«DIGITAL VISION»: THE USE OF MODERN TECHNOLOGIES IN THE COGNITIVE REHABILITATION OF CHILDREN WITH HEARING IMPAIRMENTS.

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Abstract

This article examines modern approaches to cognitive rehabilitation of children with hearing impairments using digital health technologies (DHTs). The neurobiological mechanism of compensatory plasticity of the brain is being investigated, which makes it possible to redistribute cognitive resources in favor of the visual channel in the absence of auditory stimulation. The article analyzes the effectiveness of immersive technologies (VR/AR) in the formation of vital skills and the development of spatial thinking in children with hearing impairments. Special attention is paid to the breakthrough in the use of artificial intelligence for accurate sign language recognition and the creation of predictive models of rehabilitation success with an accuracy of 92%. The application of eye tracking technology for the diagnosis of cognitive load and the development of adaptive educational interfaces based on visual attention patterns is also considered.

Key words

Sign language teaching, pedagogy, inclusive education, cognitive rehabilitation, digital health technologies, artificial intelligence in education, universal learning design, virtual reality, augmented reality, cognitive load, neuroplasticity.

Аннотация

В данной статье рассматриваются современные подходы к когнитивной реабилитации детей с нарушениями слуха с использованием цифровых технологий здравоохранения (DHTs). Исследуется нейробиологический механизм компенсаторной пластичности мозга, который позволяет перераспределять когнитивные ресурсы в пользу зрительного канала в условиях отсутствия слуховой стимуляции. В работе анализируется эффективность иммерсивных технологий (VR/AR) в формировании жизненно важных навыков и развитии пространственного мышления у детей с нарушениями слуха. Особое внимание уделяется прорыву в использовании искусственного интеллекта для точного распознавания жестового языка и создания прогностических моделей успеха реабилитации с точностью до 92%. Также рассматривается применение технологии айтрекинга для диагностики когнитивной нагрузки и разработки адаптивных образовательных интерфейсов на основе паттернов зрительного внимания.

Ключевые слова

Сурдопедагогика; педагогика; инклюзивное образование; когнитивная реабилитация; цифровые технологии здравоохранения (DHT); искусственный интеллект в образовании; универсальный дизайн обучения (UDL); виртуальная реальность (VR); дополненная реальность (AR); когнитивная нагрузка; нейропластичность.

Modern cognitive rehabilitation is undergoing a period of significant shifts due to the convergence of neuroscience and digital Health Technologies (DHTs). In the five-year period from 2020 inclusive, the scientific community has recorded an unprecedented surge of interest in using software and hardware solutions to correct cognitive deficits, especially in children with hearing impairments. The problem of cognitive deficits in this population is complex, covering not only delays in speech development, but also deficits in executive functions, attention and social adaptation, which puts a burden on families and health systems. Digital Therapeutics (Therapeutics, DTx) is now moving beyond simple assistive tools to become dynamic systems capable of personalizing and continuously monitoring the patient's condition. [3]

Brain plasticity as a foundation for technological intervention.

The effectiveness of digital rehabilitation of deaf and hard-of-hearing children is deeply rooted in the mechanisms of neuroplasticity. The complete or partial absence of auditory stimulation initiates a process of cross-modal reorganization, in which the auditory cortex begins to process visual and tactile signals. Research in 2025 confirms that this adaptation is not destructive; on the contrary, it is compensatory in nature, increasing sensitivity to movement and improving the localization of objects in the visual field. [1,2]

Analysis of evoked potentials (VEP) using electroencephalography (EEG) revealed specific markers of this plasticity. In children and adults with hearing loss, there is a change in the latency of components P1, N1 and P2. Interestingly, while the early components (P1, N1) may indicate sensory decline, the reduced latency of

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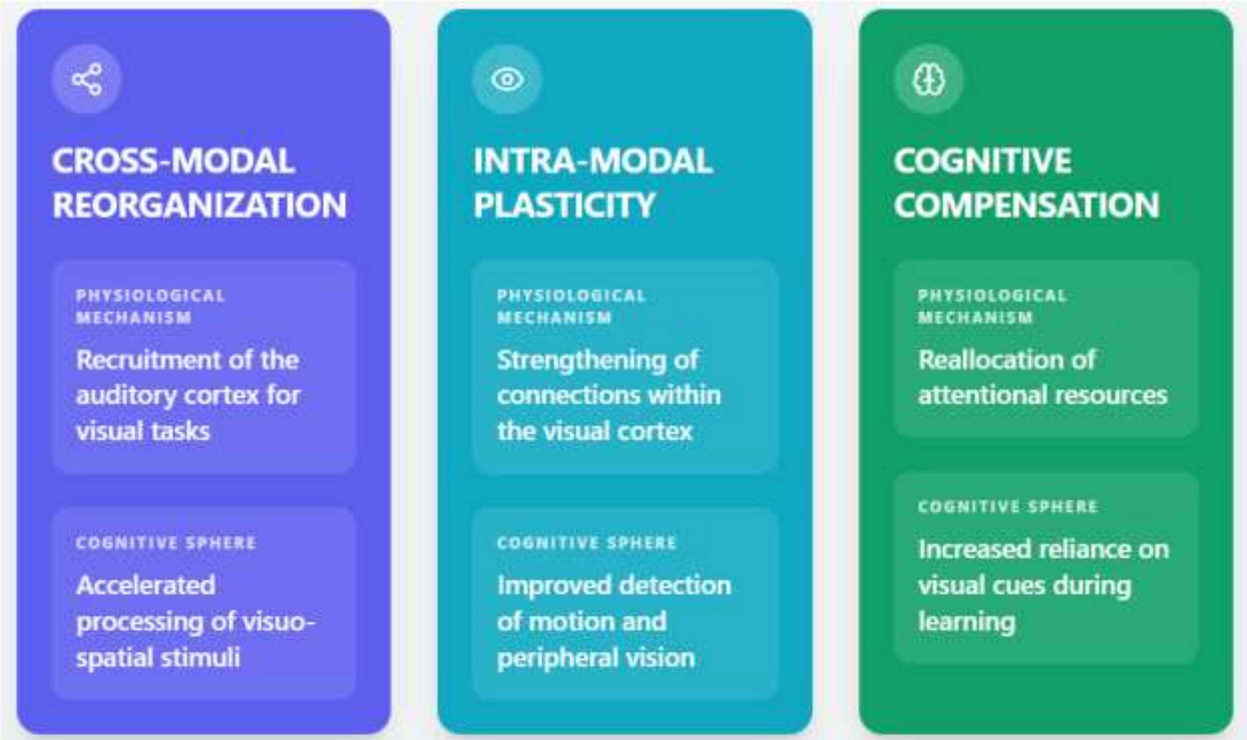
the late component of P2 provides direct evidence for strengthening visual neural networks in response to hearing deficits. This data is extremely important forthe development of digital interfaces: they point out that the brain of a deaf child is "tuned" to more intensive processing of visual information, which makes VR and AR ideal environments for learning.

Dynamics of neuroplastic changes in hearing loss

Adaptation of the brain to changes in sensory input through different levels of plasticity and compensatory mechanisms.



The brain effectively reallocates resources to compensate for the deficiency of one sensory system at the expense of strengthening others.

It is important to note that plasticity is not limited to early age. Although the critical period (the first 5 years of life) remains the most significant for language acquisition, 2025 studies on adults with age-related hearing loss show that compensation mechanisms remain active, which allows the use of digital simulators throughout life.

Immersive technologies.

By 2025, virtual (VR) and augmented (AR) reality will officially enter the school curricula of many countries as tools for inclusive education. In the context of rehabilitation of children with hearing impairments, these technologies address the challenge of creating a safe but realistic space for cognitive and life skills training. A systematic review of 55 studies confirmed that VR environments rich in context significantly increase motivation and information retention compared to traditional methods. One of the most successful examples of VR applications overthe past 2 years has been teaching personal safety skills to deaf primary school children. In a study conducted in Saudi Arabia, 22 students (grades 1-3) using Saudi sign language completed a training program in a virtual environment. The simulations covered three critical areas: street crossing, market behavior, and school safety.

The results of the experiment demonstrated the superiority of the VR technique over traditional instruction:

Skill area	VR Group result (post-test)	Statistical significance
of Road transition	Achieving maximum score (perfect execution)	$p < 0.001$ (MANOVA)
Safety in the market	Significant growth in hazard recognition	High efficiency
School safety	Improved spatial orientation	Stable progress

Efficiency is due to the fact that VR allows you to visualize the consequences of mistakes without real risk to life. This is critically important for deaf children, who often face increased risks due to the inability to hear warning signals (car horns, shouts).

Visualization of abstract concepts: Mathematics and Geometry

Traditional math instruction often relies on verbal explanations, which creates a barrier for deaf students. The use of AR and VR allows you to transform abstract formulas into three-dimensional objects that can be manipulated. Narrative Review 2025 highlights that immersive technologies strengthen DHH students ' spatial thinking, and the use of metaverses allows for collaborative environments where deaf children from different countries can work together to solve problems using avatars and subtitles in real time.

However, XR adoption faces barriers. CHI 2025 research points to a "design exception": many VR headsets do not address the needs of users with hearing aids or cochlear implants, and the lack of standardized avatars with high precision articulation of gestures makes it difficult to communicate within virtual worlds.

Artificial Intelligence: Moving to dynamic Assistance

If early assistive technologies were static, then modern systems based on artificial intelligence (AI) are adaptive "cognitive partners". AI plays a crucial role in two areas: sign language recognition and predictive analytics. The problem of the communication gap between a deaf child and their hearing environment is solved in SLR systems. Modern models using deep learning (AlexNet, VGG-16, VGG-19 architectures) achieve gesture recognition accuracy of up to 99.11%. The introduction of Indian Sign Language recognition (ISL) systems as "learning assistants" has led to a 60-70% increase in children's cognitive performance by providing instant feedback.

The Tabletop Interactive Play System (TIPS) project uses AI and augmented reality to teach parents sign language while playing with their child. The system uses cameras and microphones to analyze interactions and project instructional videos with gestures directly onto the game surface. This reduces the risk of language deprivation during a critical period of brain development and ensures emotional closeness between parent and child.

One of the most significant achievements of 2025 was the development of AI models for predicting the success of cochlear implantation. A deep learning model based on preoperative MRI scan data predicts conversational language proficiency 1-3 years after surgery with 92% accuracy. This approach allows doctors to identify children who will experience difficulties in advance and prescribe them intensive therapy.

Eyetracking as a tool for assessing cognitive load

Eye tracking technologiesайтрекингhave become the "gold standard" in studying the specifics of information processing by deaf children. Since vision is the dominant channel for them, understanding the patterns of gaze fixation makes it possible to optimize training materials.Eyetracking also revealed the effect of facial occlusion: the use of masks makes it much more difficult to recognize emotions in deaf people, depriving them of critical cues in the mouth area. For deaf readers, the distribution of attention in the reading process differs from that of hearing readers. Studies have shown that experienced deaf readers have a broader parafoveal view. Using eye tracking helps you understand how knowing a first language (such as ASL) facilitates cognitive control when reading in a second language.

Generative AI in 2025 acts as a "cognitive copilot". In higher education, 63% of deaf students use AI tools for taking notes, and 61% use them for automatic captioning.

Reinforcement learning (RL) - based systems allow you to dynamically adjust the complexity of content. If the system detects long pauses in a student's responses, it interprets this as confusion and automatically suggests a simplified version of the material or a visual metaphor.

Приложение The Peekaboo Vision (PVA) app, which uses the preemptive gaze method on the iPad, has been shown to be highly effective in assessing vision in children with cognitive barriers. At the same time, sensory substitution projects such asThrough the Ear, We Seeare developing systems for converting video to 3D audio landscapes, allowing the visual cortex to learn to interpret sound as spatial information.

Conclusion

Despite progress, the digital divide persists. The main risks include algorithmic AI bias, data privacy issues, and the problem of "technoablism", when devices are created without the participation of the deaf community. Based on the above, the following recommendations followреомендации:

- Introduction of AI technologies (TIPS) from the first year of life.
- Use of multimodal stimuli (vision + vibration).
- Following the principles of inclusive design.
- Conducting long-term clinical trials of digital programs.

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