

Review Article



Temporal Processing Abilities in Children with Repaired Cleft Lip and Palate: A Systematic Review

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Highlights

- Repaired cleft lip and palate is associated with impaired auditory temporal processing
- Deficits observed in resolution, ordering, and speech-in-noise
- Routine temporal assessment is clinically warranted

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ABSTRACT

Background and Aim: Children with Repaired Cleft Lip and Palate (RCLP) are at increased risk for auditory processing difficulties, particularly in speech perception in noise and temporal auditory processing. Although emerging evidence suggests deficits in central auditory processing in this population, a systematic synthesis of temporal processing abilities remains limited. This review aimed to critically evaluate and synthesize existing evidence on temporal auditory processing abilities in children with RCLP.

Recent Findings: A systematic literature search was conducted independently by two reviewers across PubMed, Scopus, CINAHL, ScienceDirect, and ProQuest for studies published between January 2000 and March 2025. Study selection was performed through title, abstract, and full-text screening. Eligibility criteria were defined using the PICOS framework, and risk of bias was assessed for all included studies. Of 1,132 identified records, 12 studies met the inclusion criteria. The reviewed evidence consistently demonstrated auditory processing deficits in children with RCLP, with temporal processing identified as the most frequently and severely affected domain. Across studies, children with RCLP showed significantly poorer temporal processing performance compared to craniofacially typical peers.

Conclusion: This review underscores the clinical relevance of temporal auditory processing deficits in children with repaired cleft lip and palate. Unrecognized temporal processing impairments may adversely affect academic performance, reading skills, and speech–language development. Incorporating temporal auditory processing assessment into routine audiological evaluations is therefore recommended for early identification and targeted intervention. Future research should further investigate other subtypes of auditory processing disorders in this population to enhance clinical management strategies.

Keywords: Cleft lip; cleft palate; auditory perceptual disorders; children

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Introduction

Cleft lip and palate are the most occurring congenital malformations with a prevalence rate of about 0.992/1000 births globally and were reported to be significantly higher in cleft lip and palate than in cleft lip (Group 2011) [1]. These craniofacial abnormalities are formed due to improper migration of neural crest cells. It was estimated that 70% of the cleft lip/palate are non-syndromic and 30% are associated with an additional syndrome, which refers to a cleft that is not accompanied by any abnormalities [2].

Studies have reported that individuals with Non-Syndromic Cleft Lip and Palate (NSCLP) are not only prone to facial deformities, but also structural brain abnormalities. In addition, the temporal lobe region is severely affected than any other regions of the brain in individuals with NSCLP [3]. Structural abnormalities involving the auditory cortex and central auditory pathways have been reported in individuals with cleft lip and/or palate, which may contribute to auditory and cognitive deficits [4]. Additionally, recurrent otitis media commonly seen in children with repaired cleft lip and palate results in prolonged auditory deprivation and has been associated with delays in cognitive, speech, and language development [5]. These damages in the nervous system further lead to an inability to perform auditory closure and temporal processing. Due to this, children with cleft lip/palate find difficulty in reading, articulation and language errors, difficulty in recognition of phonemes, and lack of perception of speech as they cannot detect short silence intervals due to a deficit in temporal processing [6].

The representation of time-related aspects of acoustic signals refers to auditory temporal processing and plays a crucial role in the detection and discrimination of phonemes, syllables, stress patterns, and phonological awareness. The sub-processes of temporal processing are temporal resolution, temporal ordering, temporal integration, and temporal masking. Temporal resolution can discriminate between two sounds that are different in the spectro-temporal aspects of the acoustic signal. Various tests have been used to assess the temporal processing ability, such as the Gap Detection Test (GDT) [7, 8], the Duration Pattern Test (DPT) [8], the Frequency Pattern Test (FPT) [8, 9], and the Gap-in-Noise (GIN) [10, 11] were administered. GDT and GIN are primarily considered peripheral auditory tests

that evaluate the ability to detect gaps in sound stimuli. These tests were designed to assess an individual's ability to accurately perceive and order stimulus patterns based on their frequency or duration. However, all these tests address the peripheral impairment and cortical dysfunction that affect the transmission of the acoustic signal to the central auditory pathway, affecting the temporal processing ability [12].

Several studies have been conducted to estimate auditory processing in adults and infants with cleft lip/palate. But studies on temporal processing abilities in children with repaired cleft lip/palate are warranted. Addressing the research gap provides information and understanding of temporal processing abilities in children with NSCLP. With existing information, appropriate early intervention and necessary rehabilitation strategies can be adopted to alleviate the consequences of temporal processing deficits in children with NSCLP. Even though numerous studies have been conducted to evaluate the temporal processing abilities in children with repaired cleft lip and palate, there is no systematic evidence in the literature. Hence, the current systematic review aimed to investigate the temporal processing abilities in children with repaired cleft lip and palate. The objectives of the study are to systematically identify and review research studies examining temporal processing abilities in children with repaired Cleft Lip and Palate (CLP). Reviewed publications from the past two decades in accordance with PRISMA guidelines for systematic reviews to employ database-specific search strings tailored to each data source, title, and abstract screening was made using Rayyan software to ensure unbiased study selection. Further evaluated eligible studies using the Population, Intervention, Comparison, Outcome, and Study design (PICOS) framework (Population, Intervention/Exposure, Comparison, Outcomes, Study design)

Methods

The current study used Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) [12] for framing method and reporting the results. The protocol for review was registered in the International Prospective Register of Systematic Review with the reference number CRD42024560611. The lower boundary of the literature search period was defined to coincide with the earliest year in which standardized diagnostic criteria and contemporary reporting practices for cleft lip and palate became consistently available, thereby ensuring the methodological quality, comparability, and clinical relevance of the included studies.

Inclusion and exclusion criteria

The review included studies published from January 2000 onward, corresponding to the period when standardized behavioral and electrophysiological measures of temporal auditory processing became established and when contemporary surgical and audiological management practices for individuals with cleft lip and palate were adopted. Restricting the review to the last 25 years ensured the inclusion of methodologically rigorous studies grounded in current theoretical frameworks, validated assessment tools, consistent diagnostic criteria, and clinically relevant practices. The articles incorporated for the current study were based on the PICOS criteria [13]. Hence studies with a control group were included; however, studies without a control group were not excluded if outcomes were compared against established normative or reference data. Studies lacking both a control group and a comparison to normative data were excluded from the review.

Research on temporal processing abilities in children aged 5–17 years with repaired cleft lip and palate, regardless of gender or time since surgery. Studies involving co morbid conditions such as hearing loss or intellectual disability were excluded. Treatment effects on temporal processing abilities were not considered in this study. Children without cleft lip and palate or any associated syndromes served as the comparison group. Studies assessing temporal processing abilities using behavioural tests such as Gap in Detection (GDT), Duration Pattern Test (DPT), Pitch Pattern Test (PPT), Temporal Modulation Transfer Function (TMTF), Gap in Noise (GIN), Temporal Modulation Detection (TMD), or similar measures were included, while psychoacoustic and electrophysiological tests not evaluating temporal processing were excluded.

Study design

All peer-reviewed studies that were published in English were only considered. However, studies that are translated into any other foreign language were not considered. Studies related to literature review, systematic review, meta-analysis, case studies, unclear studies and poorly described or inadequate information, and studies with only an abstract were excluded from the study. Other resources, such as unpublished papers, conference papers, books, and non-peer-reviewed studies, were excluded.

Search strategy

A comprehensive search strategy was carried out using

different electronic databases such as PubMed, CINAHL, Science-Direct, ProQuest, and Scopus to identify the studies on temporal processing abilities in children with repaired cleft lip and palate. Other sources, such as AISH repository, Shodhganga, and Google Scholar, were also considered to identify relevant studies. The references from all the included studies were reviewed systematically so that any relevant articles were not missed. A thorough search term was developed to form a search string using keywords “cleft lip”, “cleft palate”, “temporal”, “duration pattern test”, “gap-in-noise test”, “gap detection”, and “frequency pattern”. To gather more information and for precise results, keywords along with Boolean operators such as AND, OR, NOT, or “AND NOT” were used. Keywords, along with appropriate Boolean operators, provide a search string for different electronic databases (see [Appendix A](#)).

Data analysis

Data collection of the current review was carried out in different phases, that is, identification, screening, and eligibility. The initial stage of data collection was identifying studies through different electronic databases using a search string. The information obtained from the studies was compiled and subjected to the Rayyan Qatar Computing Research Institute (QCRI) System [14]. The next stage is screening all the studies, where duplicity of the studies was identified and eliminated. Further, the titles and abstracts of the studies were screened, analyzed, and considered that were potentially eligible for the current study. The extracted articles included information on title, author name, research design, population, age group, control group, sample size, methodology used, and outcome measures. The third stage was eligibility, where studies that were selected based on the title or abstract and met the inclusion criteria were selected for full-length reading. The screening and eligibility were conducted blindly by two independent researchers by NKV and YC. The discrepancies or disagreements between the two researchers were further resolved by PP and PMT. The finalized studies after comprehensive evaluation were retrieved in PICOS format for further analysis.

Certainty of evidence

To minimize potential bias in the included studies, the Quality Assessment of Diagnostic Accuracy Studies tool (QUADAS-2) was employed. QUADAS-2 [15] assesses the risk of bias across four domains: patient selection, index test, reference standard (target condition), and flow and timing. Although translation

tools are available, the review was restricted to English-language publications to ensure accurate interpretation of technical methodologies, outcome measures, and electrophysiological parameters critical for quality appraisal and data synthesis. This language restriction was defined a priori to preserve methodological rigor and feasibility, consistent with standard practices in systematic reviews within audiology and speech-language pathology.

Results

The current systematic review included studies investigating temporal processing abilities in children with cleft lip and palate. A systematic literature search yielded a total of 1132 records from PubMed (148), ScienceDirect (116), Scopus (295), CINAHL (570), Google Scholar (2), the AIISH repository (1), and Shodhganga (0). After removing duplicate records and those marked as ineligible by automation tools, 1109

records remained for screening. During title and abstract screening, 1096 records were excluded, resulting in 14 studies eligible for full-text review. Of these, two studies were excluded due to non-availability of full-text articles or failure to meet the inclusion criteria. Following the final study selection, the reference lists of the included studies were manually screened, and no additional eligible studies were identified. Ultimately, 12 studies were included in the systematic review. The detailed selection process is illustrated in the PRISMA flow diagram (Figure 1).

Study characteristics

Out of the 12 included studies, seven were standardized group studies that compared children with CLP against normative data or control groups, whereas five were single-group studies conducted without a control group. The participants who were considered for the systematic review are children with cleft lip and

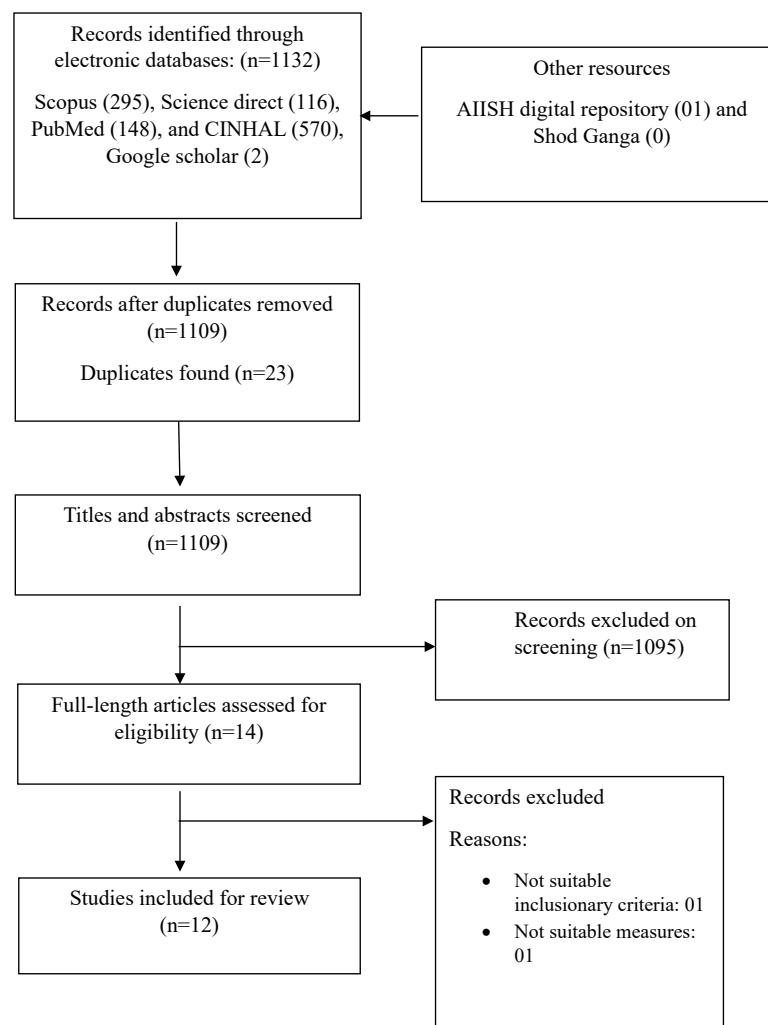


Figure 1. PRISMA chart on systematic review on temporal processing abilities in children with cleft lip and palate

palate aged between 6 and 15.67 years. A total of eleven studies that met the inclusion criteria were considered, involving 464 children with repaired cleft lip and palate and 140 craniofacially normal children. The included studies considered for experimental group to be non-syndromic children with repaired cleft lip and palate, where hearing loss, intellectual disability, and lack of attention are not associated. Among eleven studies, six studies have included age age-matched control group. The control consists of craniofacially normal children to compare the outcomes between the two different groups. The eligible studies have included children with different native speakers, such as Mandarin, Persian, Brazilian, etc.

Temporal processing tests

The included studies have administered various

Central Auditory Processing Disorder (CAPD) tests. Since the current systematic review aimed to investigate the temporal processing ability in children with repaired cleft lip and palate, the tests that assess both central and peripheral functions of the auditory system are included. The studies have adopted various methodologies to assess the temporal processing abilities in children with repaired cleft lip and palate. However, the methodology varies from study to study with respect to stimulus used, test environment, mode of presentation, etc. Tests such as temporal ordering, GIN, duration pattern and frequency pattern, or pitch pattern tests were involved in evaluating temporal processing ability. The included studies' data extraction was framed according to the PICOS guideline and depicted in Table 1.

The quality of the selected studies was evaluated using the Appraisal tool for cross-sectional studies (AXIS).

Table 1. Summary of articles selected for systematic review

Study	Country	Population	Comparison	Study design	Outcome	Findings
Ma et al. [16]	China	- CLP (n=141) - Age range 6 to 15.67 years - Gender: 96 Male; 45 Female. - Type of cleft: not specified.	Craniofacially age-matched normal children (n=60) Same age range.	Standard group comparison design	i. GDT (ms): ATRT (NBN-AC). ii. GDT (ms): ATRT (NBN-WC)	i. GDT-ATTR (NBN-AC)-significance difference in the performance by age, but not by cleft type. The scores were higher for the age group 6–8 years and reached a plateau at 12 to 15 years. ii. GDT-ATTR (NBN-WC)-significant effect was not found in different age groups and cleft type. There was no significant age effect for both the stimulus
Boscariol et al. [17]	Brazil	- CLP (n=20) - Age range 7 to 11 years - Gender: 9 Male, 11 Female. - Type of cleft: not specified.	Nil	Single group design	GDT (ms): AFT-R	AFT-R-reported highest percentage (95%) of poor performance suggesting that children with CLP may have temporal processing alterations that might result in difficult to identify acoustic variations which in turn difficult to interpret the message heard
Zarei et al. [18]	Iran	- CLP (n=23) - Age range=8 to 12 years - Gender: not specified. - Type of cleft: not specified.	Craniofacially normal children (n=30) Same age range	Standard group comparison design	GIN (threshold)	GIN-scores were lower in NSCLP children compared to control group suggesting that Children with CLP may have difficulty in recognizing rapid changes in speech-related temporal information.
Feng and Lu. [19]	China	- CLP (n=18) - Age range=7 to 15 years. - Gender=10 male; 8 female - Type of cleft: NSCLP	Craniofacially normal children (n=18) Same age range	Standard group comparison design	GIN (ms)	GIN-there was significant difference between the two groups, indicating that children with NSCLP had lower scores compared to control. However, the scores for both groups were within the normative for aged matched school going children.
de Moraes et al. [20]	Brazil	- CLP children without otitis media (n=10) - Age range=10 years old. - Gender: not specified - Type of cleft=NSCLP	CLP children with otitis history (n=10) Same age range	Standard group comparison design	GDTZAFT-R (percentage)	AFT-R-the results were poor for both groups. However, CLP children with otitis media performed worse than the without OM for auditory processing tests.

Study	Country	Population	Comparison	Study design	Outcome	Findings
Amaral et al. [21]	Brazil	- CLP children (n=44) - Age range=8 to 14 years - Gender: male=19; female=25 - Type of cleft: NSCLP	Nil	Single group design	Temporal ordering	Temporal ordering: verbal SM and non-verbal SM-11.4 % of the children with CLP had altered results and 88.6% with normal results. Overall, it was suggested that children with altered responses in BAE presented altered responses for APS and vice versa. Hence it is essential to assess all the children with CLP irrespective of BAE.
Laasonen et al. [22]	Finland	- CLP children (n=64) - Age range 10 years - Gender female=35; male=29 - Type of cleft: NSCLP	Craniofacially normal children (n=7) Same age range	Standard group comparison design	TPA (Hz)	TPA-there was no significance difference between control and cleft children group. The significant differences noted in visual and tactile temporal acuity, however no difference found in auditory temporal acuity. There was significant difference noted in subgroups of CLP.
Mäenpää et al. [23]	Finland	- CLP children (n=57) - Age range: 10 years. - Gender: not specified. - Type of cleft: 38 cleft palate or submucous, 19 cleft lip or no cleft palate.	Nil	Single group	TPA (Hz)	TPA-children with cleft lip performed better than cleft palate in audiovisual temporal processing acuity suggesting that audiovisual crossmodal sequential information processing might have impaired in children with cleft palate or submucous cleft palate.
Laasonen et al. [24]	Finland	- CLP children (n=49) - Age range: 10 years. - Gender: not specified - Type of cleft: not specified.	Nil	Single group design	TPA (Hz)	TPA-it was found that saturated fatty acids were not associated with TPA. However, components of the polysaturated fatty acids were positively associated with TPA, suggesting that there was significant correlation between cognitive and biological factor.
Maximino et al. [25]	Brazil	- CLP children (n=22) - Age range 7 to 9 years. - Gender: 11 male, 11 female - Unilateral cleft lip and palate	Nil	Single group design	R-GDT	RGDT-temporal resolution was most affected (81%) compared to other domains of CAPD. The study has suggested to use appropriate auditory and language strategies to minimise the effect of altered function and to make use of CNS plasticity in children with CAPD.
B and Jain [26]	India	- CLP children (n=16) - Age range 7 to 12 years. - Gender: 9 male and 7 female. - Type of cleft: not specified.	Craniofacially normal children (n=15) Same age range	Standard group comparison design	GDT (ms)	GDT-there was a significance difference between children with NSCLP and the control group, indicating that scores were higher in children with NSCLP. Overall study suggests that recurrent middle ear infection and abnormal cortical regions in children with NSCLP might have led to temporal processing disability.
Cinar and Polat [27]	Turkey	30 adolescents (10–17 yrs) - Type of cleft: operated non-syndromic CLP. - Gender: 15 male; 15 female	30 individuals, age and gender matched	Standard group comparison design	Behavioral auditory processing tests —duration pattern test, frequency pattern test, Turkish matrix sentence test (speech-in-noise)	The mean scores of the study group in frequency pattern, duration pattern and Turkish matrix tests were lower than the control group (p=0.000). When the participants were evaluated as under and over the age of 12, while under the age of 12 showed lower performance than over the age of 12 for the study group (p<0.05), this difference was not observed in the control group (p>0.05). Adolescents with cleft lip and palate may be disadvantaged in their auditory processing skills compared to their peers and they still may not catch up with their peers, even if improvement is observed with the maturation effect.

CLP; cleft lip and/or palate, GDT; gap detection test, ATRT; auditory temporal resolution test, NBN-AC; narrow band noise-across channels, NBN-WC; narrow band noise -within channel; AFT-R; auditory fusion test-revised, GIN; gap in noise, NSCLP; non-syndromic cleft lip and palate, GDTZAFT-R; gap detection threshold derived from auditory fusion test-revised, TPA; temporal processing assessment, R-GDT; randomized gap detection test, CAPD; central auditory processing disorder, CNS; central nervous system



Figure 2. Traffic light plot on the AXIS risk Bias assessment of review articles

The appraisal tool was developed for use in appraising observational cross-sectional studies. It is designed to address issues that are often apparent in cross-sectional studies and to aid the reader when assessing the quality of the study that they are appraising. The tool aims to aid systematic interpretation of a cross-sectional study and to inform decisions about the quality of the study being appraised. The AXIS traffic light plot illustrates the risk-of-bias assessment across the included studies, with the x-axis representing individual studies and the y-axis representing the AXIS methodological criteria. Overall, most studies demonstrated a low risk of bias (represented in green color) for core domains, such as clarity of aims, appropriateness of study design, use of validated tools, and ethical approval. However, recurrent high (represented in red color) or unclear risk (represented in orange color) was observed for items related to non-response handling, completeness of results reporting, sample size justification, and discussion of study limitations. A pictorial representation using a traffic light plot is given in [Figure 2](#).

The data extracted from the eligible studies were descriptively and comparatively assessed. The description of the results of the eligible studies includes information on the parameters used to assess, the stimulus used, the presentation level, and other relevant information.

Discussion

This systematic review evaluated behavioural and electrophysiological evidence on temporal auditory processing abilities in individuals with Cleft Lip and/or Palate (CLP). Across studies, a consistent pattern of subtle but measurable impairment in temporal resolution was identified, despite substantial heterogeneity in study design, assessment tools, and participant characteristics. Overall, the evidence indicates that individuals with CLP exhibit elevated gap detection thresholds, impaired temporal ordering, and reduced cortical discrimination responses compared to typically developing peers, suggesting the involvement of central auditory processing mechanisms beyond peripheral hearing status.

Most included studies employed cross-sectional designs with sample sizes ranging from 10 to 141 participants, providing moderate internal validity but limiting population-level generalisability. Considerable methodological variability was observed across behavioural paradigms, including the use of Gap in Noise (GIN), Random Gap Detection Test (RGDT), Auditory Fusion Test-Revised (AFT-R), and other gap detection tasks, as well as differences in stimulus type, presentation level, and response format. For example, Sharma et al. [28], using a 70 dB SPL presentation level and a three-alternative forced-choice paradigm, reported significantly elevated gap detection thresholds in children with CLP. In contrast, Dhivagar and Chandni [26], employing a different gap detection method and administering tests at 60 dB HL within a broader central auditory processing battery, also observed consistent temporal processing deficits in children with non-syndromic cleft lip and palate. Although these procedural differences (e.g. task design, presentation level, and assessment battery) influence outcome sensitivity, the convergence of findings across diverse methodologies strengthens confidence in the presence of temporal processing deficits in CLP. Behavioural evidence from gap detection and temporal ordering tasks consistently demonstrated poorer performance in children with CLP compared to controls [16, 21, 26, 27]. Developmental analyses revealed delayed maturation of temporal resolution, with children with CLP showing slower improvement trajectories and later plateauing of gap detection abilities [16]. Importantly, these deficits persisted even when peripheral hearing sensitivity was within normal limits, suggesting that reduced audibility alone does not fully account for the observed impairments. Consistent findings from temporal ordering and sequencing tasks further support the interpretation of central auditory processing dysfunction [16, 17].

Evidence from older children and adolescent populations indicates that auditory temporal and central auditory processing deficits persist beyond early childhood in individuals with cleft lip and/or palate. Hofer-Martini et al. [29] demonstrated significantly poorer auditory processing performance, including tasks reliant on temporal resolution and sequencing, in children and adolescents with cleft palate despite normal peripheral hearing sensitivity. Similarly, Maximino et al. [25] reported impaired temporal resolution using gap detection measures in children with repaired cleft lip and palate, with deficits extending into later developmental

stages and showing associations with language and academic difficulties. Together, these findings suggest that temporal auditory deficits are functionally relevant and may contribute to broader language, literacy, and learning challenges. The persistence of impairments across developmental stages argues against a purely maturational delay and instead supports enduring alterations in central auditory processing.

Studies employing auditory fusion measures, particularly those involving the Auditory Fusion Test-Revised (AFT-R), demonstrated greater variability in outcomes, but generally poorer performance in children with cleft palate compared with peers, even when peripheral hearing thresholds were normal. Behavioral evidence indicates alterations in temporal resolution in cleft palate populations, and electrophysiological assessments reveal prolonged neural transmission times and atypical auditory evoked potentials, suggesting central auditory dysfunction beyond peripheral hearing loss. Consequently, these studies were excluded from quantitative synthesis due to reduced outcome sensitivity and methodological inconsistency [16, 17]. Electrophysiological evidence further supports a central origin of temporal auditory deficits in cleft lip and palate. Ma et al. [16] demonstrated atypical cortical auditory evoked responses in children with non-syndromic CLP despite normal peripheral hearing sensitivity, indicating impaired cortical-level auditory discrimination in the absence of peripheral dysfunction. These findings align with behavioural evidence of elevated gap detection thresholds [16, 26] and suggest that cortical temporal processing abnormalities contribute to auditory perceptual deficits in CLP. Together, behavioural and electrophysiological data support the presence of enduring central auditory processing alterations rather than deficits attributable solely to peripheral hearing loss. Neurophysiological findings are further supported by neuroimaging evidence of atypical temporal lobe morphology and altered grey matter volume in individuals with cleft lip and/or palate [3, 30, 31]. For example, structural MRI studies have shown reduced posterior brain volumes including temporal regions in adults with non-syndromic CLP compared with controls, as well as reduced cortical thickness in temporal and other associative regions in children and adolescents with CLP. Although not CLP-specific, classic cross-modal temporal integration research demonstrates that temporal synchrony critically influences auditory-visual integration in the auditory cortex, suggesting

that timing abnormalities may affect multisensory processing relevant to communication. Collectively, these findings support a neurodevelopmental model in which auditory temporal processing deficits arise from altered cortical maturation and connectivity, rather than being solely secondary to peripheral hearing pathology. Middle ear pathology represents a major confounding and contributing factor across the reviewed literature. Otitis media with effusion and conductive hearing loss are highly prevalent in children with CLP and may result in intermittent auditory deprivation during sensitive periods of cortical development. Several studies reported a high incidence of otitis media among participants, which may partially account for elevated gap detection thresholds [5, 32]. However, the persistence of cortical auditory abnormalities in infants without conductive hearing loss [4] suggests that central auditory deficits can occur independently of middle ear pathology. This dissociation supports the presence of heterogeneous auditory processing profiles in CLP, encompassing both deprivation-related and intrinsically neurodevelopmental mechanisms.

Stimulus characteristics and task demand significantly influenced observed outcomes. Studies employing broadband or noise stimuli demonstrated more consistent deficits than those using pure-tone stimuli [26, 28], highlighting the importance of ecologically valid, speech-like stimuli in auditory processing assessment. Active listening paradigms were generally more sensitive to impairment than passive tasks, likely reflecting interactions between auditory temporal processing and attentional control. This interpretation is supported by evidence of co-occurring deficits in auditory attention and discrimination in children with CLP [23], suggesting overlapping neural substrates.

Developmental and cognitive factors further modulate temporal auditory processing outcomes in children with Cleft Lip and/or Palate (CLP). Although age-related improvements in gap detection are observed, maturation occurs more slowly in CLP than in typically developing peers [18, 26]. Cross-modal studies indicate that temporal processing deficits extend beyond the auditory domain, affecting audiovisual integration relevant for speech perception and reading [16, 23]. Cognitive-linguistic factors, including attention, working memory, and academic skills, have also been shown to influence auditory temporal performance [23, 31], reinforcing the need to interpret auditory processing deficits within a broader neurocognitive framework.

Limitations

The interpretation of findings from the included studies should be approached with caution due to several limitations inherent in the existing evidence base. Most studies reviewed employed relatively small sample sizes and cross-sectional designs, thereby limiting statistical power and the ability to infer developmental or causal relationships. Evidence is largely derived from behavioural measures of temporal processing, with an absence of electrophysiological or neurophysiological indices to support inferences regarding central auditory mechanisms. In addition, variability in participant characterization —particularly with respect to hearing status and history of middle ear pathology —may have influenced auditory outcomes and reduced interpretive clarity. Methodological heterogeneity across studies, including differences in assessment tools, stimulus parameters, and outcome measures, further constrained cross-study comparability and limited the feasibility of quantitative synthesis.

The present systematic review also has methodological limitations that warrant acknowledgment. The literature search was restricted to peer-reviewed studies published in the English language, which may have resulted in the exclusion of relevant non-English research. Additionally, the review was confined to a predefined publication period, potentially limiting the inclusion of earlier studies that could have contributed to a broader understanding of auditory processing in this population. Importantly, the scope of the review was intentionally focused on temporal processing abilities, rather than encompassing the full spectrum of Auditory Processing Disorder (APD) subcategories. Consequently, the findings should be interpreted as specific to temporal processing deficits in individuals with repaired cleft lip and palate and should not be generalized to APD as a whole. Future reviews incorporating multiple APD subdomains and broader methodological approaches are necessary to provide a more comprehensive characterization of auditory processing abilities in this population.

Future direction

Future research should employ multimodal and longitudinal designs integrating both behavioural and electrophysiological measures to delineate the trajectory of auditory temporal maturation in CLP. Larger, well-characterized samples with stratification based on cleft type, hearing status, and cognitive profile are needed.

The inclusion of speech-based temporal processing tasks (e.g. GDT, DPT) combined with functional neuroimaging could help identify cortical regions and neural dynamics —particularly within auditory and auditory-motor networks—that. Auditory training and noise-based temporal exercises represent rehabilitation-oriented approaches that may promote functionally relevant neural plasticity in the auditory system. Finally, standardization of test parameters —stimulus type, presentation level, and analysis criteria—would enhance the comparability and reproducibility of findings across laboratories.

Clinical implications

In summary, the reviewed evidence underscores that children with cleft lip and palate exhibit measurable impairments in auditory temporal processing, particularly in gap detection and temporal resolution tasks involving complex acoustic stimuli. These findings point toward a disruption not only in auditory perception but also in the broader neural systems supporting timing, attention, and speech decoding. Clinically, this highlights the need for comprehensive auditory processing evaluations in children with CLP, extending beyond routine audiometric testing. Early identification of temporal deficits could guide targeted auditory training programs, support speech-language intervention, and inform strategies for classroom listening environments. Incorporating temporal processing assessments into standard audiological and speech-language protocols can thus facilitate a more holistic understanding of communicative difficulties in this population and promote evidence-based rehabilitation that leverages the brain's plasticity during critical developmental windows.

Conclusion

This systematic review provides converging behavioural and electrophysiological evidence that individuals with Cleft Lip and/or Palate (CLP) exhibit clinically meaningful deficits in auditory temporal processing, including elevated gap detection thresholds, impaired auditory fusion, and reduced cortical discrimination responses. Importantly, these abnormalities are detectable as early as infancy and are predominantly central in origin rather than solely attributable to peripheral hearing loss. Evidence from adolescent populations further demonstrates that temporal processing deficits persist across development

and are associated with functional listening and academic outcomes. Collectively, these findings indicate that auditory temporal processing impairment in CLP is an early-emerging and enduring characteristic with potential implications for speech perception, language development, and learning. The results highlight the need for standardised, developmentally sensitive auditory processing assessments and support early, targeted intervention approaches to minimise long-term communicative and educational consequences in individuals with CLP.

Ethical Considerations

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Authors' contributions

PM,PP and NKV: Screening abstract, finalizing the manuscript; YBC: Involved in search of articles, screening of abstracts, preparing manuscript; AS-Preparing manuscript.

Conflict of interest

No conflict of Interest.

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Appendix A. Search results obtained from electronic databases.

Database	Search strategy	Date	No. of hits
PubMed	((“cleft lip*”[Title/Abstract] OR “cleft palate*”[Title/Abstract]) AND 2000/01/01:2024/06/01[Date - Publication] AND ((“temporal*”[All Fields] OR “Gap detection test”[All Fields] OR “Duration pattern test”[All Fields] OR “Gap in noise”[All Fields] OR “Frequency pattern test”[All Fields]) AND 2000/01/01:2024/06/01[Date - Publication])) AND (2000/1/1:2024/6/1[pdat]	4 July 2024	158 results
Scopus	(TITLE-ABS-KEY(Cleft-lip*) OR TITLE-ABS-KEY(cleft-palate*) AND TITLE-ABS-KEY(temporal*) OR ALL(gap-detection-test) OR ALL(frequency-pattern-test) OR ALL(duration-pattern-test) OR ALL(gap-in-noise-test)) AND PUBYEAR > 2000	4 July 2024	261 results
ProQuest	<u>title(cleft-lip*) OR title(cleft palate*) AND title(temporal*) OR gap-in-noise OR frequency-pattern-test OR duration-pattern-test OR gap-detection-test AND pd(20000101-20240601)</u>	4 July 2024	986 results
CINAHL	TI (cleft lip and palate or cleft lip or cleft palate) AND Temporal* OR gap detection test OR duration pattern test OR frequency pattern test OR gap in noise test	4 July 2024	209 results
Science direct	Cleft lip OR cleft palate AND temporal Year: 2000-2024 Title, abstract, keywords: gap-detection OR frequency-pattern OR duration pattern OR gap-in-noise	5 July 2024	106 results

Note: CINAHL: Cumulative Index to Nursing and Allied Health Literature; ABS: Abstract, AND- and; OR-or; PUBYEAR- Published Year.