PSYCHOACOUTIC TESTS FOR CENTRAL AUDITORY PROCESSING: NORMATIVE DATA

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ABSTRACT

The comprehension of spoken language is based on the analysis of complex acoustic signals by the central auditory system. Direct relationships between gradual, spectrottemporal modifications of speech sounds and the impairment of the comprehension of such altered sounds have been found in many psychophysical studies. Thus, it is reasonable to assume that deficits in the understanding of speech seen in patients with acquired brain lesions may, to a certain degree, result from impaired central processing of acoustic signals. We report normative data collected from 94 young normal-hearing subjects on a battery of psychoacoustic tests designed to evaluate signal processing at different levels of the central auditory system. Monaural pure tone thresholds were used to evaluate the performance of peripheral hearing. The integrity of auditory brainstem processing was evaluated by quantifying masking level difference (MLD) values and gap detection (GD) thresholds. Three monaural speech tests (time-compressed speech [CS], filtered speech [FS] and speech in noise [SIN]) were conducted to evaluate the processing of distorted speech materials by cortical auditory processing mechanisms. Evaluating performance of naive, young normal-hearing subjects, as we did here, is indispensable for (a) evaluating the effectiveness of potential tests, (b) evaluating their suitability for the examination of patients, and (c) the revision and further development of central auditory tests.

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central auditory processing, gap detection, masking level difference, time-compressed speech, filtered speech, speech in noise

INTRODUCTION

The simplest way to define central auditory processing (CAP) is that it is “what we do with what we hear” /1/. CAP refers to the auditory mechanisms and processes responsible for sound localization and lateralization, auditory discrimination, auditory pattern recognition, temporal aspects of audition (temporal resolution, temporal masking, temporal integration and ordering), and auditory performance decrements with competing or degraded acoustic signals /2/. Neurophysiologically, auditory processing involves a series of events that are initiated in the cochlea and involve brainstem centers and higher cortical levels along the auditory pathway. In addition, auditory processing is not contingent only on the abilities of the auditory system, but also on other factors such as memory, attention, phonological skills, learning and cognition /3,4/. Therefore disruption of CAP can have severe consequences in terms of skills and capacities important to everyday life and academic abilities.

CAP tests are designed to evaluate the various auditory functions of the brain. However, before this type of testing begins, it is important that each person being tested receives a routine audiometric test. There are numerous auditory tests that the audiologist can use to assess central auditory function. These fall into two major categories: behavioral tests and electrophysiological tests. The behavioral tests are often broken down into four subcategories, including monaural low-redundancy speech tests, dichotic speech tests, temporal patterning tests and binaural interaction tests. Electrophysiological tests are measures of the brain’s response to sounds. For these tests, electrodes are placed on the earlobes and scalp of the patient for the purpose of measuring electrical potentials that arise from the central nervous system in response to an auditory stimulus such as a click sound or a speech segment. Some electrophysiological tests are used to evaluate processing lower in the brain (auditory brainstem response) /5/, whereas others assess functioning higher in the brain (middle latency responses, late auditory evoked responses, auditory cognitive or P300
responses) (6,7). The results obtained on these tests are compared to age-appropriate norms to determine whether any abnormalities exist.

The aim of the present study was to establish norms for five CAP tests which are routinely used in clinical settings, yet lack normative data. Two of these tests use non-verbal stimuli (gap detection [GD] and masking level difference [MLD]), whereas the other three use low-redundancy speech materials (compressed speech [CS], filtered speech [FS] and speech in noise [SIN]).

METHODS

Participants

Ninety-four young normal-hearing listeners from 20-32 years of age participated in the present study. All participants were found to have normal peripheral hearing thresholds (0-15 dB HL) across speech frequencies assessed with monaural pure tone thresholds, and normal word recognition scores in quiet. The subjects were divided into five groups and each group participated in only one of the CAP tests described below to be sure that listeners were truly naive and that their performance was not influenced by familiarity with the testing environment and procedures.

Auditory processing evaluation tests

All tests were conducted in the institute for hearing research in our department. The tests were performed in a sound attenuated room with calibrated audiometers.

Masking level difference (MLD)

Twenty listeners (10 males, 10 females), 20-30 years old (mean age 24 years) participated in this test. The MLD test is made up of 33 presentations of narrow band noise within which a series of 500 Hz tone pulses may or may not be present. Stimuli are presented binaurally at 70 dB HL and the tones are variable with respect to level and phase, both of which are indicated on the scoring form. The listener’s task is to report the presence of the tone pulses when these are present. The test is administered with two phase conditions: SoNo - tones are presented binaurally in phase with background noise, and
SnNo - tones are presented binaurally out of phase with noise. The difference in signal to noise ratio (SNR) thresholds between the two conditions is the MLD value.

**Gap detection (GD)**

Twenty listeners (10 males, 10 females) participated in this test. Ten listeners were tested with click stimuli /8/ and the other ten received white noise stimuli (500 ms long) /9/. Stimuli were presented in an oddball paradigm at 50 dB HL. In each trial, three tones were presented - two continuous tones and one tone (the test) with a silent gap that varied from 40-40 ms. Listeners were asked to indicate the stimulus in which they perceived the gap. The time interval (gap interval) in which listeners correctly identified the test tone 50% of the time was considered the GD threshold.

**Speech in noise (SIN)**

Eighteen listeners (9 males, 9 females) participated in this test. They were asked to repeat words presented in quiet and in three levels of background noise (signal to noise ratio [SNR] = 0, -5, -10 dB) and the percent of words correctly repeated was determined. Each list of words consisted of 50 monosyllabic (phonetically balanced) words divided between the four test conditions. Words were presented at the most comfortable level (35 dB above speech reception threshold [SRT]).

**Filtered speech (FS)**

Twenty listeners (10 males, 10 females) completed this test. Filtered words were presented at the most comfortable level (35 dB above SRT). Words were filtered digitally with Adobe Audition\textsuperscript{\textregistered} v1.5 program with one of two band pass filters with a central frequency of 1,600 Hz and 96 dB/octave slope. One filter had a bandwidth of 1 octave (frequency cutoffs: 1,131-2,262 Hz) and the other of 1/3 octave (1,425-1,796 Hz).

**Time-compressed speech (CS)**

Sixteen listeners (8 males, 8 females) participated in this test. Speech material included monosyllabic words which were compressed.
at 60% and 70% compression rates, using an advanced algorithm (Cool Edit Pro 2.00 Program) which preserves the pitch and the speech spectrum. The monosyllabic word lists were presented at 50 dB HL.

**Statistical analysis**

Statistical tests included paired and unpaired t-tests. Probabilities less than 0.05 were considered as statistically significant.

**RESULTS**

**Non-verbal auditory processing tests**

The outcomes of the two non-verbal tests are shown in Figure 1 which presents the MLD (Fig. 1A) and gap detection (Fig. 1B) for two different stimuli (white noise [WN] and click) in normal hearing young listeners. With respect to the MLD test, in the SoNo condition, the mean SNR threshold for the 500 Hz tone signal was -12.1 dB (SD = 2.79, range = -8 to -16), while in the SrNo condition, the threshold for detection of the signal improved to -23.5 dB (SD = 1.43, range = -22 to -26), giving an MLD value of 11.4 dB (SD = 2.35, range 8-14).

Concerning the GD test, for the click stimuli, the average GD threshold was 4.4 ms (SD = 4.83) with a large variability between the subjects, ranging from 2 to 17 ms. In contrast, using WN stimuli, the GD threshold decreased to 3.97 ms (SD = 0.81), with less variability between subjects, ranging from 2 to 5 ms.

**Verbal auditory processing tests**

Figure 2A depicts the results of speech discrimination at three fixed SNRs (0, -5, -10 dB) compared to speech discrimination in quiet, in which performance averaged 99% correct (SD = 3.08) and ranged from 94-100%. At SNR 0, the mean of the speech discrimination score was 81% (SD = 9.19) with a range of 68-96%. When noise was louder than the signal by 5 dB (SNR -5), the mean identification values (80.78%, SD = 11.08, range 68-96%) were similar to those obtained when the signal and noise were of equal intensity. However, when noise increased further at a SNR of -10 dB, mean speech identification scores decreased significantly (t-test, p < 0.05) to 68% (SD = 11.91, range 45-89%).

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Fig. 1:  A: Mean values and standard deviations (in dB) of the masking level difference (MLD) between SoNo (signal and noise are in phase between the ears) and SzNo (signal is out of phase, but noise is in phase between the ears). B: Mean values and standard deviations (in msec) of gap detection threshold for noise and click.
In the filtered speech test (Fig. 2B), the mean speech discrimination score in the young normal hearing listeners for the one octave bandwidth condition (see Methods) was 68.9% (SD = 11.97, range 52-84%). For the third octave bandwidth, the average discrimination score decreased to 50.2% (SD = 11.71, range 40-72%). Compared to without filtering (mean 98.1%, SD = 2.56, range 92-100%), the one octave band wide condition was found to be significant (t(19) = 29.2; p < 0.01).

In Figure 2C, the 60% time-compression speech condition, the mean was 79.25% (SD = 7.41, range 62-92%), while in 70% compression rate, the discrimination score deteriorated significantly to 55% (SD = 7.61, range 44-68%) (t(15) = 9.905; p < 0.005).

DISCUSSION

The primary aim of this study was to provide normative data for several verbal and non-verbal auditory tests for the evaluation of central auditory processing. It is our intention that this data will be used as a basis for the clinical evaluation of subjects with normal hearing but suffering from CAP disorders, as well as in the elderly and in patients with hearing impairments. In addition, the auditory test battery presented in this study offers the possibility to evaluate the processing and integrity of different segments along the auditory pathway. The integrity of auditory brainstem processing was evaluated by quantifying MLD values and GD thresholds. The three monaural speech tests (CS, FS and SIN) reflect the perception of distorted speech materials by cortical auditory processing mechanisms.

The MLD values found in this study are in agreement with the results of previous reports /10-12/. Reversing the phase of the signal by 180° between the ears, in the presence of binaural noise, resulted in the improvement of signal detection threshold. This improvement is due to brainstem mechanisms which detect differences in phase between the ears and enhance signal detection /13/. Abnormal performance on the MLD test is consistent with brainstem disorders /14,15/.

The monaural GD test reflects the ability of auditory brainstem mechanisms to detect silent gaps between stimuli and is a measure of the temporal resolution of the auditory system. For example, this ability is critical for the detection of rapidly changing segments of speech /16/. The GD thresholds of noise were significantly smaller...
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A

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<thead>
<tr>
<th>SIN at SNR -10</th>
<th>SIN at SNR -5</th>
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<td>68</td>
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B

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<tr>
<th>Filtered speech 1/3 octave</th>
<th>Filtered speech 1 octave</th>
<th>Speech without filtering</th>
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<td>50.2</td>
<td>68.9</td>
<td>98.1</td>
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Fig. 2: A: Mean values and standard deviations of the discrimination scores of speech in noise (SIN) at four signal to noise ratio (SNR) conditions. B: Mean values and standard deviations of the discrimination scores to filtered speech in three conditions. C: Mean values and standard deviations of the discrimination scores to time-compressed speech for two compression rates.

than those for clicks. This can probably be attributed to the differences in spectrum and duration of stimuli between clicks and noises. In click stimuli, the spectrum is narrower and duration is shorter, making the task of gap detection harder than that with the noise stimuli. Since the between-subject variability of the GD thresholds was larger for clicks than for noise stimuli, we suggest that noise stimuli can be used in clinical applications of the GD test.

Using low-redundancy speech materials in the monaural speech tests, the function of the auditory system in difficult situations can be probed. In general, understanding deteriorates with increasing distortion of the speech signal/17,18/. Indeed, among listeners in the current study, performance deteriorated when noise was added to the speech in several SNRs, when the speech was compressed gradually, and also when the band width of the speech spectrum was varied. Particularly
detrimental were the narrow band filter and the 70% time compression rate, indicating that large alterations in either the temporal or the spectral domain are significantly sufficient to affect perception. Because performance in the speech tests can be influenced by factors that are difficult for the audiologist to quantify (e.g., language and speech skills and cognition), we suggest assessing performance with different levels of difficulty for each task (e.g., different rates of compression) for each listener and to look at the deterioration of performance as a function of distortion level.

In conclusion, by using both verbal and non-verbal materials, we believe that the battery of auditory tests as suggested in this study reflects more comprehensively the processing of the auditory system. However, before clinical application, this auditory test battery should be evaluated in patients with different CAP disorders as well as in older normal hearing individuals.

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