 2 kHz as oddball stimulus.

Conflicting results have been observed using MMN in the auditory processing ability of children with SLI. Some studies found that an increase in amplitudes, while others found decreases. It has been proposed that the increase in amplitude may indicate the increased effort employed by children with SLI to process stimuli [31]. Thus, problems with physiological processing are responsible for poor discrimination of acoustic contrasts at pre-attentional and preconscious levels, contributing to poor perception [23]. On the other hand, a clear and robust MMN waveform with no significant difference in latency or amplitude compared to typically developing children indicates that children with SLI have intact auditory processing that reflects pre-attentive processing [26].

P300

There were three P300 based articles that met the inclusion criteria. P300, earlier commonly known as P3, is a positive wave that occurs 300–800 ms after a change in the auditory environment [32]. It has been used to assess cognitive processing, especially information processing and to measure the cognitive workload imposed by a particular task [33]. Less research has been conducted to understand the auditory processing abilities in children with SLI using the P300 potential. A summary of the three articles on using the P300 in children with SLI is given in Table 2.

Some studies found an increase in P300 amplitude in children with SLI, while others found them a decrease. Reduced amplitude reflects a shut-off of later memory or attention which in turn reflects the higher order processing. Similarly, a few studies have shown delayed latencies in children with SLI compared to the TD group. Delayed latency indicates the time required to complete evaluation of an auditory stimulus at the higher processing level. However, studies have also shown a clear and robust P300 response with no significant difference between SLI and TD children in latency or amplitude, indicating intact neural generators of P300 and neural processing.

N400

The N400 is an event related potential with a negative deflection at 400 ms post-stimulus presentation. Recent research indicates that N400 reflects processing of semantic memory [37]. It can be used to investigate neural representation and functions supporting language processing and comprehension [38]. A summary of the three articles on N400 in children with SLI is shown in Table 3.

Many studies have found no significant differences in N400 responses between children with SLI and TD children. The amplitude and timing of N400 was found to be similar in children with SLI and TD children [41]. This indicates that the lexical representations are similar in children with SLI and TD children.

P600

The P600 is a positive-going deflection that occurs around 500 ms. It is elicited by hearing or reading grammatical errors and other syntactic anomalies. Hence, it can be used in neuro-linguistic experiments investigating sentence processing in the human brain. The P600 can be elicited in both visual (reading) and auditory (listening) experiments. A summary of one article on P600 in children with SLI is given in Table 4.

Results	Comments
1. Children with SLI exhibited prolonged latencies and lower P300 amplitudes. 2. Increased speed of processing was related to expressive language age, auditory closure, speech discrimination, auditory sequential memory, sound blending, and grammatical closure. 3. Correlations were also observed between P300 amplitude and auditory sequential memory in the SLI group ($p = 0.033$*). 4. P300 amplitude improved with sound blending and grammatical closure. 5. As expressive language age improved, P300 latency also improved. 6. Strong correlations were observed between P300 amplitude and auditory association and verbal expression.	This indicates higher cortical neurophysiological changes and late auditory perceptual processing deficit in children with SLI. This means slow processing of information and working memory deficits which affect both language and cognitive development. Children with SLI exhibited cognitive and central auditory processing deficits in the form of prolonged latencies which indicate a slow rate of processing and defective memory as evidenced by small amplitude. These results indicate that cognitive and language development in children with SLI are affected and should be considered in the planning of intervention programs.
1. No difference was observed between the two groups when the memory load was kept low (1-back memory load). 2. As the memory load increased, children with SLI exhibited a decrease in accuracy and attenuated P3b responses. 3. P3b amplitude was significantly lower for the SLI group in comparison with the control group, under both low and high memory load conditions. 4. There was no difference in ERP latency.	The results suggest that both processing speed and working memory are co-morbid deficits in children with SLI. These processing deficits may operate slightly differently in the auditory and visual modalities. The results also suggest that reduction in P3b amplitudes in children with SLI may reflect an immature auditory system. This does not directly reflect reduced working memory capacity; instead it indicates a demand for greater cognitive resources to maintain degraded representations in memory while inhibiting extraneous information.
1. P300 latency was significantly longer in children with SLI in all age groups compared to TD children. 2. In both groups a significant correlation was seen between the age of the child and a decrease in P300 latency.	Consistent results of the study lead to the conclusion that P300 can be used as an effective tool in the early diagnosis of auditory processing dysfunction in children with SLI. Early diagnosis enables implementation of an appropriate listening training during rehabilitation.

Discussion

To date, few studies have investigated the lexical–semantic, morpho–syntactic, and syntactic correlates of ERPs in children and even less those with SLI [18]. Research from the above studies shows contrasting results: some showed the presence and others the absence of robust potentials. Finding a less robust, or absent, N400 or P600 might indicate difficulty in linguistic processing of speech in children with SLI. However, robust potentials with no differences in latency and amplitude compared with typically developing children would seem to indicate normal processing of language in language-impaired children. To resolve the issue, further studies are needed to improve our understanding of language processing in children with SLI.

The review articles emphasize that there is very little data available on the evaluation of auditory processing skills in language impaired populations using endogenous potentials. Fewer studies have attempted to include these potentials in the battery of tests to assess auditory processing. These studies have attempted to objectively characterize auditory processing problems in children with SLI. Results from the MMN based articles indicate a deficit in the auditory processing of linguistic as well as non-linguistic information in children with SLI. They also exhibit weaker frequency discrimination ability which may in turn lead to language impairment in children with SLI. A contradicting study in MMN suggested that these children have intact neurophysiological measures of auditory processing. The results from the P300 studies indicate that the cognitive and language development in children with SLI are affected and they may also have an immature auditory system. The articles based on N400 suggest that children with SLI exhibit weaker lexical–semantic representation of verbs, poorer vocabulary, and deficits in short term working memory. This indicates weakened or less efficient connections within the language networks in children with SLI. The P600 study indicated that these children exhibit deficits in the processing of prosodic information which hampers normal syntactic development. Of course, mismatch negativity [10], P300 [38], N400 [40], and P600 [42] assess isolated neuro-audiological structures and do not give insight into whether these children have problems at a specific level of the auditory system or have co-morbid conditions (brainstem to cortex).

The review found contradictory results in articles on endogenous auditory evoked potentials. Four out of the five MMN-based studies suggested that there was an auditory processing delay or deficit in children with SLI [28], whereas one study found that processing skills were intact in this population [26]. Other studies from P300, N400, and P600 indicated auditory processing deficits at a particular level in some areas in children with SLI. Contradictory results were seen in the review articles on exogenous auditory evoked potentials (ABR, MLR, LLR) in children with SLI [16]. Some studies reported a statistically significant difference in morphology, latency, and amplitude of AEPs between children with SLI and controls, indicating auditory processing problems at the level of brainstem, sub-cortical, or cortical areas in children with SLI. At the same time, a few other studies showed no abnormalities in auditory processing in children with SLI, with intact waveform morphology, latency, and amplitude of AEPs. With limited documented evidence, the article on exogenous potentials highlighted the fact that subtle auditory processing deficits may be observed in children with SLI

Table 3. Summary of 3 identified N400 articles. TD, Typically Developing children; SLI: Specific Language Impairment

S/N	Study	Age range	No of subjects	Material
1.	Sabisch, Hahne, Glass, von Suchodoletz & Friederici, 2006 [39]	9.7 years	SLI: 16 TD:16	Children with SLI were selected based on the criteria of ICD-10. IQ test, language test, working memory, and vocabulary tests were conducted. Poorer scores in language comprehension and production were observed in the impaired group. Children with SLI performed poorly in working memory and vocabulary. ERP (N400) was recorded. The stimuli were presented in 4 conditions. Each consisted of 48 sentences in passive voice presented through a loudspeaker. All sentences consisted of a noun, an auxiliary, and a past participle.
2.	Pijnacker, Davids, van Weerdenburg, Verhoeven, Knoors & van Alphen, 2016 [40]	4.2–6.5 years	SLI: 37 TD: 25	Nonverbal IQ, language abilities (comprehension and production), audiological evaluation, vocabulary, and articulation were assessed. Children with SLI obtained significantly lower scores than the TD group on all the language tests. Semantically congruent and incongruent naturally spoken sentences to elicit N400 responses.
3.	Cummins & Ceponiene, 2010 [41]	7–15 years	SLI: 16 TD: 16	Hearing evaluation, neurological assessment, vocabulary, and language tests were done. N400 was recorded using picture–sound matching (words vs. environmental sounds). Environmental sounds included animal cries, human nonverbal vocalizations, machine noises, alarms, water sounds, event sounds, and music. Visual stimuli. Pictures were full-color, digital photos of common action-related objects that can produce an environmental sound and be described by a verb or noun.

Table 4. Summary of one identified P600 article. TD, Typically Developing children; SLI, Specific Language Impairment

S/N	Study	Age range	No of subjects	Material
1.	Sabisch, Hahne, Glass, von Suchodoletz & Friederici, 2009 [42]	SLI: 9.8 years TD: 9.7 years	SLI: 16 TD: 16	IQ, language assessment, audiological evaluation, neurological assessment, psychiatric and behavioral assessments were done using screening procedures. Children with SLI had poorer language comprehension and/or production abilities. ERP (P600) was recorded using correct sentences or sentences with a word category violation (syntactic level) and adjoining prosodic incongruity (prosodic level).

which may pose a risk for normal language development in this population. Further research using a battery of tests is required to understand the auditory processing abilities in language impaired children. A standard protocol including the behavioural assessment and auditory evoked potentials (exogenous and endogenous) to assess the higher auditory areas must be formed. This would help us better understand the auditory area that might be affected and which is responsible for the deficit of a particular auditory processing skill in children with SLI.

Conclusion

All the above studies on endogenous potentials in children with SLI have assessed neuro-audiological structures in isolation and do not give insight into whether these children

Results	Comments
1. TD children exhibited a broadly distributed N400 followed by a late positivity. 2. Children with SLI did not show an N400 effect, but they exhibited a late and broadly distributed positivity. 3. The data obtained from children in both groups indicated that larger N400 amplitudes were associated with better use of verbal short-term working memory. This larger amplitude was significantly associated with the better use of word language. 4. In both groups verbal short-term memory could be predicted by the grouping but not by the peak amplitude of N400.	Absence of N400 could be due to the presence of large negativity for correct sentences. This suggests that children with SLI have weaker lexical–semantic representations of verbs and exhibit restrictions in the selection of verbs or difficulties in lexical–semantic integration. Smaller or absent N400 might be associated with poorer verbal short-term working memory capacity and poorer vocabulary across groups of children.
1. Different pattern of N400 was observed for spoken language in children with SLI. 2. TD group demonstrated a robust N400 in both time windows (300–500 ms and 500–800 ms) whereas the SLI group exhibited a significant N400 in only the 500–800 ms window. The SLI group had larger N400 for incongruent words compared with congruent words at the end of a sentence. These findings point to a delayed time course of N400 for the SLI group and thus indicate that linguistic processing is delayed in SLI. This might indicate a general delay in processing in the SLI group. 3. Control group showed a posterior N400 effect in both the 300–500 ms and 500–800 ms windows whereas the SLI group showed it only in the later time window for incongruent words compared with congruent words at the end of a sentence. 4. In the early time window of 300–500 ms, there was no significant correlation between the N400 response and language and intelligence abilities in both groups. 5. In the SLI group, the N400 in the time window 500–800 ms was associated with language comprehension, vocabulary, grammar, and nonverbal intelligence. Thus, smaller N400 effects in the SLI group were associated with lower levels of language and intelligence.	The results indicate that there is a delay in linguistic processing in children with SLI. Neuronal processing of semantic information at the sentence level is deviant in SLI compared with TD peers as indicated by the later and less focalized N400. N400 response to a sentence context is obtained when multiple words are held and integrated in working memory. This might have been hampered in the SLI group due to deficits in working memory.
1. N400 amplitude was similar in both groups for words and environmental sounds. 2. N400 latency was observed to be prolonged in children with language impairment for word stimuli, whereas no difference in latency was observed for environmental sounds across the groups.	The results indicate that children with SLI appear to have a semantic integration deficit specific to the verbal domain. This in turn suggests that these children might have weakened or less efficient connections within language networks.

Results	Comments
1. TD children performed better than children with SLI in judging the correctness of all types of sentences. 2. TD children showed a bilateral early starting anterior negativity that was sustained into late anterior negativity. P600 was observed in posterior regions in response to incorrect sentences in the TD group. 3. A comparable P600 was seen in children with SLI but there was only a late, clearly left-lateralized anterior negativity. 4. There was a complete absence of right anterior negativity in the SLI group. 5. Distinct differences in ERP response patterns were observed between the two groups during auditory sentence comprehension.	The results indicate that children with SLI may not be able to access prosodic information in the same way as TD children. The absence of a prosody-related right-anterior negativity in children with SLI indicates a deficiency in the processing of prosodic information which may in turn hamper the development of early syntactic processing as reflected by absence of an early, left-anterior negativity.

have problems at a specific level of the auditory system or have a co-morbid condition (brainstem to cortex). Methodological limitations were also observed in the articles. Few studies have conducted a detailed assessment of speech and language development, cognitive skills, and audiological evaluation. Some studies have included only a basic assessment protocol. The number of included subjects were very limited in some studies. The number of electrodes and their placement also varied across the studies, with some studies following the standard international 10–20 system while others did not.

The present review is aimed to assist researchers in understanding auditory processing at the level of higher auditory areas in children with SLI, as well as plan a structured assessment that might help in the early identification of auditory processing deficits in children with SLI. This would help in formulating research design and selecting appropriate protocols for further research. In turn, this would help clinicians plan suitable management techniques during interventions. Appropriate rehabilitation can now be provided to children at a young age, which results in enhancing their language abilities. Ample research needs to be conducted which focuses on administering a neuro-audiological test battery on children with SLI, so that insight into the subtle auditory problems in individuals with SLI can be attained and help provided in the appropriate management of their auditory problems. In this way, the impact on normal language development in SLI children might be reduced.

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