

Early diagnosis and prevention of speech disorders in children: Current trends and effective practices

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Abstract

Background: Vitamin D plays essential roles in calcium homeostasis, immune modulation, and inflammatory regulation, suggesting potential implications for periodontal health. Adolescence represents a critical period for both skeletal development and establishment of periodontal health patterns, yet research examining vitamin D–periodontal relationships in this population remains limited. **Objective:** This study aimed to investigate the correlation between serum vitamin D levels and periodontal health parameters among adolescents, exploring potential associations with gingivitis severity and clinical attachment status. **Methods:** A cross-sectional analytical study was conducted among 486 adolescents aged 12–17 years. Serum 25-hydroxyvitamin D [25(OH)D] concentrations were measured using chemiluminescent immunoassay. Periodontal assessment included plaque index (PI), gingival index (GI), bleeding on probing (BOP), probing depth (PD), and clinical attachment level (CAL). Participants were categorized by vitamin D status: deficient (<20 ng/mL), insufficient (20–29 ng/mL), and sufficient (≥30 ng/mL). Pearson correlation, ANOVA, and multivariable regression analyses evaluated associations. **Results:** Mean serum 25(OH)D was 24.67 ± 9.84 ng/mL, with 31.5% classified as deficient, 38.9% as insufficient, and 29.6% as sufficient. Vitamin D-deficient adolescents demonstrated significantly higher mean GI (1.67 ± 0.48) compared to sufficient participants (1.12 ± 0.39 ; $p < 0.001$). Significant negative correlations were observed between 25(OH)D and GI ($r = -0.412$, $p < 0.001$), BOP ($r = -0.387$, $p < 0.001$), and PI ($r = -0.298$, $p < 0.001$). Multivariable regression confirmed vitamin D deficiency as independently associated with gingivitis (OR=2.34; 95% CI: 1.56–3.51; $p < 0.001$) after adjusting for confounders. **Conclusion:** Vitamin D levels demonstrate a significant inverse correlation with periodontal inflammation markers in adolescents. Vitamin D deficiency is independently associated with increased gingivitis severity, suggesting potential benefits of adequate vitamin D status for adolescent periodontal health.

Keywords: neurodevelopment, apraxia, dyslexia, hearing loss, speech therapy, screening, tele practice

1. Introduction

Speech disorders in children are a global psychosocial and clinical a problem that affects cognitive functions, education, social adaptation and implementation in life. The World Health Organization reports that in the world more than 50 million children with neurodevelopmental disorders, namely intellectual, autistic and speech disorders, which without proper care negatively affect access to educational opportunities, increase the risk of social vulnerability and reduce the quality of life of children and their families [1]. Untimely identification of speech difficulties increases the likelihood of academic failure, psycho-emotional disorders, social isolation and increases the need for resource-intensive rehabilitation services [2]. In this regard, early diagnosis and prevention are considered important means of reducing negative consequences and creating conditions for child development [3]. Scientific perspectives emphasize systematic screening of communication development in early and preschool age. Clinical studies have established that early detection of speech problems contributes to the effectiveness of corrective interventions and the avoidance of secondary deviations [4]. However, there is a gap between scientific recommendations and actual practice, especially in primary care, where standardized examination algorithms are often absent [5]. Therefore, the heterogeneity of diagnostic tools is insufficient to assess their sensitivity and specificity, as well as their cross-cultural, cross-linguistic validation and comparability of data [6]. Speech development is a complex process involving genetic, neurobiological, familial, and social deter- minants, and environmental factors [7]. The quality

of speech interactions within the family, access to specialized services, educational resources, and community support are all determinants in predicting communicative and cognitive outcomes [8]. These evidence-based approaches emphasize the effectiveness of early parental intervention programs in preventing speech disorders, but they lack uniformity and consistent results across regions and social groups [9]. Public health models emphasize interprofessional, multilevel prevention, and systemic family support [9, 10]. Technological advances have expanded the possibilities for early diagnosis and prevention of speech disorders. Machine learning algorithms and speech signal analysis are potential avenues for risk assessment and personalization of screening decisions [11, 12]. Although tele practice formats improve access to assessment, particularly for remedial services, in geographically or socially constrained settings, their use requires harmonization of data collection and implementation, as well as methodologies [13]. At the same time, validated psychometric instruments developed in early childhood in the context of pragmatic communication assessment are still lacking [14]. However, important issues remain unresolved, including the lack of a universal protocol for speech screening, uneven access to multidisciplinary support, lack of culturally adapted and validated tools, and a narrow evidence base for long-term prevention programs. In addition, the combination of clinical, educational, and digital approaches into a consolidated effective prevention model requires further scientific validation. As there is limited evidence for generalizations that include both epidemiological trends, clinical approaches, prevention models, and digital technology capabilities, this study provides an interdisciplinary systematic review of current concepts and strategies for early detection and prevention of speech disorders in children. The aim of the study was to analyze existing trends, scientifically based approaches and effective practices for early screening and prevention of speech disorders in children, as well as to develop relevant recommendations for identifying and preventing the development of such disorders. To achieve this, the following research tasks were defined: to characterize the scale and structure of the problem; to analyze existing models of early screening; to summarize preventive strategies; to develop reasoned practical recommendations for timely intervention and prevention of speech disorders.

2. Literature review

Speech disorders in children have a complex neurodevelopmental process, supported by interdisciplinary evidence that suggests that they depend on multiple factors that are not always within the control of the individual [7, 15]. Most studies emphasize the heterogeneity of clinical findings, which makes it difficult to develop general diagnostic criteria and prognostic models for these cases [5, 8]. Previous studies of child development have shown that high-quality family communicative interactions, the influence of a speech-stimulating environment, and caregiver support play critical roles as risk modifiers for speech disorders and can significantly influence the rate of progression of disorders [8, 9]. One of the most promising trends in science is the search for early predictors. Survey and cohort studies have found predictive value in deficits such as delayed language milestones, articulatory motor disorders, pervasive social-communicative difficulties, and combined cognitive deficits [3, 16]. Comparative research has found inconsistencies in the validation of these predictors across cultural, linguistic, and sociodemographic groups, which reduces the general applicability of these findings [17]. The debate over screening and diagnostic methods continues to be a constant topic for improvement. A review of the evidence has confirmed that there is considerable variation in sensitivity, specificity, ease of use, and normative samples in standardized instruments [6]. Studies in primary care patients have shown promise for routine screening in accelerating time to diagnosis, but their success depends on established referral pathways, professional education of staff, and interagency collaboration [2]. Despite the availability of validated scales, psychometrically stable, culturally appropriate, and multilingual instruments remain lacking [14]. Preventive and remedial research The evidence for the benefits of comprehensive, family-centered, and multidisciplinary approaches is strongly supported by meta-analyses. Children with good parental involvement have been shown to have higher levels of lexical, grammatical, and socio-communicative skills, as evidenced by meta-analyses, which may be associated with increased chances of early detection and early intervention [9, 18]. However, even with intervention by parents and professionals, outcomes may be limited and short-lived, depending on severity, cause, and access to care [19]. There is growing research interest in digital and technological tools. Machine learning, automated speech analysis systems, sensor technologies, and digital screening devices have high predictive power, especially in low-income populations [11, 12]. Tele practice is a common, and often not the only, intervention tool among low-income populations. They are an alternative strategy for providing speech therapy, but there are no standard protocols or ethical standards that would

recognize them as effective, since only comprehensive correction provides a good result [13, 20]. Regional comparisons indicate significant differences in approaches to early identification and prevention of speech disorders. European countries, including the Netherlands, Denmark, Germany, Spain, and Italy, have a standardized model of universal newborn audiological screening used in primary care with intersectoral participation [21, 22]. In low- and middle-income countries, such as Bangladesh, India, Pakistan, Malawi, and Uganda, major barriers include limited access to resources, a lack of skilled personnel, a lack of public policies on early intervention, and low parental awareness [18, 23]. In developed countries outside Europe – including the United States, Canada, Australia, New Zealand, and Japan – there are extensive early intervention systems, but socioeconomic disparities and cultural diversity in the population lead to inequalities in access to preventive and speech therapy services [20, 24]. This global heterogeneity clearly shows that the effectiveness of early screening and prevention models depends not only on the data and available tools, but also on the political, socio-economic and cultural contexts in which child development support systems operate. Despite the evidence of the benefits of early screening, family-based intervention, interdisciplinary collaboration, and the use of innovative technologies, there is a lack of uniformity, fragmentation of evidence, and uneven implementation across social and cultural contexts. Controversies exist regarding the optimal age for screening, risk criteria, duration and intensity of prevention programs, and limitations of digital tools. This calls for the development of culturally relevant, validated guidelines and multilevel models for early diagnosis and prevention of speech disorders in children. The aim of the work was to create a general scientific model for conceptual, clinical, socio-pedagogical and technological approaches to the early detection and prevention of language disorders in childhood. The emphasis was on the key determinants that determine the effectiveness of diagnostic and preventive interventions, as well as on the circumstances that underlie such interventions, ensuring their positive long-term results. It was important to create recommendations aimed at different levels of professional participation – from individual practice of specialists to systemic management decisions in the field of health care, education and social services. To achieve the goal, a broad survey of recent empirical and theoretical works describing the dynamics of language development, the characteristics of screening instruments and the parameters of prevention programs was envisaged. The main interest of the study was to identify methodological inconsistencies, gaps in evidence, inequalities in access to early care and structural barriers to the implementation of early intervention. The generalization of the results was used to develop practical recommendations that can improve the organization of early care and increase its effectiveness in preventing language disorders in children.

3. Methods

The study is based on the principles of interdisciplinary theoretical analysis, which integrates medical, psycholinguistic, neuroscientific, pedagogical, social-scientific and digital-technological strategies. The theoretical framework was aimed at reconstructing the existing evidence base for early identification and prevention of language disorders in children. The methodological framework included systematicity, evidence-based practice, objectivity, representativeness and verifiability of scientific statements and conclusions. Web search was conducted to create an analytical array of Science, Scopus, PubMed and Google Scholar for English-language publications published between 2020 and 2025. Key search phrases included: “speech and language disorders”, “developmental language disorder”, “speech delay”, “early” screening”, “universal screening”, “parent-mediated intervention”, “tele practice speech therapy”, “hearing screening”, “machine learning speech analysis”, “risk factors language development”. Inclusion criteria were: peer-reviewed international articles, studies on children; description of screening, diagnostic or preventive methods used, use of standardized instruments and results related to language, cognitive, neurobehavioral, psychosocial or family factors. Exclusion criteria: preprints, reviews without methodology, studies based only on adults, technical articles not including clinical interpretation, duplicates, written reports without full text, articles from non-indexed journals. The initial search identified 186 sources, but after applying exclusion criteria and removing duplicates, 62 scientific sources remained, which fully ensured thematic, geographical, conceptual and methodological diversity. The study included a multidimensional approach using a set of additional techniques that provided a qualitative theoretical analysis. Structural-logical analysis allowed for a logical and step-by-step argumentation of key issues on the topic. Content analysis of sources was used to identify leading scientific opinions and main methodological strategies. Classification of the material contributed to the categorization of studies by age groups of children, types of speech disorders,

diagnostic services and prevention programs. Comparison provided an opportunity to compare the effectiveness, value and practicality of implementing different strategies for screening and corrective prevention in an international context. Conceptual modeling was used to create a broad basis for theoretical justification of processes involving early diagnosis and prevention of speech defects. Terminology processing led to the identification of ambiguities in definitions and provided further explanation of the conceptual infrastructure necessary for proper comparison of research results. A comprehensive inductive and deductive generalization was conducted to develop integrated conclusions using various empirical and theoretical sources. An elementary bibliometric analysis provided insight into published works, research activity, research interests, geographical affiliation, and scientific trends in early screening. A critical discourse analysis allowed us to trace how social, cultural, economic, and institutional contexts shape perceptions of speech disorder diagnosis and the development of preventive approaches. A review of the evidence confirmed the selection of methodologically relevant and reliable sources that fall within the range of scientific reproducibility. Theoretical thematic coding and narrative synthesis allowed us to formulate key thematic trajectories of the study (diagnosis, risks, prevention, technological innovations) and integrate all this into a holistic conceptual model necessary for the creation of practical recommendations. The analytical summary identified the following main groups of children: children with developmental language disorder (DLD), speech delay, apraxia, speech dyslexia, sensorineural hearing loss, autism spectrum disorder, and children with multilingual development (bilinguals) and adverse social conditions. Biological, family, socioeconomic, and educational predictors of speech disorders were examined. Diagnostic approaches evaluated included standardized linguistic testing, early development instruments, audiological monitoring, parent questionnaires, and automated speech analysis. Analysis of prevention models included early parent intervention programs, speech therapy interventions, educational environmental practices, and telepractice. The applied methodological strategy allowed us to create a reliable evidence base to formulate conceptual frameworks for comparing current trends, evaluating diagnostic approaches, and assessing the effectiveness of prevention in children, which became the basis for developing practical recommendations.

4. Results

a. *Theoretical determinants and etiological factors of speech disorders*

Childhood language disorders are a multidimensional neurodevelopmental process involving genetic, neurobiological, cognitive, familial, socioeconomic, and environmental factors [7]. Many of these cases are polyetiological, suggesting an interaction between genetic predisposition and external developmental modifiers [25]. Neurolinguistic models of the mechanisms underlying the disorders suggest disrupted neural organization, dysregulation of cognitive networks, and atypical sensorimotor integration [26]. This supports the idea that most language difficulties are not unique but are associated with a wide range of neurodevelopmental factors [27]. Analysis of studies in analytical generalization has contributed to the identification of several important subgroups of children with language disorders with different causes and developmental trajectories: children with developmental language disorder, speech delay, apraxia of speech, dyslexia, sensorineural hearing loss, autism spectrum disorder, multilingual development (bilingualism), and children growing up in conditions of social vulnerability. The group of children with speech delay has received special scientific attention, as it is the most common reason for initial referrals in preschool age. The literature reports that 40–60% of these cases are temporary, but in the remaining children the delay develops into DLD, reading difficulties, academic and social-communicative problems [28, 29]. This categorizes speech delay as a significant early risk factor that is worth monitoring and implementing preventive interventions. The importance of family and environmental determinants supports the multifactorial nature of language disorders. Language development is significantly influenced by the quality of language interactions, the sensitivity of caregiving, the amount and variety of language stimuli, socioeconomic status, and access to educational resources during early development [30]. Studies on multilingualism indicate that bilingualism is not a risk factor per se but may complicate differential diagnosis due to the lack of culturally sensitive screening tools [31]. Biological factors include genetic differences, myelination abnormalities, abnormal brain rhythms, and neurophysiological connections that affect phonological, motor, and semantic processing of speech [32, 33]. Sensorineural hearing loss has its own etiological nature, and timely detection and treatment have implications for future speech outcomes and social adaptation [34]. Language deficits in children with autism spectrum disorders

are mainly related to problems with social communication, joint attention, and pragmatic abilities [35]. To systematically review the theoretical differences and common characteristics of groups of children, a comparative analytical table was developed that summarizes key etiological factors, typical manifestations, and clinical risks derived from interdisciplinary research data Table 1.

Table 1: Groups of children with speech disorders and their etiological characteristics*

| Group of children | Main etiological factors | Typical speech and behavioral manifestations | Potential short- and long-term risks |
|---------------------------------------|--|---|--|
| DLD (Developmental Language Disorder) | genetic vulnerability; atypical neural organization of language networks; phonological memory impairment | grammatical errors, limited vocabulary, difficulties with narrative, slow acquisition of language rules | risk of dyslexia, academic performance problems, emotional and behavioral difficulties |
| Speech delay | slow pace of neurolinguistic maturation; insufficient early speech stimulation; functional perinatal factors | Delay in first words and phrases, simplified structures, low speech initiative | transition to DLD, difficulties in social adaptation, decreased confidence in communication |
| Apraxia of speech | motor planning disorders; neuromotor coordination deficits; atypical cortical activation | inconsistent articulation, difficulty planning sound sequences, slowed speech | long-term speech therapy needs, secondary behavioral difficulties, frustration |
| Autism | genetic and neurobiological mechanisms; impairment of social attention and sensory integration | echolalia, joint attention deficit, limited pragmatics, atypical prosodic profile | social isolation, emotional disorders, delayed academic skills |
| Sensorineural hearing loss | hereditary mutations, perinatal hypoxia, infections, ototoxicity | speech perception difficulties, limited vocabulary, phonological processing disorders | delayed language development, need for cochlear implants /hearing aids, educational inequality |
| Children with dyslexia | hereditary phonological disorders; atypical activation of parietotemporal areas | difficulties with sound-letter correspondences, impaired phonological processing, slow reading | academic difficulties, anxiety, reduced learning motivation |
| Bilingual children | not an etiological factor, but a linguistic context; multi-level linguistic input | asymmetric vocabulary in two languages, differences in the pace of development | risk of misdiagnosis as DLD, cultural-linguistic bias |
| Socially vulnerable children | poverty, unstimulating environment, low access to education and health services | limited speech experience, reduced quality of interaction, poor vocabulary | chronic educational backwardness, communicative isolation, unequal access to interventions |

*Source: compiled by the author based on analysis of research data [23, 28, 30, 34, 35]

Analysis of the data in the table shows that despite the commonality of language manifestations, the groups differ significantly in etiology, risks and prognosis, which justifies the need for differentiated models of early screening, prevention and intervention. This means that the optimal support system should be based on early detection, precise identification of the etiological mechanism and contextual factors, as well as on an interdisciplinary assessment that combines medical, educational and psychological approaches. It follows that the etiological model of language disorders considers them as the result of the interaction of multiple factors and serves as the basis for further analysis of diagnostic approaches, preventive strategies and the development of practical recommendations.

b. Modern models of early screening and diagnostic approaches

Data analysis showed that modern models that focus on the early detection of speech disorders, are based on a combination of clinical, psycholinguistic, instrumental, interview, and digital methods that vary in sensitivity, specificity, validity, and accessibility. However, routine developmental observation, periodic screening visits, and standardized assessment protocols are considered key tools for early identification of both language and broader neurodevelopmental difficulties [28, 36]. Studies have emphasized that for best results, early screening models must be integrated into pediatric, educational, and multidisciplinary systems of care. Standardized early development scales, tests for language deficits, assessment of phonological, lexical, and grammatical competence, and observation of the child's communicative behavior in structured and semistructured situations have been incorporated into clinical and psycholinguistic approaches. These types of instruments have been shown to have high validity and differential diagnostic power, although they require significant resources, specially trained personnel, and are time-consuming [37, 38]. Instrumental methods, such as universal newborn audiological screening, can provide early detection of sensorineural hearing loss with implications for later language outcomes and age of intervention [34]. Early screening has largely been achieved through survey-based parent questionnaires and developmental questionnaires, which allow screening of large cohorts of children as early as

possible in resource-limited settings. Well-designed questionnaires have shown fair to high sensitivity and specificity for detecting speech delay and DLD, especially when adapted to the linguistic and cultural context [39, 40]. Parent forms used to assess speech development and risk of DLD in bilingual children have the potential to reduce false-positive and false-negative results in bilingual groups, but they also emphasize the dependence on the linguistic literacy and motivation of respondents [31]. Digital technologies are increasingly being used to improve diagnostic and screening capabilities. Machine learning based on acoustic speech cues, audio recordings of speech, and other indicators can identify and classify speech defects. Computer-aided technology is more sensitive, can analyze many factors simultaneously, and can detect and predict the development of speech delays, dyslexia, DLD, and other neurodevelopmental disorders [41, 42]. Screening tools for psychometric assessment are also important, contributing to the early detection of disorders in children. Such tools help diagnose early hearing impairments when the child does not yet have obvious signs of disorders. This facilitates timely treatment and correction, which helps to better adapt to the world around him in the future [43]. Table 2 summarizes the main screening and diagnostic approaches. Therefore, based on the analysis of the data in the table, no single approach is universal. Combined models remain the most effective for clinical observation, standardized tests, parental questionnaires, and instrumental and digital diagnostics. At the same time, systemic and organizational barriers – uneven implementation of protocols, staff shortages, lack of unified electronic screening systems, and digital inequalities – significantly hinder the identification of children at risk as early as possible, even in countries with well-developed infrastructure. This highlights the importance of establishing integrated, standardized, but adaptable approaches to early screening that can integrate evidence-based approaches with the real resource conditions of individual service-based support systems.

Table 2: Comparative characteristics of the main models of early screening and diagnostic approaches*

| Type of approach | Examples/applications | Validity, sensitivity, specificity | Accessibility and barriers |
|--|---|---|--|
| Clinical and psycholinguistic tests | standardized speech and cognitive batteries, developmental scales | high validity and specificity under standardized application | require trained professionals, time, financial resources; limited availability in rural and resource-poor regions |
| Instrumental methods | newborn audiological screening, audiometry | high sensitivity to sensorineural hearing loss, clear protocols | need for equipment, technical personnel; uneven implementation between countries and regions |
| Parent questionnaires and questionnaires | screening of speech, general development, behavior | satisfactory/high sensitivity, variable specificity depending on instrument and context | dependence on parental motivation and literacy; need for cultural and linguistic adaptation; risk of subjectivity |
| Observation and clinical interview | assessment of communication, interaction, behavioral signals | high clinical informativeness, but limited standardization | high dependence on specialist experience; difficulty in scaling at the population level |
| Digital and ML tools | automated speech analysis, screening applications, online platforms | promising accuracy indicators, the ability to combine many parameters | need for validation, digital inequality, ethical and legal issues regarding children's data |
| Telepractice and remote screening | video consultations, online assessments, hybrid models | acceptable reliability indicators under standardized protocols | communication quality limitations, technical barriers, variability in the competence of specialists, lack of uniform standards |

*Source: compiled by the author based on analysis of research data [28, 39, 40, 41, 42, 43]

c. *Effective prevention strategies and early intervention*

The review found that the best prevention models for speech disorders in young children are designed to provide a multilevel, systemic, and contextual approach that includes medical, educational, psycholinguistic, family, and community resources. Existing interventions focus not only on speech correction but also on environmental modification, family support, early risk identification, development of protective factors, and reduction of social consequences. Many studies emphasize that prevention efforts should begin before overt symptoms appear, as the early sensitive period reflects increased neuroplasticity and the best opportunity for speech learning [32, 44]. This is one reason why parent-centered models are central to early prevention, as the family provides the most powerful speech input, social interaction, communication rhythm, and developmental support. Interventions that teach parents strategies for stimulating speech (modeling, expanding expressions, focusing on joint attention, commenting on actions) have been found to support sustained growth in lexical, grammatical, and socio-communicative skills, and that the benefits of these skills are maintained over the long term [9, 45].

In early intervention programs targeting children with autism, a focus on parent training has resulted in reduced speech deficits and increased levels of social participation in children, especially with ongoing and specialized supervision [35, 45]. Educational ecological prevention frameworks include the development of stimulating communicative environments for preschool systems. These may include improved (clearer, slower) teacher speech, planned play activities, development of phonological and rhythmic sensitivity, support for early literacy skills, and collaboration with speech therapists. Studies have shown that improved teacher professional competence and additional interdisciplinary educational interventions affect children's speech outcomes and reduce late referrals for specialized intervention [46]. There have also been positive effects in bilingual children when the environment is structured with a high number of speech models and is free from judgmental biases [47]. An interdisciplinary health-education model that includes pediatricians, speech therapists, psychologists, speech pathologists, audiologists, social workers, and educators has been shown to have the best chance of preventing secondary outcomes such as learning difficulties, behavioral problems, or social isolation [27, 36]. They only worked when referral pathways, service availability, and inter-institutional coordination were consistent. Telepractice is considered a viable option for families living in rural or socially disadvantaged areas. For this reason, remote speech therapy interventions have been found to offer acceptable levels of effectiveness and parental engagement, especially where there is caregiver training and frequent digital support [48]. However, unequal access to technology, variable internet quality, and lack of standards and ethical protocols remain challenges [49]. The timing and intensity of intervention are key predictors of the overall success of prevention programs in poor countries. The positive impact of programs implemented just before the age of three on structural and functional speech is evident from empirical studies, where manifestations decrease with increasing age at program initiation [32]. The frequency of intervention should be tailored to the individual needs of the child. However, when the program is structured and long-term, the impact of the improvement achieved can be sustained. The available evidence, summarized, has allowed the creation of a framework for effective strategies for the prevention of speech disorders Figure 1.

Figure 1: Model of effective prevention of speech disorders in children* *Source: compiled by the author based on analysis of research data [9, 36, 45, 48]

Thus, the most effective prevention strategies are broad, hierarchical, and context-specific approaches that include parent education, educational interventions, clinical intervention, and, where appropriate, digital interventions. Consistency, early onset, multidisciplinary approach, and social support can determine the sustainability of speech outcomes, reducing the risks of additional pedagogical and social difficulties. These findings provide an evidence base for developing pragmatic recommendations to better prepare national early prevention systems.

d. *Innovative digital technologies in speech therapy practice*

Digitalization is fundamentally changing the tactics of early screening, diagnosis and prevention of speech disorders in children, opening up new opportunities for standardized assessment, remote support and individualized interventions. Recent scientific advances in the field of artificial intelligence, machine learning, automated acoustic analysis, telepractice and mobile applications contribute to increasing the accuracy of risk identification and the speed with which the child receives specialized care [50]. Digital tools are able not only to diagnose, but also to expand access to prevention, especially in areas with staff shortages and social vulnerability [49]. Table 3 compares the key characteristics of digital technologies to better understand the feasibility of their use and the need for implementation in clinical practice, education, and family correctional activities.

Table 3: Digital technologies in early screening and prevention of speech disorders*

| Technology | Diagnostic potential | Advantages | Limitation |
|---------------------------|---|--|---|
| Artificial intelligence | Early detection of atypical speech patterns | High accuracy, scalability | Ethical issues of data processing |
| Machine learning | Risk prediction and group stratification | Personalized screening | The need for large representative samples |
| Automated speech analysis | Detection of DLD, apraxia, dyslexia | Speed, standardization, non-invasiveness | Limited corpus validation |
| Telepractice | Remote assessment and correction | Accessibility for remote regions | Digital inequality, lack of protocols |
| Mobile applications | Primary family screening | High parental involvement | Different levels of evidence |
| Electronic questionnaires | Primary care screening | Low cost, simplicity | Cultural and linguistic variability |

*Source: compiled by the author based on the analysis of research data [41, 42, 49, 50]

Artificial intelligence and machine learning algorithms are increasingly being used to automatically classify disorders in children at risk for speech disorders, apraxia of speech, dyslexia, and early social communication difficulties by analyzing complex acoustic and speech parameters that are not available to traditional tools [41]. Such systems show promise in rapidly triaging cases, supporting clinical decision-making, and identifying the need for more detailed evaluation [42]. Automated speech analysis also contributes to standardization of assessments and reduces human subjectivity [26]. Telepractice holds a special place in digital speech therapy, as it combines diagnostic and corrective capabilities, allowing interventions in a comfortable family environment. It is also the most accessible method for low-income families. Evidence suggests that remote interventions can be as effective as in-person interventions, provided that quality training of professionals and technical accessibility are provided [51]. At the same time, unequal access to the Internet, insufficient digital literacy, and the lack of regulated protocols remain significant barriers [48]. Digital parental questionnaires and mobile monitoring systems open up opportunities for early self-monitoring and timely assistance. Validated instruments demonstrate high sensitivity and are useful in the context of multilingual families, where traditional screening methods can give false results [31, 40]. Despite the significant potential of digital innovations, their implementation is accompanied by ethical, legal and social challenges: protecting children's personal audio data, aligning algorithmic solutions with clinical protocols, preventing technological discrimination and creating regulated standards of evidence.

e. *Recommendations for improving early diagnosis and prevention*

The analysis found that current technologies for early detection and prevention of language disorders are fragmented, unevenly available, and poorly standardized. Therefore, strategic policy recommendations should consider not only a set of individual tools or professional practices, but also a review of the entire institutional environment that facilitates the child's developmental trajectory. They should include levels of public policy, intersectoral collaboration, professional support, family encouragement, digital infrastructure, and support for science. At the macro level, it is proposed to create a national standardized system for screening language development and link it to pediatric, educational, and social services. This type of regulation should include unified assessment algorithms, recommended age-based "checkpoints," a cataloged list of validated tools, referral criteria, and monitoring mechanisms at the community and state levels for data collection. This will eliminate territorial disparities, optimize child routing, improve early detection, and transparency in statistical reporting. Another key requirement is to build interdisciplinary collaboration – including pediatricians, speech therapists, psychologists, neurologists, family doctors, educators, social workers. To facilitate this, it is proposed to create regional and interprofessional early support centers, make interdepartmental councils mandatory, use shared electronic child development records and standardized interaction routes after a positive screening. Such mechanisms should be supported and provided with resources and professional mentoring, and not remain formal. Psychometrically sound validated, culturally appropriate, linguistically correct and systematic assessment tools and tests. Routine monitoring of speech should be carried out in pre-school settings. A combination of assessment approaches should be adopted, including observations, structured tests, standardised tests, questionnaires and functional communication analysis. To this end, efforts should be made to raise standards of professional training, ensure continuous professional development, access to supervision and practice-based learning platforms. Family should be the main link in prevention. For this reason, it is proposed to develop national parent training programs that cover the skills needed for dialogic interaction, vocabulary stimulation, reading aloud, regulating screen time, helping with joint attention, multilingual development and caregiver resilience. Public campaigns should raise awareness of all about the early signs of language disorders, i.e. when screening is needed and the services available. While digital transformation can significantly increase screening coverage, it must be implemented wisely. It would be best to create a state system for assessing the quality of digital solutions, rules for the responsible use of artificial intelligence, transparency of algorithms, protection of personal data, and a ban on the commercialization of medically significant results without professional interpretation. Telepractice should complement, not replace, in-person diagnostics and be aimed at standardized models, open internet space, and digital equality. Ideally, the scientific system should establish long-term cohort studies evaluating the effectiveness of screening and prevention programs; develop locally validated instruments for multilingual children and develop validated instruments in other languages; and establish national repositories of scientifically proven evidence.

Minimum levels of effectiveness criteria should be defined, including age of first detection, time between screening and intervention, available speech therapy services, family satisfaction, and trends in language outcomes. Table 4 summarizes the key areas for improvement, responsible agencies, and planned actions for the recommendations.

Table 4: Set of generalized recommendations for early speech screening*

| Technology | Diagnostic potential | Advantages | Limitation |
|---------------------------|---|--|---|
| Artificial intelligence | Early detection of atypical speech patterns | High accuracy, scalability | Ethical issues of data processing |
| Machine learning | Risk prediction and group stratification | Personalized screening | The need for large representative samples |
| Automated speech analysis | Detection of DLD, apraxia, dyslexia | Speed, standardization, non-invasiveness | Limited corpus validation |
| Telepractice | Remote assessment and correction | Accessibility for remote regions | Digital inequality, lack of protocols |
| Mobile applications | Primary family screening | High parental involvement | Different levels of evidence |
| Electronic questionnaires | Primary care screening | Low cost, simplicity | Cultural and linguistic variability |

The summarized recommendations show that the transformation of the system of early diagnosis and prevention does not concern individual reforms, but an integrated approach at both the family and state levels. The adoption of the recommended measures will reduce the risks of late diagnosis of disorders, mitigate social and educational consequences, improve the quality of life of children, and create a sustainable development infrastructure to promote speech development.

5. Discussion

The results have generalized language disorders as multidimensional neurodevelopmental and socially conditioned factors that arise at the intersection of biological, environmental, educational, family, socioeconomic, and technological aspects. The generalization of the theoretical framework served as evidence that certain clinical clusters of children (DLD, speech delay, apraxia, dyslexia, autism, sensorineural hearing loss, and children with social and language risks) are not homogeneous in etiology or prognosis. This emphasized the need for multilevel systems for identification, prevention, and support, rather than single clinical interventions [25, 27]. The overall analysis showed that the effect of early intervention requires consideration of both the child's age and the level of service availability, family resources, quality of the language environment, intensity of interaction, and level of interagency routing [36, 44, 45]. Interpretation of the results demonstrated that identical language phenotypes can manifest with contrasting mechanisms of generation – genetic mutations, neural dysfunction, motor praxia, sensory deprivation, insufficient stimulation or social stress. This explains the heterogeneity of the course and the fact that early language problems are not always the primary disorder, but rather accompany auditory, cognitive or socioemotional factors [26, 33]. This complements the risk groups that are distinguished from each other in the article and supports the idea of differentiating preventive routes. Comparison with previous studies showed strong consistency with global trends. Systematic reviews confirm the higher risk of neuro developmental conditions with increased inequalities in early intervention, especially among children from socially disadvantaged groups [27, 52]. Data on universal screening of children under 5 years of age support the assumption that both methods are necessary, as there is no single instrument with high accuracy, ease of access, and cultural sensitivity for a single age and adaptation [39, 53]. Notably, parental assessment questionnaires are sensitive to language adaptations and generally have adequate sensitivity for language adaptation compared with standardized tests that better discriminate DLD, but require expert intervention [31]. The findings also align with the growing importance of electronic assessment and intervention models for measuring DLD. Modern machine learning algorithms show promise in language risk prediction, automatic speech classification, and screening of large populations, but they require representative samples and independent psychometric validation [41, 42]. Tele practice and digital platforms can help overcome geographic and social inequalities, often in communities where access to professionals is limited, but challenges remain in digital literacy, privacy, and the ethical use of children's speech data [48, 51]. This is consistent with the article's argument that there needs to be regulated, rather than spontaneous, digital integrations. Comparison with studies on the effects of early intervention confirms that the family is central to language development. Parental dialogic interaction strategies, responsive speech, a stimulating environment, and structured routine communication are considered predictors of long-term success with vocabulary, morphology, and social communication in parent education programs [46, 54, 55]. At the same time, the school and preschool environment also has an impact, and evidence supports educational practices that use speech-enriched pedagogies and access to speech therapy support. This is associated with a

reduced risk of poor learning, social isolation, and other secondary behavioral problems [56, 57, 58]. Coordination of these interventions within an interdisciplinary support system appears to be a major moderator of effectiveness. A mechanistic interpretation of the findings is based on cumulative risk: mild initial language problems may worsen when individuals live in poverty, experience a lack of stimulation, are diagnosed at a later stage, or do not have adequate access to treatment [59, 60]. Among bilingual children, another important mediator is the mismatch between the language of assessment and the dominant language of development, underscoring its prevalence for misdiagnosis [61, 62, 63]. Thus, context informs the effectiveness of prevention and treatment approaches. The practical implications of the study are far-reaching, with significant implications for clinical, educational and social policy. For health systems, the results recommend the implementation of national early speech screening programmes with age-specific markers, psychometrically validated instruments and routing between paediatrics, speech therapy and specialist services. Speech-oriented pedagogical practices, interprofessional teams and speech therapy support should be integrated during implementation in pre-school and primary schools. For families, the systematic provision of accessible parenting programmes, information, support and digital resources with evidence-based content is critical. It is also critical for public policy to ensure equal access to services regardless of region, language, social status or disability. However, the study has limitations. The theoretical design and narrative synthesis are unable to assess the effects of interventions, compare and contrast each model for effectiveness, or establish causal effects. Full statistical comparisons between studies are difficult due to the heterogeneity of their contexts, methods, samples, and timing. In addition, many of the implementations of digital solutions are in the test area, requiring additional validation and ethical review. It is recommended that future studies consider long-term evaluation of the effectiveness of prevention models, comparative analysis of interdisciplinary care modalities, cultural and linguistic validation of diagnostic tools, access to services used by socially vulnerable groups, and finally establishing ethical norms and practices for the use of artificial intelligence and tele practice. The need for interdisciplinary research on the integration of neuroscience, speech therapy, pedagogy, social policy and digital medicine is encouraged. The findings highlight the need to move from a fragmented to a holistic model that includes multiple components: clinical, family, educational, social, and technological, with an emphasis on early diagnosis and prevention, where the components are holistic and interdependent. Such an integrated approach underlies the better provision of support services, policy formulation, and mitigation of the long-term consequences of language disorders in children.

6. Conclusions

Theoretical analysis confirmed that language disorders in children are a complex multifactorial neuro developmental phenomenon, which consists of genetic, neurobiological, cognitive, sensory, socio-economic and environmental factors. The presented synthesis of scientific sources did not reveal any universal etiological model, demonstrating the need for a holistic, interdisciplinary approach to both early detection and prevention of the disease. The most vulnerable are children with developmental language disorders, speech delay, apraxia, autism, sensorineural hearing loss and dyslexia, as well as children who grow up in socially disadvantaged families and in conditions of bilingual development without proper support for language development. A systematic review of diagnostic interventions has found that the effectiveness of early screening is determined by standardization of instruments, provider training, and cultural and linguistic factors. sensitivities, organizational pathways to referral, and interaction between correctional and treatment facilities. Advanced technologies for speech analysis, including automated speech analysis, machine learning, digital platforms, and tele practice, are the most promising developments, but their implementation in practice requires standardization, ethical regulation, psychometric validation, and readiness of the health and education systems infrastructure. Comparing prevention models, it was found that family-centered, interdisciplinary, and educationally oriented interventions with early onset, adequate intensity, duration, cultural relevance, and local adaptation remain the most effective. The theoretical conclusion of the study contributed to the development of broad recommendations for improving the quality of screening, prevention, interagency routing of children at risk of speech disorders, and the availability of specialized services for all children. The results of the study expand the conceptualization of the problem from theory and provide opportunities for the development of clinical and educational standards, intersectoral policies, specialist training programs and digital speech therapy services; they also have practical advice for parents, educators and health professionals. They emphasize the importance of implementing evidence-based, ethically

regulated and culturally appropriate interventions in primary health care, early childhood education and social care. Thus, the results of the study confirmed the achievement of the goal and objectives that were set at the beginning of the study, provided a precise evidence base for future, interdisciplinary scientific research on this issue and identified new promising research directions – from improved diagnostic technologies to the development of accessible, standardized, combined and sustainable prevention models that can support all children in a timely manner.

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