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Review

Assessment of auditory discrimination in hearing-impaired patients

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ABSTRACT

Hearing loss can impair auditory discrimination, especially in noisy environments, requiring greater listening effort, which can impact socio-occupational life. To assess the impact of hearing loss in noisy environments, clinicians may use subjective or objective methods. Subjective methods, such as speech audiometry in noise, are used in clinical practice to assess reported discomfort. Objective methods, such as cortical auditory evoked potentials (CAEPs), are mainly used in research. Subjective methods mainly comprise speech audiometry in noise, in which the signal-to-noise ratio can be varied so as to determine the individual speech recognition threshold, with and without hearing rehabilitation, the aim being to highlight any improvement in auditory performance. Frequency discrimination analysis is also possible. Objective methods assess auditory discrimination without the patient's active participation. One technique used for patients with auditory rehabilitation is the study of auditory responses by CAEPs. This electrophysiological examination studies cortical auditory rehabilitation oddball paradigms, enabling wave recordings such as mismatch negativity, P300 or N400, and analysis of neurophysiological markers according to auditory performance. The present article reviews all these methods, in order to better understand and evaluate the impact of hearing loss in everyday life.

1. Introduction

In normal-hearing subjects, binaural function enables acoustic location, loudness summation and binaural demasking, thanks to binaural interactions between ascending auditory pathway neurons in the brainstem. These mainly take place in the superior olivary complex, lateral lemniscus and inferior colliculus. Acoustic location is achieved by analysis of interaural time and intensity differentials in the superior olivary complex [1].

In noise, the auditory system breaks down incoming acoustic information according to source, enabling speech to be extracted from noise [2–4]. This central capability is reinforced by binaural hearing. Acoustic information from either ear is analyzed in the auditory cortex; comparison after addition and subtraction improves speech perception in noise.

In hearing-impaired subjects, speech perception in noise is complicated by several factors: elevation of absolute thresholds and loudness recruitment, frequency selectivity loss (cochlear filter enlargement proportional to hearing loss) [5], impaired temporal resolution, and loss of fine structure temporal information. These impairments make listening more complicated in noise than in silence. In congenital or acquired unilateral hearing loss, central reorganization has been described following loss of binaural function [6–10]. Impaired discrimination secondary to hearing loss and loss of binaural function requires increased listening effort and impairs identification of speakers and acoustic location [11], and hence quality of life [12]. It is therefore important to assess auditory discrimination quality using both subjective and objective methods.

Speech audiometry in noise analyzes hearing difficulty in noisy environments and assesses rehabilitation efficacy. It is now a routine clinical test, indispensable in research to assess the performance of different hearing aid systems. Cortical auditory responses are mainly used in research, being complicated to collect and analyze.

The objective of the present review is to describe the various techniques of auditory discrimination assessment.

2. Subjective methods

Subjective unlike objective methods require the subject's active participation. They are essential for assessing auditory perception and understanding in noise. Perceptual deficits and quality of

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life cannot be assessed objectively. The most common subjective methods assessing auditory discrimination are audiometry under competition (audiometry in noise, or dichotic listening tasks) and frequency discrimination tests. One limitation concerns longitudinal reproducibility.

2.1. Speech audiometry in noise

For speech audiometry in noise, the subject is asked to repeat a list of syllables, words or sentences presented in noise. The examiner varies the intensity of the voice while the intensity of the nose is held constant: this signal-to-noise ratio (SNR) is the difference in intensity between noise and speech, in decibels (dB HL). The signal-to-noise ratio can also be held constant, and the examiner counts the number of correctly repeated syllables, words or sentences in a given list. The aim is to determine: (1) the speech perception threshold, being the SNR at which the subjects correctly repeats 50% of the syllables, words or sentences; and (2) the maximum speech perception threshold, being the SNR at which the subjects correctly repeats all of the syllables, words or sentences in a given list. The other means of assessing speech perception in noise uses an adaptive test in which the noise level is automatically varied by a software application until the threshold is reached. Standardized sentence lists exist, such as those used in the Hearing in Noise Test (HINT), which have the advantage of being used with a classical audiometer, not requiring special software [13]. Recently, a sentence test was developed and adapted in French, based on the Oldenburg Sentence Test [14]. This auditory discrimination test, known as the French Matrix Test, uses sentences with fixed syntax (forename-verb-number-object-color) under cocktail-party noise of varying intensity [14]. The Oldenburg Measurement Application software determines the speech perception threshold by auto-adjustment of the voice intensity according to the subject's responses. For example, when the subject correctly repeats more than 50% of the sentences, the SNR decreases, and vice-versa. These calibrated methods with standardized test conditions can be used to compare performance between subjects and for longitudinal study. However, they require specific equipment, whereas the HINT, comprising just 5 sentence lists, can be used in simple free field. With just 5 lists, the HINT is exposed to learning artifacts, especially in longitudinal follow-up. Finally, another drawback of the French Matrix Test is that it requires training lists for the test to be run properly, making it rather long and burdensome.

Studies in normal-hearing subjects established normal values for HINT and French Matrix sentences. In HINT, SNR is defined as −3 dB when noise and speech are emitted by the same frontally positioned loudspeaker, and as −11.4 dB for speech emitted frontally and noise at 90° to the left or right [13]. In the French Matrix test, the reference value is −6 dB for noise and speech presented binaurally via headphones [14].

These speech audiometry tests are usually delivered in free field, using at least 2 loudspeakers. Noise and speech positioning depends on the listening situation being tested. In dichotic listening, both are emitted by the same loudspeaker, enabling binaural summation to be assessed; speech is sent to the poorer and noise to the better ear. In inversed dichotic listening, speech is sent to the better and noise to the poorer ear. Dichotic and inversed dichotic tests enable assessment of head shadowing and binaural demasking. The aim is to assess hearing performance in noise after auditory rehabilitation and to test the efficacy of the hearing aid noise reduction system.

2.2. Auditory frequency discrimination

The frequency discrimination threshold enables assessment of the minimal frequency variation perceptible to the subject, which is an essential parameter of speech perception. The discrimination mechanism in noise comes into play in listening to music [15,16] and language learning [17,18].

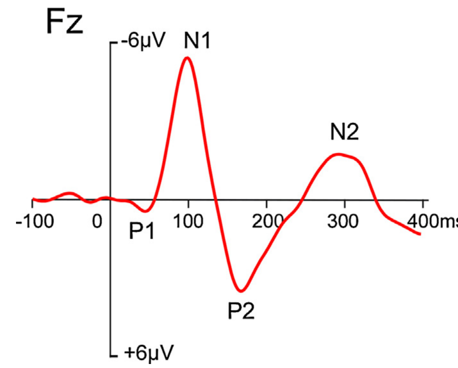

Fig. 1. Cortical auditory evoked potentials. Mean evoked potential recorded at Fz in 8 normal-hearing adults with 70bBA tone burst. X-axis: time in ms; Y-axis: amplitude (µv). Waves P1, N1, P2 and N2 can be seen. Negativity is shown below.

3. Objective methods

Objective methods assess auditory perception without the subject's active involvement. They supplement subjective techniques, and comprise functional MRI (fMRI), positron-emission tomography coupled to CT (PET-CT), functional near-infrared spectroscopy (fNIRS) and cortical auditory evoked potentials (CAEP).

CAEPs provide fine-grained temporal information following neuronal activity associated with auditory information processing, and are collected after at least 50 ms [19].

In normal-hearing adults, frontocentral responses recorded at the vertex (Cz) or Fz (Fig. 1) after auditory stimulation classically comprise a positive wave (P1; latency 60–80 ms), followed by a negative wave (N1; latency 90–100 ms), then a second positive (P2; latency 100–160 ms) and negative wave (N2; latency 180–200 ms) [20]. The P1 and N1 generators are located in the supratemporal plane [21]; the P2 generator is located in the primary auditory cortex in the lateral sulcus [22]; and the N2 generator has been identified in the supratemporal cortex [22,23]. The generators of these waves are all located in the superior temporal gyrus. The CAEP technique enables cortical auditory responses to be studied in children; these are predominantly recorded in the temporal area, in the form of the T complex, mainly comprising 2 negative waves, whereas frontocentral responses differ in morphology and latency from adult responses: in children, frontocentral responses comprise waves P1, N2 and N4, with longer latencies due to incomplete maturation of the auditory cortex. Recording is more difficult in children, due to muscular artifacts induced by movements. The child needs to be kept awake, to avoid the alpha waves associated with falling asleep, which would mask the cortical auditory responses [24]. Recording usually takes 20–30 minutes, depending on the protocol; if the child is agitated, pauses may be needed to avoid movement artifacts; moreover, the time needed for electrode positioning has to be added.

In patients with cochlear implants, cortical auditory responses are studied to explore cortical processing of auditory information. The aim is to shed light on post-implantation cortical reorganization and to identify neurophysiological indices of auditory and language performance [15,25–28]. Electrophysiological studies identified P1 peak latency as a neurophysiological marker of auditory cortex maturation after cochlear implantation in children [26]. For CAEP study, the stimulus artifact induced by the cochlear implant needs to be minimized [29,30]; independent component analysis allows the artifact to be extracted [31–35].

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