Original Article

Central Auditory Processes Evaluated With Psychoacoustic Tests in Normal Children

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Abstract

Objective: To identify the natural tendencies of hits and calculate the cut-off for a test group of central auditory processes (CAP): binaural fusion, filtered words, dichotic digits, frequency patterns and duration patterns, and ambient sounds in normal 5-, 7-, 9-, and 11-year-old children.

Material and methods: We studied 369 children (738 ears) who attend public schools in Puebla City, administering 6 CAP tests (2 binaural and 4 monaural); we used an audiometer at 50 dB SL re-threshold at 1 kHz, from a CD recorded at the CCECADET-UNAM-INR (Centre for Applied Science and Technological Development at the National Autonomous University of Mexico and the National Institute for Rehabilitation).

Results: We determined the cut-off points for the 6 tests.

Conclusion: This information represents an advance in the normative standards in the field of psychoacoustic tests for CAP in Spanish and in the socio-educational context prevalent in Mexico. It is important to evaluate these results against CAP disorders.

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Keywords
Child; Psychoacoustic tests; Central auditory processes; Auditory neuro-maturation; Cut-off points

Palabras clave
Niño; Pruebas psicoacústicas;
Introduction

The study of hearing as a central phenomenon is based on the functional and ontogenetic perspective that, although biological bases determine certain powers of these processes, they are not the main object of study. This kind of approach requires a broad array of tests by the physician, along with the demands of the protocols employed. Experimental and clinical methodologies in the study of central auditory processes are based on different techniques: psychoacoustic, electrophysiological-EEG, imaging, biochemical studies, studies based on lesions, and behavioural observation studies.1

Sensitivity to sound is developed in complex ways that continue even after 5 years of age, although the ability to select and discriminate frequencies is already well-developed in infants.2 The auditory processing carried out through cross-pathways reflects different central levels of analysis related to the levels of the auditory pathway. The cortical level is mature at the beginning of adolescence.3

The primary auditory cortex includes the ventral and lateral areas of the temporal lobe. The secondary auditory cortex receives projections from the primary cortex and covers the upper part of the temporal lobe, surrounding the primary cortex. Some regions sensitive to the perception of timbre have been found. Extensive damage to the auditory cortex produces an auditory agnosia syndrome characterised by an inability to identify the meaning of verbal and nonverbal sounds.4–7

The evaluation of central auditory processing (CAP) in children formally began with the intervention of Willeford (1974) at the American Speech-Language-Hearing Association (ASHA). Willeford described the results of a battery of tests applied to children with language and learning disorders.8

Some of the materials for psychoacoustic tests adopted from tests designed for adults cannot be considered appropriate for children. On the other hand, it is necessary to include dichotic and monaural tests in the evaluation of CAP in children, as well as tests that explore different functions.9

Since the 1990s, ASHA has convened expert panels on CAP to identify qualified consultants in the field, as well as accepted diagnostic and treatment procedures.10–13

CAP disorder (CAPD) describes a condition in which, despite the existence of normal peripheral hearing (ear and nerve), the subject experiences alterations in laterality and difficulties to locate the source of the sound signal, to discriminate degraded signals or to receive material with temporal modifications applied to verbal or nonverbal stimuli, as well as to detect auditory signals applied simultaneously with noise or contralateral/ipsilateral messages.14 These patients have difficulty understanding spoken language in environments where there is competitive background noise or in the presence of reverberation. Children with CAPD often ask to have verbal information repeated to them. They exhibit a lack of auditory attention in many situations, may misinterpret verbal messages, have difficulty following directions presented as complex auditory signals and exhibit problems in locating sounds. The prevalence of this disorder varies slightly according to different researchers. Recent data place it at 2% in children and up to 80% in the elderly, with a male:female ratio of approximately 2:1.15,16 Auditory behaviours in patients with CAPD have been described by Bellis and Cañete.17–19

Tests to study CAP have the following principles: being performed with a clinical basis; exploring different CAP features; including verbal and nonverbal tests (for example: tones, clicks, and complex wave forms); creating designs for the determination of sensitivity and specificity; reliability and validity tests, as well as appropriateness and age. It is important for the person who administers and interprets the tests to have theoretical and practical knowledge about CAP. In our environment, physicians specialising in communication, audiology, and speech therapy are qualified to apply and interpret such tests.20,21

There is general agreement that a test battery should be used, as opposed to a single test. However, there is some disagreement as to which tests are the best predictors and, therefore, which should be included in the test battery for CAP.22–24 The selection of specific procedures depends on several factors and could be individualised for each child.

Our working group has conducted research and clinical evaluation of CAP since 2002 on children, adults, and elderly patients.25–27 Nevertheless, we do not have sufficient specific experience in Spanish-speaking countries to help us...
The aim of this study was to apply a CAP test battery on a population of Mexican children from an official public primary school in the city of Puebla (Mexico). The tests comprising the battery were selected after a rigorous analysis of the experiences reported on CAP with English-speaking children, as well as the experience obtained in Spanish in the area of CAP-National Institute of Rehabilitation in the last 7 years. This battery should be reliable and specific for the identification of children without CAPD. Children aged 5, 7, 9, and 11 years, with good school performance, studied within their school environment using a battery of 6 tests selected for CAP should show their natural tendencies in each test. These results could be used to gauge the usefulness of each test when scores of 60% or above are obtained for each test. The cut-off point for each test was obtained by subtracting the standard deviation from the mean result of both ears in the study population.\textsuperscript{9}

### Subjects and Method

This was a cross-sectional, descriptive, population-based study with an epidemiological, descriptive, and exploratory design. Ethics: the parents of participating children signed an informed consent.

The sample size was calculated in an exploratory manner for a reported prevalence between 2% and 80%. Considering a prevalence rate of 40%, the sample size was obtained using the following formula: \( \text{No.} = \frac{(1.96)^2 \times (0.40 \times 0.60)/(0.05)^2}{14} \)

This resulted in a total of 369 children.

Children were divided into 4 groups according to their ages: 5, 7, 9, and 11 years. We attempted to obtain representation of competencies to carry out monaural and binaural psychoacoustic testing in preschool and school ages, assuming that children who were not explored (6, 8, and 10 years of age) could be considered within intermediate values between the groups. The children had a school rating of 8 or above for the school year in course. Normal hearing was considered at frequencies 500 Hz to 4 kHz. The threshold should be no more than 25 dB.

We selected children of both genders. Group 1 (G1) included children aged from 5 years to 5 years and 11 months, selected from a preschool population. With the aid of their teacher, we identified an adequate development pattern for children of their age.

Group 2 (G2) included children aged from 7 years to 7 years and 11 months, Group 3 (G3) included children aged from 9 years to 9 years and 11 months and Group 4 (G4) included children aged from 11 years to 11 years and 11 months. The last 3 groups included children from a school population.

Surveys about the behavioural patterns observed in children were applied to parents and teachers. Only cases in which more than 5 positive items for CAP in both procedures had not been presented were included.\textsuperscript{14} Spanish was the children’s mother tongue. They did not present otoscopic evidence of cerumen occlusion or active manifestations or sequelae of otitis media, nor did they present dysmorphic syndrome or show evidence of upper respiratory infection at the time of the study. We excluded cases without informed parental consent. A criterion for exclusion was incomplete assessment.

### Equipment

The area of study was validated by an expert in acoustics. We used a two-channel Midimate 602 clinical/diagnostic audiometer (Madsen Electronics) with a RS232C serial data interface. We also used Madsen TDH39 air conduction headphones and a Sound Track CD player. The sounds employed were from a CD with voice recordings elaborated by the Acoustics Laboratory of the Centre for Applied Sciences and Technological Development (CCADT) of the Universidad Nacional Autonoma de Mexico. The design and recording of tests were developed following previous recordings,\textsuperscript{7,26} based on a sample of the Spanish language used in Mexico City- Universidad Nacional Autonoma de Mexico.

### Procedure

Parents and teachers from each group resolved the formats for the recognition of potential CAPD signs.\textsuperscript{17} The children were studied ordered by age groups. This was performed by a physician specialising in audiology and speech therapy, on the same school population and with the same equipment. We included only 2 schools, 1 from preschool level and another 1 from school level. Parents or staff assigned by the management of the school verified the minimal intervention procedure and the performance of the tests.

The doctor introduced herself or himself to the child and explained the functions that were going to be evaluated. Otoscopy was performed, followed by recording of tonal audiograms.

### Tests

These were: binaural fusion (BFT); the monaural filtered speech test (FST), frequency pattern test (FPT), duration pattern test (DPT); laterality, binaural dichotic digit test (DDT) and, as right hemisphere test, monaural environmental sounds perception test (EST). The procedure began with the right ear in all tests.

The CD player on which the tests were recorded was connected to the audiometer and, from there, applied in each case through shell headphones at 50 dB above the tonal audiometric threshold obtained previously for 1 kHz.

All tests were monitored by the physician during their administration and response. The physician verified the accuracy or error for each item on the checklist.

BFT. This test evaluated the sensitivity of the central auditory nervous system (CANS) to integrate the information provided in a complementary manner for each disyllabic word in both ears. Words were separated into low pass and high pass components from a sharp cut-off point at 1200 Hz whose slope was 46 dB/octave. The inter-stimulus interval was 2 s. The list contained a total of 25 items. Examples of stimuli were: "suela", "talco", "corta", "nena", and "cura".

FST. This test was sensitive to contralateral deficits in patients with temporal cortical lesions and brainstem
lesions. It presented monosyllables to each ear separately.
The test contained a total of 25 items. Examples of stimuli were: "ara", "ene", "ser", "cur", and "set".

**DDT.** This test evaluated brain stem and interhemispheric brain functions. It presented different digits, simultaneously in paired segments, 2 pairs and 3 pairs of digits (other features are described in Ref. 9). The children had to repeat 1 number from each pair, whichever they heard better or seemed more important. Responses were recorded as right (DDTR), left (DDTL), mixed (DDTM), and omissions (DDTO).

**FPT and DPT.** These tests were sensitive to malfunctions of the auditory cortex, its interhemispheric relations, corpus callosum, and neural maturation. They employed tone triads that differed in frequency for the FPT and in duration for the DPT. For the FPT, the recording contained frequencies at 1122 Hz as high frequency and 880 Hz as low frequency. For the DPT, the long tones lasted for 500 ms and the short tones lasted for 250 ms. In both tests, 5 triads that the child had to imitate were applied per ear and per test.

**EST.** This test evaluated the functions of the right hemisphere. A monaural test contained a recording of environmental sounds from animals or objects such as a dog or a bell. A total of 10 stimuli were applied on each side. The child had to identify the sounds or establish a close association.

In the 4 monaural tests we applied contralateral white noise at minus 30 dB relative to the white stimulus.

**Results**

We studied 369 children with ages in biennial intervals between 5 and 11 years old. There was a slight predominance of the female gender, except in Group 4 (Table 1). Five children were excluded due to a lack of informed consent. The 5-year-old group (G1) included 90 children, representing 24.3% of the total. The 7-year-old group (G2) included 97 children, representing 26.2% of the total. The 9-year-old group (G3) included 89 children, representing 24.1% of the total. Lastly, the 11-year-old group (G4) included 93 children, representing 25.2% of the total (Table 1).

With the exception of the dichotic digit test, both ears were included in the same category for binural and monaural CAP tests, so the final sample comprised 738 studied ears. The percentage of correct results for the BFT test was 86.37%, with a standard deviation (SD) of 6.18%; for the FST test, it was 82.88% (SD 5.04%); for the DDTR test, it was 58.22% (SD 21.88); for the FPT test, it was 48.87% (SD 31.76%); for the DPT test, it was 46.86% (SD 31.34%); finally, for the EST test, it was 87.60% (SD 9.82%). Table 2 shows the general cut-off points per test, considering the 4 groups, noting the condition of usefulness for the BFT, FST, EST, and probably the DDT tests.

Table 3 shows the cut-off points defined for each group and each test. The same table also shows the DDT limited against its 4 possible responses (thus identifying it in a unique manner compared to the other 4 tests), the standard error and ANOVA significance.

Lastly, Table 4 shows the significance levels for the Pearson correlation between the 6 tests applied.

**Discussion**

Of the 6 tests studied, 3 of them returned mean values equal to or higher than 60%. These results are initially encouraging, making it possible to use them as tentative auxiliary diagnostic tools in the study of CAP in children. The trend of the mean values was heterogeneous, bearing in mind that the best scores were expected in the older age groups and that this was not constant, especially in the group of 11-year-olds.

The verbal tests showed efficacy in measuring the verbal skills of 5-year-old children, compared to those observed in the FPT and DPT. This result was unexpected, as the

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**Table 1** Number of Children and Percentage Included in Each Group.

<table>
<thead>
<tr>
<th>Groups</th>
<th>G1</th>
<th>G2</th>
<th>G3</th>
<th>G4</th>
<th>Total Children</th>
<th>Total Ears</th>
</tr>
</thead>
<tbody>
<tr>
<td>Female</td>
<td>47</td>
<td>52</td>
<td>51</td>
<td>46</td>
<td>196</td>
<td>392</td>
</tr>
<tr>
<td>Male</td>
<td>43</td>
<td>45</td>
<td>38</td>
<td>47</td>
<td>173</td>
<td>346</td>
</tr>
<tr>
<td>Total children</td>
<td>90</td>
<td>97</td>
<td>89</td>
<td>93</td>
<td>369</td>
<td>738</td>
</tr>
<tr>
<td>%</td>
<td>24.3</td>
<td>26.4</td>
<td>24.1</td>
<td>25.2</td>
<td>100</td>
<td></td>
</tr>
</tbody>
</table>

G1: Group 1, children aged 5 years; G2: Group 2, children aged 7 years; G3: Group 3, children aged 9 years; G4: Group 4, children aged 11 years.

Figures in bold indicate the total number of children included in each group.

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**Table 2** Usefulness of Each Test if the Cut-Off Point is Over 60%.

<table>
<thead>
<tr>
<th>Tests</th>
<th>BFT</th>
<th>FST</th>
<th>DDTR</th>
<th>FPT</th>
<th>DPT</th>
<th>EST</th>
</tr>
</thead>
<tbody>
<tr>
<td>% correct</td>
<td>86.4</td>
<td>82.88</td>
<td>58.22</td>
<td>48.87</td>
<td>46.86</td>
<td>87.6</td>
</tr>
<tr>
<td>SD</td>
<td>6.18</td>
<td>5.04</td>
<td>21.88</td>
<td>31.76</td>
<td>31.34</td>
<td>9.82</td>
</tr>
<tr>
<td>% SD</td>
<td>80.22</td>
<td>77.84</td>
<td>36.4</td>
<td>17.111</td>
<td>15.52</td>
<td>77.78</td>
</tr>
<tr>
<td>Usefulness</td>
<td>Useful</td>
<td>Useful</td>
<td>Probable</td>
<td>Not useful</td>
<td>Not useful</td>
<td>Useful</td>
</tr>
</tbody>
</table>

BFT: binaural fusion test; DDTR: dichotic digits test right; DPT: duration pattern test; EST: environmental sounds perception test; FPT: frequency pattern test; FST: filtered speech test; SD: standard deviation.
Table 3 The Dotted Area Describes the Results of the Dichotic Digits Test, With its 4 Response Options: Right DDTR, Left DDTL, Mixed DDTM and Omission DDTO.

<table>
<thead>
<tr>
<th>Tests</th>
<th>G1</th>
<th>G2</th>
<th>G3</th>
<th>G4</th>
<th>Standard Error</th>
<th>ANOVA/Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>BFT</td>
<td>80.55</td>
<td>79.81</td>
<td>80.31</td>
<td>80.01</td>
<td>0.22766</td>
<td>0.142</td>
</tr>
<tr>
<td>FST</td>
<td>77.68</td>
<td>77.07</td>
<td>77.86</td>
<td>80.48</td>
<td>0.18548</td>
<td>0.000</td>
</tr>
<tr>
<td>DDTR</td>
<td>40.1</td>
<td>31.38</td>
<td>38.18</td>
<td>36.12</td>
<td>1.13882</td>
<td>0.002</td>
</tr>
<tr>
<td>DDTL</td>
<td>2.85</td>
<td>3.74</td>
<td>2.25</td>
<td>7.08</td>
<td>0.66834</td>
<td>0.026</td>
</tr>
<tr>
<td>DDTM</td>
<td>6.73</td>
<td>12.36</td>
<td>6.97</td>
<td>35.85</td>
<td>0.63147</td>
<td>0.002</td>
</tr>
<tr>
<td>DDTO</td>
<td>1.53</td>
<td>1.38</td>
<td>1.38</td>
<td>1.77</td>
<td>0.30154</td>
<td>0.184</td>
</tr>
<tr>
<td>FPT</td>
<td>−0.9</td>
<td>44.89</td>
<td>53.78</td>
<td>48.21</td>
<td>1.16987</td>
<td>0.000</td>
</tr>
<tr>
<td>DPT</td>
<td>−0.08</td>
<td>42.76</td>
<td>50.12</td>
<td>38.86</td>
<td>1.15382</td>
<td>0.000</td>
</tr>
<tr>
<td>EST</td>
<td>77.38</td>
<td>77.58</td>
<td>76.41</td>
<td>82.94</td>
<td>0.36144</td>
<td>0.000</td>
</tr>
</tbody>
</table>

BFT: binaural fusion test; DDT: dichotic digits test (DDTR right, DDTL left, DDTM mixed, DDTO omissions); DPT: duration pattern test; EST: environmental sounds perception test; FPT: frequency pattern test; FST: filtered speech test.

Cut-off points calculated per group (arithmetical mean minus 1 standard deviation).
Cut-off points above 60% are marked in bold and identify the test as useful per group.

Table 4 Correlations and Significances (Below) Are Noted for Each Test, Except for Among Themselves.

<table>
<thead>
<tr>
<th>Tests</th>
<th>Pearson Correlation Between the CAP Tests Applied</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No.=738</td>
</tr>
<tr>
<td>BFT</td>
<td>0.345b</td>
</tr>
<tr>
<td>No.=738</td>
<td></td>
</tr>
<tr>
<td>FST</td>
<td>0.345b</td>
</tr>
<tr>
<td>No.=738</td>
<td></td>
</tr>
<tr>
<td>DDTR</td>
<td>0.000</td>
</tr>
<tr>
<td>No.=369</td>
<td></td>
</tr>
<tr>
<td>DDTL</td>
<td>−0.849b</td>
</tr>
<tr>
<td>No.=369</td>
<td></td>
</tr>
<tr>
<td>DDTO</td>
<td>−180b</td>
</tr>
<tr>
<td>No.=369</td>
<td></td>
</tr>
<tr>
<td>DDTM</td>
<td>0.023</td>
</tr>
<tr>
<td>No.=369</td>
<td></td>
</tr>
<tr>
<td>FPT</td>
<td>0.082a</td>
</tr>
<tr>
<td>No.=738</td>
<td></td>
</tr>
<tr>
<td>DPT</td>
<td>0.090a</td>
</tr>
<tr>
<td>No.=738</td>
<td></td>
</tr>
<tr>
<td>EST</td>
<td>−0.141b</td>
</tr>
<tr>
<td>No.=738</td>
<td></td>
</tr>
</tbody>
</table>

BFT: binaural fusion test; DDT: dichotic digits test (DDTR right, DDTL left, DDTM mixed, DDTO omissions); DPT: duration pattern test; EST: environmental sounds perception test; FPT: frequency pattern test; FST: filtered speech test.

a The correlation is significant at the 0.05 level (bilateral).
b The correlation is significant at the 0.01 level (bilateral).

The literature mentions the need for non-verbal tests in the study of CAP in younger children.

The DDT test was special due to several factors. One was its orientation towards auditory laterality, based on the fact that the child was asked to express only 1 of the 2 numbers heard, either the more important one or the one perceived more intensely. This response was analysed through 4 possible variants, unlike the other tests, which only quantified the successful responses for the right and left ears. The DDT test exhibited a clear predominance of right ear scores, with cut-off values between 31% and 40% and the highest scores being obtained by the 5-year-old group. The left ear scores were lower, between 2% and 7%. The values for mixed laterality ranged between 6.73% and 35.85%. The case of omissions was special. Although its response variants were entered into the overall score of the DDT test as part of a 100% result, the connotations were not the same since they did not correspond to successful responses; instead, their presence was attributed to central functions related to cognition, such as attention, auditory memory, and even motivation. In a previous study, we observed the possible relationship of mixed laterality with dyslexia. Unexpectedly, mixed laterality appeared in high proportions in children in the 11-year-old (G4) group.
in this study, in whom we expected conditions of greater definition towards right laterality. We are unable to establish an explanation for this observation.

Considering all the groups studied (No.=738), the cut-off points for the DPT and FPT tests did not reach the minimum 60% percentage required to be considered useful. However, it should be noted that Musiek\textsuperscript{23} reported FPT test results of 40% in 8-year-old children, which increased to 65% in 9-year-olds, 72% in 10-year-olds, and 75% in 11-year-olds. In our case, the same test (FPT) presented scores below 1 in 5-year-old children, which increased in subsequent groups, except in the 11-year-old group whose cut-off values were lower than those of the 9-year-old group (Table 3).

Table 3, which breaks down the specific cut-off points for each group in relation to each of the tests applied, gives evidence of a slight trend towards better scores in the responses of the 11-year-old group (G4). Only the EST and FST tests showed this trend. In fact, the G4 group stood out for the irregularity of the percentages obtained. At times, there was a trend towards higher effectiveness with increasing age, such as in the DPT or FPT tests, which could be explained by auditory maturation. However, this trend was lost in the G4 group. From the early stages of the analysis, our attention was drawn to this G4 manifestation, which was unexpected and difficult to explain, especially considering that other case series showed practically the consolidation of the prevailing patterns in adults. In our case, we consider the fact that children of this age are entering adolescence and that this population was studied in a school environment, that is, in a context where children express their full potential and concerns. This group of children (11-year-olds) was the first to be studied.

Despite the heterogeneity we have commented, the results obtained in this study have provided us with a good approach to the possibilities of children to perform a series of psychoacoustic tests useful for evaluating CAP. We have determined that the FPT and DPT tests are definitely not useful for the group of 5-year-old children in this application model of screening tests. Nevertheless, all the remaining tests studied can be usefully applied in this group, including the DDTR test. We consider that the subtraction of 1 SD from the mean of the test is an appropriate procedure for field tests, since standardisation procedures in sound-proofed chambers suggest up to 2 SD less.

ANOVA values express that there were no significant differences among the 4 groups, except for the BFT and the omissions of the DDT test. Furthermore, low values for the standard error can be observed for all the tests applied.

The Pearson correlation test, whose significance levels are noted in Table 4, makes it clear that there was a correlation between all tests applied. This was true to a lesser extent only in the case of the EST test, since this test obtained correlation only with the condition of omissions in the DDT test.

Conclusion

Three of the tests applied were considered useful for the study of CAP in children. Although there were some irregular patterns in the cut-off points obtained, it is of fundamental importance to have these results to guide clinical decisions, the need for rehabilitative programs and follow-up procedures. Further research is needed to obtain more accurate cut-off points. Likewise, it is important to obtain better explanations for unexpected trends. The results obtained in this study should be contrasted in the near future with results obtained in children with CAP disorders.

Conflict of Interest

The authors have no conflicts of interest to declare.

References