Auditory training in cochlear implanted children

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Abstract:

Cochlear implants (CIs) have transformed hearing rehabilitation for individuals with severe to profound hearing loss, significantly improving speech perception and communication. However, CI users, especially children, often face many challenges that hinder speech intelligibility and overall auditory performance. To improve auditory performance and intelligibility, remediation materials comprised the non-formal central auditory exercises in Arabic language are used. P300 and MMN are adapted to monitor improvement after auditory training in hearing-impaired subjects using CIs. Auditory training (AT) in children with CIs leads to improvements in speech and language development, cognition, and quality of life. Furthermore, children receiving bimodal stimulation exhibited higher performance when compared to children using monaural CI.

Keywords: Auditory training, cochlear implant, children, bimodal stimulation, P300, MMN

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Introduction:

Auditory training involves a set of structured exercises designed to improve various aspects of auditory processing such as auditory discrimination, temporal processing and auditory localization, in addition to other cognitive abilities functioning in auditory modality such as auditory memory and attention. These exercises reinforce normal pathways through consistent challenges and enhance the brain's ability to interpret auditory information through repetitive sessions and gradual exposure to auditory tasks. Finally, this aims to improve communication, academic performance, and overall quality of life **(1).**

Classifications of Auditory Training Strategies:

Strategies of auditory training can be classified according to the direction of stimulation of training exercises into bottom-up and top-down strategies of training. Another way of classification is according to the involvement of equipment and the nature of training material in formal and informal training **(2).**

I-Bottom-Up Training:

It is a therapeutic approach that focuses on enhancing fundamental auditory processing skills by starting at the most basic level of sound perception and analysis.

This training emphasizes the improvement of the auditory system's ability to detect, discriminate and process acoustic signals at the peripheral level before these signals are further processed by higher auditory and cognitive functions. It involves structured exercises that enhance the listener's ability to recognize and differentiate basic sound features such as frequency, intensity and temporal aspects of sounds **(3).**

II-Top-Down training:

It is described when training exercises involve higher cognitive and linguistic tasks such as memory, attention and speech manipulation that directly influence the interpretation of acoustic information. This training utilizes language, cognitive strategies and educational interventions to support learning and enhance performance in various settings. It could be more suitable for individuals with hearing impairments **(4).**

III-Formal Training:

Mostly it involves presenting computerized recorded stimuli with accurate control over stimulus levels and method of presentation. It often uses a sound booth and sometimes audiometers to minimize interference from environmental sounds and is more structured, typically utilizing computer-based auditory training programs. Formal training sessions are strictly designed and graded, and not selftailored for the candidates of training. Little personal or live communication is found during sessions using this type of training **(5).**

VI-Informal Training:

Stimuli are often presented without specialized equipment. Presentations are done face-to-face rather than using pre-recorded material. This training typically occurs in everyday settings like home or school settings. It usually uses ageappropriate words or sentences, although non-verbal sounds can also be incorporated. On the contrary to formal training, informal training uses adaptable material that can be easily manipulated during sessions and self-tailored for each candidate. They can be modified and rearranged during sessions according to personal motivation and performance. Furthermore, live or face-to-face presentation of material enforces the generalization of the developing auditory and cognitive skills into daily life situations, such as classroom activities **(2).** This type of training is considered the most suitable form of training for subjects with hearing loss **(6).** They involved missing word exercises, auditory vigilance exercises, auditory memory exercises **(7)**, phonemic awareness exercises and auditory directives **(8).** The remediation was performed using material developed by **Hassaan et al. (9)** which is suitable for school-aged children.

1. Missing word exercise:

This exercise evaluates and trains the auditory closure ability. This can be stimulated by presenting an auditory material with a missed part. This missed part could be a word in a meaningful sentence. The missing word was the last in the sentence to enable the child to expect it from the context **(10)**. One hundred and twenty informative sentences were prepared and arranged into three

groups according to the sophistication of their information content. The child was instructed to listen carefully to the sentence (ten sentences per session) and to guess the missing word **(9).**

2. Auditory vigilance exercises:

This test estimates concentration-vigilance-inhibition, verbal working memory, selective attention, sustained attention, categorization and decisionmaking. These functions require auditory alertness, maintaining a focus on the relevant information, the ability to respond correctly to auditory stimuli and to withstand disturbing cues over a long period **(11).**

Auditory vigilance ability can be stimulated by keeping the child attentive to a selected target. The difficulty of the material depends on the selected target, which could be a specific word (e.g. the word ball), a word related to a certain topic (e.g. any word related to wood) or a certain phoneme at the beginning or the end of a word (e.g. the phoneme "L" in the words **L**amp, Ba**l**l). These targets were randomly impeded in an interesting paragraph or semi-story. According to the type of the target (word, certain topic or phoneme), the developed material was classified into three stages (each stage involved 35 items) **(9).**

Variable degrees of exercise difficulty inside each stage were created based on the previously known fact that the more random the target, the more difficult the task **(7).** This was preceded by a short training in which the examiner alerts the child whenever he/she misses the target.

3. Auditory memory exercises:

Memory tests for *content* and *sequence* were used to estimate short-term memory that describes the storage and consecutive recall of information within a temporary period **(9, 12).** In addition, a memory test for *recognition* was used to examine verbal working memory that expresses further processing and alteration of information while retaining a sequence of verbal stimuli in short-term memory **(9, 13).**

The developed material comprised words and digits. Familiar words within the children's vocabulary were utilized in these tests. The CI users were instructed to repeat the words in no specific order in the content-memory test while keeping their order in the sequential memory test. The recognition-memory test involved word repetition in a particular order, such as repetition of only the first, third and fifth words **(14).**

4. Phonemic awareness exercises:

Phonemic awareness training included exercises for phonemic comparison, phonemic segmentation and phonemic blending. A large number of words of variable vocabulary levels and variable number of phonemes were used. Five exercise materials (each comprising 20 items) were available, five for each of the preceding five phonemic awareness tasks **(9).**

5. Auditory directives exercises:

Enhancement of auditory inter-hemispheric transfer can be accomplished by using auditory directives. It is important to be sure that the completion of the directive involves a motor task that can be observed by the examiner **(8).** The child was asked to follow a series of drawing orders given

to him or her and to start drawing after completion of the series. The difficulty of the directive depends on the number of orders inside it. According to this number (from two to four) directives were classified into three stages. Fifteen directives were prepared for each stage **(9)**.

Principle of auditory training:

I -Assumptions:

The first assumption is that all hearing-impaired children are potential candidates for auditory training after their peripheral hearing loss (as much as possible) by devices or surgeries. This is beneficial in addressing issues such as sound deprivation which leads to a generalized deficiency in auditory abilities and subsequent cognitive and metacognitive impairments in auditory modalities. The second assumption is that these deficiencies will lead to lessthan-normal performance in listening skills. Despite Central Auditory Processing Disorder (CAPD) is generally considered a bottom-up deficit, it works under the control of top-down cognitive processing, where the consumption of allocated resources for certain tasks in either direction will affect the other. The third assumption is that performing adaptive exercises to variable listening skills will obligate the underlying auditory abilities and processes to grow. This involves skill formation guided by the principle "fire together, wire together," which promotes neural connections and automaticity, enabling subconscious performance. The fourth assumption is that this socially interactive training will directly benefit the generalization of these improved abilities in daily life situations and support cross-modality integration because the Central Auditory Nervous System (CANS) maintains robust connections with other sensory, cognitive and language systems **(15)**.

II- Guidelines:

The CI candidates, especially those who are prelingually deafened, acquire APD due to a period of sensory deprivation during the age of auditory neural pathway maturation. Auditory training should be started for this category of patients whenever their peripheral hearing loss is corrected. They often struggle with other cognitive abilities such as auditory memory and attention, which can impair their ability to follow verbal instructions. Moreover, they may have trouble localizing the source of sounds, understanding speech in noisy environments, or comprehending rapid speech or overlapping conversations. Auditory training typically follows a hierarchical structure, progressing from basic sound awareness passing through more complex sound discrimination and identification tasks until reaching the complex cognitive and linguistic tasks. The training emphasizes the development of listening skills to improve the interpretation of speech sounds, even in the presence of hearing deficits. It involves repeated presentation of sounds, where the individual listens, makes judgments about what he/she hears, and receives feedback on the accuracy of his/her responses. It should be tailored to the individual's specific needs, whether they have normal peripheral hearing or peripheral hearing loss, acquired hearing loss or APD. This can be achieved through various modalities, including computer-based programs, face-toface exercises, and even non-auditory tasks like visual-spatial games, which can lead to improvements in auditory processing. The duration and frequency of training can vary, but studies suggest that 2-3 training sessions/week of at least 20 minutes are often effective **(14)**.

III-Auditory plasticity:

The brain's remarkable ability to reorganize and adapt, known as plasticity, is a crucial element in auditory training and refers to the capacity of the auditory system to modify its structure and function in response to changes in the sensory environment, learning or as a result of injury. This neuroplastic adaptability is crucial for optimizing auditory processing and is facilitated through both physiological changes at the cellular level and alterations in neural connections and pathways. By engaging in targeted listening exercises and tasks, the brain can create new neural connections, strengthen existing pathways, and refine its auditory processing. This adaptability allows the brain to compensate for auditory system limitations, including those arising from hearing loss or CIs **(16).**

Auditory training induces both functional and structural reorganization in the auditory neural pathway. It replaces non-functional neurons, forms new connections (arborization), increases neuron thickness and enlarges synapses to enhance signal transmission. In addition, improved neurotransmitter release and heightened sensitivity of synaptic terminals collectively enhance the brain's ability to process auditory signals efficiently **(17).**

Neuroplasticity can be categorized into three main forms: **ExperienceDependent Plasticity:** This type involves modifications in brain function as a direct response to external stimuli encountered during rehabilitation. Targeted auditory training exercises fall under this category, as they help the brain to improve its auditory processing abilities. **Experience-Independent Plasticity:** Changes in brain structure or function occur due to spontaneous, internally generated activity rather than external input. This type of plasticity reflects the innate adaptability of neural networks. **Experience-Expectant Plasticity:** In this form, the brain depends on environmental inputs to guide its structural development. For example, auditory stimuli encountered during critical periods shape the organization and efficiency of neural pathways, ensuring effective auditory processing. Recognizing these forms of plasticity is essential for designing auditory training programs that maximize the brain's adaptability and promote optimal rehabilitation outcomes **(9).**

Monitoring the outcome of auditory training in hearing-impaired subjects

Longitudinal monitoring, follow-up sessions and maintenance programs along with regular post-training assessments are necessary to identify long-term benefits and areas requiring further improvement. Such comprehensive evaluation ensures the training's sustained effectiveness and guides refinements in intervention strategies **(18).**

A comprehensive approach is essential for assessing improvements and understanding the impact of auditory training. Psychophysical tests are the most widely used in the assessment of hearing-impaired subjects owing to their feasibility, availability and adaptability to different ages and levels of hearing residual function. This process typically begins with pre- and post-training assessments, including audiometric tests that measure hearing sensitivity and speech perception, like speech-in-noise tests, to evaluate speech comprehension in background noise **(19).** Other central auditory tests can be adapted to the available age and the residual hearing function of the hearing-impaired subjects such as temporal patterning tasks and gap detection tasks. Cognitive testing, which assesses functions like attention and memory, is also crucial to validate improvement after auditory training **(20).**

The auditory late evoked potentials constitute valuable objective monitoring tools of remediation programs of APD. As intrasubject monitoring tools, they express reliable validating measures. The most widely used are the slow cortical response (SCR), P300 potential and MMN potential. These measures gradually reflect the efficiency of the auditory neural pathway up to the cortical level (2). Assessment of auditory late evoked potentials in the aided condition is a very useful modification of measurement. In spite that their intrasubject variabilities are relatively high, especially in cortical potentials, they proved to be useful in comparison before and after remediation owing to their reasonable intrasubject variabilities. the auditory late evoked potentials involve:

I- MMN:

MMN represents neurophysiologic changes in the brain's electrical activity in response to auditory discrimination. It is used to assess selected auditory subprocesses that are important for normal and efficient processing of auditory formation (7). Therefore, it is considered an objective measure to assess the CAP function (21). Two stimuli were presented as an odd-ball paradigm with a frequent tone-burst of 750 Hz and a deviant tone-burst of 1000 Hz, with a probability of 80% and 20%, respectively. The response involves two waves: standard and deviant. A difference wave was computed by subtracting the standard wave from the deviant one separately for each child. At the beginning of the analysis, the baseline was corrected according to the 50 ms pre-stimulus period. The MMN was identified as a negative trough in the difference wave nearly after 250 ms (22).

II- P300:

The P300 is a CAEP that reflects cognitive activities, including memory updating and sustained and selective attention (11). It is used as an identification tool in auditory sequential processing deficit and a prognostic tool in the evaluation of remediation programs. It was recorded in response to a speech oddball paradigm that consisted of a frequent /ga/ stimulus (80% probability) and a rare /da/ stimulus (20% probability). Recording was carried out while the child was attentive to the deviant stimulus (da). The response involved two traces, the slow vertex response and deviant waves, that were elicited in response to the frequent and deviant stimuli of the speech oddball paradigm, respectively. The P300 wave was identified as a positive peak in the deviant trace between ≈250–400 ms (23).

P300 and MMN are used in the assessment of static improvement after using hearing aids or CIs. Moreover, they can be adapted to monitor improvement after auditory training in hearing-impaired subjects using hearing aids or CIs (23).

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