Central Auditory Processing and Cognitive Functions in Children

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Abstract

Introduction Nowadays, there is no consensus on whether central auditory processing disorder is a primary or a secondary deficit to other cognitive deficits. A better understanding of the association between cognitive functions and central auditory skills may help elucidate this dilemma.

Objective To investigate possible associations between auditory abilities and cognitive functions in schoolchildren.

Methods Fifty-eight schoolchildren, aged between 8 years and 0 months old and 11 years and 11 months old, who underwent the following tests: masking level difference, gaps in noise, pitch pattern sequence test, dichotic digits test, sustained auditory attention ability test, Wechsler intelligence scale for children – IV, junior Hayling test, five digits test, and behavior rating inventory of executive function.

Results Significant correlations were found between the hearing ability of temporal resolution and executive functions, temporal ordering/sequencing, binaural integration and separation, and sustained auditory attention, operational memory, inhibitory control, and cognitive flexibility; binaural integration was also associated with intelligence. The statistically significant positive correlation found between the ability of binaural interaction and the components of emotional control and behavior regulation of the behavior rating inventory of executive function was unexpected.

Conclusion The associations identified reinforce the complexity of the tasks involved in the evaluation of central auditory processing and the need for multidisciplinary evaluation for the differential diagnosis of auditory processing disorder. Confirmation of the presence or absence of comorbidities between different disorders allows directing the therapeutic behaviors and reducing the impact of possible auditory and/or cognitive deficits in the different daily life situations of children.

Keywords ► auditory perception ► attention ► memory ► intelligence ► executive functions

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Introduction

Central auditory processing (CAP) refers to a series of processes and mechanisms that occur from sound being picked up by the outer ear to being interpreted in the auditory cortex, and involves the following skills: sound localization and lateralization; discrimination and recognition of acoustic stimulus differences; temporal processing (resolution, masking, integration, and sequence) and auditory background; and perception of the target stimulus in situations with competitive signals. The mechanisms involved in auditory processing are: binaural interaction, dichotic listening, monaural low redundancy, and temporal processing.

Binaural interaction is the way the two ears work together for the purpose of locating and lateralizing auditory stimuli, lowering the threshold by masking, detecting acoustic signals in noisy environments, and binaural fusion. Dichotic listening consists of the simultaneous presentation of different stimuli in both ears, which causes suppression of ipsilateral auditory pathways and predominance of contralateral auditory pathways and predominance of contralateral auditory pathways. Tests with dichotic listening tasks assess binaural integration skills (ability to hear and understand different stimuli at the same time), binaural separation (when it is possible to ignore one of the stimuli and direct attention to the other simultaneous stimulus), and are sensitive to dysfunctions or injuries of interhemispheric and intrahemispheric connections of the right hemisphere and the left hemisphere. The monaural low redundancy mechanism occurs when there is degradation of the acoustic signal reducing extrinsic redundancy (phonemic and contextual speech cues) requiring intrinsic redundancy (repetition of acoustic signal analyses along the auditory pathway) to perform auditory closure of missing information allowing understanding of information. Temporal processing refers to the way nonverbal patterns (rhythm, intonation, emphasis, and intervals) of auditory information are perceived, associated, and interpreted. It has four subcategories: temporal ordering and sequence, temporal resolution, temporal integration, and temporal masking. There are no clinically viable measures yet to assess integration and temporal masking.

The difficulty in the perception of auditory information along with the central auditory nervous system, evidenced by the poor performance in one or more of the mechanisms mentioned above, characterizes central auditory processing disorder (CAPD). Alterations of higher functions, such as language, attention, and memory, are not included in the definition of CAPD, but may coincide. Therefore, a multidisciplinary assessment may be necessary for differential diagnosis, identifying the primary deficit and the presence of comorbidities. There is no consensus in the literature about the nature of CAPD, and many discussions have taken place in an attempt to clarify the diagnosis. Some researchers believe that CAPD could only occur when there is a specific auditory deficit and that the tests used to assess CAP show more global responses regarding general intelligence, language comprehension, attention, memory, and executive functions. Other authors, supported by studies of auditory and cognitive neurophysiology, state that considering the specific modality as a diagnostic criterion is untenable from a neurophysiological point of view, since the central auditory nervous system is complex and responds to stimulation of nonauditory areas.

The complexity of the processes that occur in the central auditory nervous system requires knowledge of the auditory and/or cognitive skills required to perform the behavioral tests used to assess CAP. Hearing disability, manifested by the difficulty of understanding auditory information, can leave cognitive, social, and emotional functions vulnerable. Functions such as attention, perception, memory, language, and executive functions form human cognition, and acting in an integrated manner, allow individuals to function well in different contexts according to the requirements of the environment. The tests developed to evaluate these auditory processes are complex and involve tasks that may require the action of executive functions, such as attention and working memory.

Executive functions are defined as a set of cognitive processes that guide behavior to achieve goals. There is no consensus on which functions are involved and how their constructs work, but Diamond proposes one of the most accepted models, which considers executive functions to have three basic skills: inhibition (self-control and interference control), working memory, and cognitive flexibility. Other skills, such as planning, reasoning, and problem-solving, are complex and emerge from the core. The prefrontal cortex is the main region involved in executive functioning, but it also depends on the activity distributed in different neural circuits, with the involvement of various brain areas, including temporal lobe regions. Therefore, changes in regions that affect executive functioning may also affect auditory skills, and difficulties in the perception of auditory stimuli may limit the use of an executive function, preventing the generalization of strategic listening behaviors in different situations.

Studies have been conducted to understand the relationship between CAPD and other higher mental functions, but there are only a few studies involving the relationship between CAP and executive functions. Considering that CAPD can coexist with other cognitive and language disorders, the present paper aims to describe the association between auditory skills and cognitive functions to better understand this relationship, which may contribute to health and education, enabling more accurate diagnoses and optimized interventions, reducing the impact of hearing and/or cognitive impairment on the daily life of individuals.

Methodology

The present study was conducted on Centro de Neuropediatría del Hospital de Clínicas (CENEP-HC) da Universidade Federal do Paraná (UFPR) and Centro de Psicologia Aplicada (CPA) da UFPR and was approved by the Research Ethics Committee/UFPR Health Sciences Sector, as Coordinating Center (Opinion 3.037.057) and by the Research Ethics Committee/HC, as a coparticipant institution (Opinion 2.675.148). The present study was conducted on Centro de Neuropediatría del Hospital de Clínicas (CENEP-HC) da Universidade Federal do Paraná (UFPR) and Centro de Psicologia Aplicada (CPA) da UFPR and was approved by the Research Ethics Committee/UFPR Health Sciences Sector, as Coordinating Center (Opinion 3.037.057) and by the Research Ethics Committee/HC, as a coparticipant institution (Opinion 2.675.148) and by the Research Ethics Committee/HC, as a coparticipant institution (Opinion 3.037.057).
School of the Julia Amaral Di Lenna Municipal School (n = 36), and/or attended at the outpatient clinic CENEP-HC (n = 22), and who are enrolled in elementary school in other Curitiba and metropolitan area municipal public schools.

During recruitment, 71 children were included considering the following criteria: regularly enrolled between the 3rd and 6th grade of elementary school, in municipal public schools of Julia Amaral di Lenna (n = 46) and/or attended at the clinic of Neuropediatric of CENEP-HC (n = 25); absence of diagnosis of neurodevelopmental disorder (attention-deficit / hyperactivity disorder, autistic spectrum disorder and language disorder); free and informed consent form (ICF) signed by parents or guardians; informed consent form signed by the child (ICFC).

According to the exclusion criteria, 13 participants were excluded: conductive hearing loss (n = 3); intellectual disability (IQ < 70) (n = 1); oral language impairment (phonetic/phonological disorders) (n = 1); did not complete both assessment steps (n = 8).

The final sample consisted of 58 children, 33 males (53.9%) and 25 females (43.1%), with an average age of 9 years and 7 months old (standard deviation [SD] = 1.16). The evaluated children attend between the 3rd and 6th grade of elementary school. The complaint of difficulty in school was reported during anamnesis by 46.6% of the parents or guardians of the children in the sample. - Fig. 1 demonstrates the data collection process.

The assessment protocol consisted of 2 parts, auditory and cognitive assessment, composed of the following instruments: tonal audiotometry threshold hearing thresholds search at frequencies from 250 to 8,000 Hz and speech reception threshold (SRT); tympanometry and acoustic reflex research; masking level difference (MLD), pure tone (500 Hz) hearing threshold determination in the presence of narrowband noise under two conditions: homophobic – when there is the same phase relationship for tone and noise in both ears (SoNo) – and antiphrastic – when noise is in the same phase in both ears, and pure tone is in inverted phase in one ear (SnNo). The intensity used is 45 dBNS, and the result analysis is performed based on the difference between the SoNo and SnNo thresholds. Values > 9 dB are considered appropriate. Gaps in noise (GIN), monaural presentation of series with segments of 6 seconds of broadband noise. In each segment, zero to three intervals of silence or gap can occur. The gap duration can be presented in 2, 3, 4, 5, 6, 8, 10, 12, 15, and 20 seconds. The intensity used is 50 dBNS. Values < 8 milliseconds are considered adequate. Pitch pattern sequence (PPS), 200 milliseconds 3-tone sequences, with intervals of 10 milliseconds between them; between sequences, the interval is 150 milliseconds. The tones are presented binaurally at the frequencies of 880 Hz and 1,122 Hz, representing bass and treble sounds. The sequence of stimuli should be named according to the frequencies shown. The intensity used is 50 dBNS. From the values described by Schochat et al., the reference values are defined as normality criteria for both ears: 8 years: 47%; 9/10 years: 62%; 11/12 years: 69%; dichotic digits (DD), presentation of 20 pairs of digits (1 to 9 syllables), 2 simultaneous digits in each ear. Dichotic digits is performed in two steps: binaural integration, in which the four digits presented must be repeated, and binaural separation, where only the digits presented in the requested ear are repeated. It is performed at an intensity of 50 dBNS. Performance is considered adequate according to the reference values for each age group described in the test manual. Sustained auditory attention ability test (SAAAT) is a continuous performance test (CPT), which requires the maintenance of vigilance and the identification of a previously determined target stimulus. It consists of the simultaneous presentation in both ears of a list of 21 recorded monosyllabic words that are repeated and rearranged randomly, forming a list of 100 words, including the 20 occurrences of the target word “no,” presented 6 times without interruption (1 word per second) – totaling 600 monosyllabic words. The individuals should raise their hand each time they hear the target word “no.” The intensity used for the stimulus presentation is 50 dBNS. The reference values by age range described in the test application are used for the analysis of the results. The junior Hayling test (JH) (adapted for Brazilian Portuguese), consists of a two-step task, in which the subject must complete sentences in which the last word is missing. In part A, one must use the word that completes the sentence consistently. Part B uses a word that does not have a meaningful relation to the sentence, inhibiting the dominant response, looking for a word that has no relation to the syntactic and semantic context of the sentence. For the classification are considered the percentiles described in the test manual. The five digit test (FDT), a nonverbal instrument that uses 5 quantities (numbers from 1 to 5) as simple recurrent cognitive units within tasks of increasing difficulty. It consists of four parts: reading, counting, choosing, and toggling; the first two measure automatic and straightforward processes, and the last two measure more complex processes. It allows a brief and straightforward assessment of cognitive processing speed, ability to focus, refocus attention, and ability to deal with interference. For the classification, the percentiles described in the test manual are considered. Wechsler children’s intelligence scale (WISC) IV, a clinical instrument that aims to assess children’s intellectual capacity and problem-solving process. It provides information on the total intelligence coefficient (IQ) and four indices: verbal comprehension (VCI), perceptual organization (POI), working memory (WMI), and processing speed (PSI). To meet the objectives of the present research, WMI and PSI were analyzed for the evaluation of executive functions, and total IQ for intelligence classification. For classification purposes, composite scores are considered as described in the manual. Behavior rating inventory of executive function (BRIEF), parent version, a questionnaire consisting of 86 questions that parents must grade from a scale (never, sometimes, consistently) to the frequency of occurrence of problem behavior in the child. It evaluates the behavior of executive functions of children aged between 5 and 18 years old in the family environment. The classification of the results is performed according to the norms of the application manual, and indices > 65 are considered indicative of changes in the evaluated indices. The questionnaire was answered by a parent or guardian who accompanied the child on the day of the assessment. The experimental version provided and authorized by Mello (Universidade
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Figure

Letter of invitation/telephone contact: n = 521 (n = 437 - school; n = 84 - ambulatory)
Agreed with the child’s participation in the study: n = 162 (n = 127 - school; n = 35 - ambulatory)

Inclusion Criteria - n = 71 (n = 46 - school; n = 25 - Ambulatory)
- Age range from 8 years old to 11 years and 11 months old, both genders
- Regularly enrolled between the 3rd and 6th year of elementary education, in municipal public schools of Julia Amaral Lenna and the outskirts area and/or attended at the Neuropediatrics Clinic of CNEP-HC
- Absence of diagnosis of Neurodevelopmental Disorder: Attention Deficit/Hyperactivity Disorder, Autism Spectrum Disorder and Language Disorder
- Informed consent form signed by parents or guardians
- Informed consent form signed by the child

AUDITORY ASSESSMENT
- Pure tone audiometry
- Tympanometry
- Sustained Auditory Attention Ability Test (SAAT)
- Behavioral tests of central auditory processing assessment

COGNITIVE ASSESSMENT
- WISC-IV - Wechsler Intelligence Scale for Children
- JHT – Junior Hayling Infantil
- FDT – Five Digit Test
- BRIEF - Behavior Rating Inventory of Executive Function

Exclusion Criteria – n = 13
- Presence of conductive hearing loss (n = 3)
- Oral language impairment: phonetic and phonological changes (n = 1)
- Intellectual Disability - QI < 70 (n = 1)
- Failure to attend one of the assessment steps (n = 8)

Final Sample – n = 58 (n = 36 – school; n = 22 – Ambulatory)
- 8 years old, n = 19
- 9 years old, n = 10
- 10 years old, n = 18
- 11 years old, n = 11

Federal do Estado de São Paulo (UNIFESP, in the Portuguese acronym) was used; Carin, Miranda, and Bueno.52

The children were submitted to the assessment protocol applied individually with a total duration of ~3 hours and 30 minutes, divided into 2 days and in different places. The psychological tests were performed and appraised by a psychologist of the Postgraduate program in psychology of UFPR team.

For the hearing tests, performed in the CNEP-HC, the following equipment was used: a) São Luiz brand acoustic
booth; b) Clinical Beta two-channel audiometer, with headphones TDH-39 and cushion MX-41, coupled to the compact disc (CD) of a DELL computer; c) Interaudios brand middle ear analyzer, model AZ-7, with TDH-39 earphone, MX-41 cushion, with probe tone 220 Hz at 70 dB; d) CD with recording of MLD tests, GIN and PPS (CD purchased directly from the author Frank Musiek), and DD. f) download of SAAAT test audio file available to registered speech therapists at http://thaas1.foh.usp.br. (Sustained Auditory Attention Ability Test - THAAS. Faculdade de Odontologia de Bauru, Universidade de São Paulo. São Paulo. Brazil).

The data were distributed to descriptive analyzes of mean, median, minimum values, maximum values, SD, and frequency analyzes. The use of the Shapiro-Wilk test indicated that some variables are not standard. Therefore, the association between hearing tests and cognitive tests was verified with the Spearman correlation test. The data were analyzed using IBM SPSS Statistics for Windows, version 22.0 (IBM Corp. Armonk, NY,USA).

The auditory skills evaluated were appropriate to the age group in 22.4% of the participants. For classification purposes, the students who presented underperformance for the age group of ≥ 2 hearing tests (58.6%) were considered as having CAPD. When the change was identified in only 1 test, it was classified as evidence of CAPD (19%).

The data that characterize cognitive performance are presented in Table 2, with information from the general sample, and in Table 3, with the participants grouped by age. It is observed that the median of the participants in the total IQ of the WISC-IV test was 101 points, with the most significant difference in performance in the 10-year-old participants (44 points between the minimum and maximum value), and the lowest in the 11-year-old age group (29 points). In the SAAAT test, the total number of errors varied between 2 and 70 errors, mainly in the age groups of 8 and 9 years old. In the JHT, the variability in response time, especially in part B of the test, was also abundant in all age groups, with time differences between 18 and 150 seconds. In the FDT, the participants took more time to perform the flexibility tasks, with time varying between 11 and 109 seconds; in the age group of 11 years old, the participants had faster responses with a median of 24 seconds. The BRIEF responses indicate T scores with a median of ~55 points on all items assessed. The number of participants in the BRIEF test is lower (n = 52), as 3 parents did not answer the questionnaire, and 3 questionnaires were excluded from the sample due to a high rate of inconsistency and negative responses.

Regarding the classification in cognitive tests, it is evident that ~90% of the participants have a mean score for the

### Table 1: Performance of students in hearing tests in the general sample and by age group

| Variable           | MLD (dB) | GIN (ms) | PPS (%) | DD Integration (%) | DD Separation (%) |
|--------------------|----------|----------|---------|--------------------|------------------|
|                    | RE       | LE       |         | RE                | LE               |
| General sample (n = 58) |          |          |         |                   |                  |
| median             | 10       | 5        | 6       | 33                 | 95               |
| min/max            | 4/14      | 4/15     | 4/15    | 10/86              | 50/100            |
| 8 years old (n = 18) |          |          |         |                   |                  |
| median             | 10       | 5        | 6       | 30                 | 92               |
| min/max            | 6/12      | 4/10     | 4/10    | 10/63              | 50/100            |
| 9 years old (n = 10) |          |          |         |                   |                  |
| median             | 11       | 6        | 6       | 30                 | 95               |
| min/max            | 6/14      | 5/10     | 5/12    | 20/83              | 62/100            |
| 10 years old (n = 18) |          |          |         |                   |                  |
| median             | 8        | 5        | 5       | 33                 | 97               |
| min/max            | 4/12      | 4/15     | 4/15    | 16/80              | 72/100            |
| 11 years old (n = 11) |          |          |         |                   |                  |
| median             | 10       | 5        | 6       | 46                 | 100              |
| min/max            | 6/14      | 4/8      | 4/6     | 23/86              | 90/100            |

Abbreviations: dB, decibel; DD, digit dichotic; GIN, gaps in noise; LE, left ear; max, maximum; min, minimum; MLD, masking level difference test; ms, milliseconds; n, number; PPS, pitch pattern sequence; RE, right ear.
| Variable | 8 years old | 9 years old | 10 years old | 11 years old |
|----------|-------------|-------------|--------------|--------------|
|          | n           | min/max     | med          | n            | min/max     | med          | n            | min/max     | med          | n            | min/max     | med          |
| **WISC-IV** |             |             |             |              |             |             |              |             |             |             |             |             |
| VCI      | 19          | 82/128      | 104         | 10           | 90/138      | 108         | 18           | 82/121      | 102         | 11           | 91/113      | 104         |
| POI      | 19          | 86/126      | 102         | 10           | 90/118      | 107         | 18           | 75/130      | 101         | 11           | 79/126      | 108         |
| WMI      | 19          | 77/123      | 94          | 10           | 74/106      | 97          | 18           | 71/118      | 97          | 11           | 85/118      | 100         |
| PSI      | 19          | 83/115      | 97          | 10           | 86/100      | 95          | 18           | 80/115      | 95          | 11           | 74/118      | 100         |
| IQ       | 19          | 83/119      | 102         | 10           | 84/122      | 103         | 18           | 80/124      | 99          | 11           | 90/119      | 98          |
| **SAAAT** |             |             |             |              |             |             |              |             |             |             |             |             |
| TE       | 19          | 5/70        | 23          | 10           | 11/55       | 17          | 18           | 3/35        | 15          | 11           | 2/35        | 10          |
| DS       | 19          | 1/7         | 3           | 10           | 0/7         | 3           | 18           | -2/6        | 3           | 11           | -1/11       | 0           |
| **JHT**  |             |             |             |              |             |             |              |             |             |             |             |             |
| B Part   | 19          | 18/150      | 56          | 10           | 27/123      | 37          | 18           | 18/134      | 40          | 11           | 23/108      | 38          |
| Error Categ. | 19     | 4/25        | 12          | 10           | 3/26        | 12          | 18           | 3/19        | 9           | 11           | 3/27        | 14          |
| **FDT**  |             |             |             |              |             |             |              |             |             |             |             |             |
| Inhib.   | 19          | 11/88       | 25          | 10           | 26/55       | 43          | 18           | 13/62       | 31          | 11           | 21/69       | 35          |
| Flex.    | 19          | 37/109      | 43          | 10           | 22/65       | 51          | 18           | 11/92       | 40          | 11           | 14/44       | 24          |
| **BRIEF**|             |             |             |              |             |             |              |             |             |             |             |             |
| BR       | 18          | 42/77       | 55          | 9            | 44/74       | 54          | 16           | 42/72       | 49          | 9            | 58/67       | 59          |
| Metacog. | 18          | 33/80       | 54          | 9            | 46/70       | 53          | 16           | 39/75       | 52          | 9            | 41/76       | 57          |
| GEC      | 18          | 33/77       | 55          | 9            | 46/70       | 56          | 16           | 40/72       | 49          | 9            | 42/74       | 60          |

Abbreviations: BR, behavior regulation; BRIEF, behavior rating inventory of executive function; DS, decreasing surveillance; Error categ., error category; FDT, five digit test; Flex., flexibility; GEC, global executive composition; Inhib., Inhibition; JHT, junior Hayling test; max, maximum; med, median; Metacog., metacognition; min, minimum; n, number; POI, perceptual organization index; PSI, processing speed index; TE, total errors; SAAAT, sustained auditory attention ability test; TIQ, total intelligence quotient; VCI, verbal comprehension index; WISC-IV, Wechsler intelligence scale for children; WMI, working memory index.
indexes evaluated in the WISC-IV, and the WMI presented the most significant number of participants with inferior performance (5.2%), and the POI with superior performance (10.3%). Not borderline or much higher scores were evidenced in this test. In the JHT test, ~30% of the students presented a borderline performance in all indexes evaluated in the test, mainly in part B (32.8%) and in the error category (37.9%). The data obtained in the FDT test show that 60.3 and 44.8% of students had, respectively, percentiles of cognitive flexibility and inhibition, with performance classified as average. The percentiles obtained for inhibition were classified as borderline in 22.4% of the participants and as lower in 27.6%. For flexibility, the rating was 8.6 and 19%, respectively. In the SAAAT test, the total errors were adequate in 75.9%, and the decrease in vigilance in 96.6% of the students. Among the types of errors, inattention was observed in 44.8% of participants and impulsiveness in 20.7%. The classification in the BRIEF indicates that ~70 to 88% of the students do not present difficulties in the executive functions investigated in the inventory, according to their parents’ perception. However, the data show that ~30% of the students have difficulty in working memory.

Table 4 shows the estimated correlation measures between each of the variables for the entire sample, and Table 5 shows the study performed according to the age group. In the estimation of the correlations, the following scores of each auditory test were used: MLD, dB; GIN, ms; PPS and DD, percentage of correct answers. Percentile scores for the WISC-IV, JHT and FDT indexes, gross scores for SAAAT and T score indexes for BRIEF were considered for instruments that assess cognitive functions.

Tables 4 and 5 show the following correlations between auditory skills and cognitive functions: binaural interaction (MLD) and executive functions (BRIEF); temporal resolution (GIN), processing speed (WISC-IV), inhibitory control (JHT and BRIEF) and planning (BRIEF); temporal ordering/sequence (PPS), working memory (WISC-IV and BRIEF), sustained auditory attention (SAAAT), inhibitory control (JHT), cognitive flexibility (FDT) and metacognition (BRIEF); binaural integration (DD), intelligence (WISC-IV), sustained auditory attention (SAAAT), inhibitory control (JHT and FDT) and cognitive flexibility (FDT); binaural separation (DD), sustained auditory attention (SAAAT), cognitive flexibility (FDT) and inhibitory control (FDT).

| Table 4 Correlation between behavioral tests that assess central auditory processing and cognitive function tests in schoolchildren |
|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| Variable        | MLD RE | MLD LE | GIN RE | GIN LE | PPS RE | PPS LE | DD - Integration RE | DD - Integration LE | DD - Separation RE | DD - Separation LE |
| WISC-IV         |        |        |        |        |        |        |        |        |        |        |
| VCI             | -0.058 | -0.217 | -0.054 |        | 0.200  | 0.272  | -0.030 | -0.122 | -0.030 | -0.122 |
| POI             | -0.033 | -0.063 | -0.022 |        | 0.179  | 0.393  | -0.030 | -0.122 | -0.030 | -0.122 |
| WMI             | 0.048  | -0.172 | -0.050 |        | 0.337  | 0.407  | -0.030 | -0.122 | -0.030 | -0.122 |
| PSI             | 0.098  | -0.262 | 0.044  |        | 0.007  | 0.213  | 0.153  |        | 0.030  | -0.004 |
| IQ              | -0.006 | -0.233 | -0.013 |        | 0.235  | 0.424  |        |        | 0.067  | 0.011  |
| SAAAT           |        |        |        |        |        |        |        |        |        |        |
| Total Errors    | -0.072 | -0.030 | 0.032  |        | -0.513 | -0.259 | -0.363 | -0.381 | -0.299 |
| Inattention     | -0.043 | -0.106 | -0.009 |        | -0.482 | -0.260 | -0.314 | -0.271 | -0.258 |
| Impulsiveness   | -0.041 | 0.123  | 0.008  |        | -0.297 | -0.067 | -0.157 |        | -0.446 | -0.263 |
| JHT             |        |        |        |        |        |        |        |        |        |        |
| B Part - TE     | -0.098 | -0.086 | -0.070 |        | 0.023  | 0.202  | 0.272  | -0.075 | -0.059 |
| TB / TA         | -0.103 | -0.193 | -0.352 |        | -0.001 | 0.153  | 0.210  | -0.154 | -0.087 |
| Error Category  | 0.123  | -0.157 | -0.141 |        | 0.293  | 0.311  | 0.324  | 0.181  | 0.175  |
| FDT             |        |        |        |        |        |        |        |        |        |        |
| Inhibition      | 0.066  | 0.136  | 0.035  |        | 0.214  | 0.347  | 0.196  | 0.299  | 0.054  |
| Flexibility     | 0.152  | 0.048  | 0.008  |        | 0.383  | 0.338  | 0.226  |        | 0.432  | 0.137  |
| BRIEF           |        |        |        |        |        |        |        |        |        |        |
| Inhibition      | 0.257  | 0.012  | 0.359  |        | -0.136 | -0.077 | -0.089 | -0.056 | -0.107 |
| EC              | 0.358  | 0.017  | 0.202  |        | -0.134 | -0.037 | -0.018 | 0.056  | 0.029  |
| BR              | 0.337  | 0.000  | 0.253  |        | -0.163 | -0.057 | -0.055 | -0.010 | -0.057 |
| WM              | 0.091  | -0.022 | 0.156  |        | -0.341 | -0.256 | -0.215 | -0.081 | -0.161 |
| Planning        | 0.098  | 0.040  | 0.289  |        | -0.260 | -0.180 | -0.129 | -0.078 | 0.057  |
| Metacognition   | 0.074  | 0.050  | 0.253  |        | -0.313 | -0.182 | -0.138 | -0.101 | -0.079 |
| GEC             | 0.215  | 0.000  | 0.269  |        | -0.256 | -0.117 | -0.082 | -0.031 | -0.041 |

Abbreviations: BR, behavior regulation; BRIEF, behavior rating inventory of executive function; DD, digit dichotic; EC, emotional control; FDT, five digit test; GEC, global executive composition; GIN, gaps in noise; JHT, junior Hayling test; LE, left ear; MLD, masking level difference test; POI, perceptual organization index; PPS, pitch pattern sequence; PSI, processing speed index; RE, right ear; SAAAT, sustained auditory attention ability test; TA, time part A; TB, time part B; TE, total errors; TIQ, total intelligence quotient; VCI, verbal comprehension index; WISC-IV, Wechsler intelligence scale for children; WM, working memory; WMI, working memory index.

Note: *p ≤ 0.05; **p ≤ 0.01.
Table 5  Correlation between behavioral tests that assess central auditory processing and cognitive function tests in schoolchildren by age group

| Variable   | MLD      | GIN      | PPS      | DD - Integration | DD - Separation |
|------------|----------|----------|----------|------------------|-----------------|
|            | RE       | LE       | RE       | LE               | RE              | LE              |
| 8 years old|          |          |          |                  |                 |
| WISC-IV    |          |          |          |                  |                 |
| POI        | -0.276   | 0.170    | 0.251    | 0.095            | 0.496*          | 0.354           | 0.205           | 0.337           |
| WMI        | 0.064    | -0.045   | 0.103    | 0.209            | 0.523*          | 0.106           | 0.329           | 0.014           |
| PSI        | 0.466*   | -0.128   | 0.225    | -0.037           | 0.057           | -0.146          | 0.382           | 0.001           |
| IQ         | -0.043   | 0.006    | 0.187    | 0.148            | 0.531*          | 0.266           | 0.353           | 0.195           |
| SAAAT      |          |          |          |                  |                 |
| Total errors | -0.090   | 0.226    | 0.128    | -0.350           | 0.018           | -0.492*         | -0.086          | -0.333          |
| Impulsiveness | -0.333   | 0.204    | 0.061    | -0.710**         | -0.306          | -0.489*         | -0.704**        | -0.423          |
| JHT        |          |          |          |                  |                 |
| B Part - TE | 0.055    | -0.269   | -0.065   | 0.158            | 0.189           | 0.490*          | 0.038           | 0.192           |
| Error Category | 0.324    | -0.117   | -0.161   | 0.462*           | 0.141           | 0.562*          | 0.318           | 0.267           |
| FDT        |          |          |          |                  |                 |
| Flexibility | 0.573*   | -0.318   | -0.278   | 0.215            | 0.260           | 0.199           | 0.372           | 0.016           |
| BRIEF      |          |          |          |                  |                 |
| WM         | 0.520*   | -0.082   | 0.124    | -0.003           | 0.088           | 0.102           | 0.397           | 0.191           |
| 9 years old|          |          |          |                  |                 |
| Total errors | 0.147    | 0.271    | 0.440    | -0.635*          | -0.568          | -0.706*         | -0.488          | -0.466          |
| FDT        |          |          |          |                  |                 |
| Flexibility | 0.147    | -0.065   | -0.141   | 0.620            | 0.634*          | 0.900**         | 0.729*          | 0.400           |
| BRIEF      |          |          |          |                  |                 |
| Inhibition | 0.478    | 0.214    | 0.155    | -0.067           | -0.311          | -0.120          | -0.360          | -0.867**        |
| BR         | 0.751**  | -0.100   | 0.309    | -0.313           | -0.259          | -0.072          | -0.102          | -0.383          |
| Planning  | 0.189    | 0.365    | 0.543    | -0.830**         | -0.752**        | -0.380          | -0.610          | -0.151          |
| 10 years old|          |          |          |                  |                 |
| PSI        | -0.038   | -0.566*  | -0.224   | -0.011           | 0.394           | 0.478*          | 0.048           | 0.040           |
| IQ         | -0.058   | -0.364   | -0.027   | 0.430            | 0.502*          | 0.459           | 0.230           | 0.194           |
| SAAAT      |          |          |          |                  |                 |
| Total errors | -0.231   | -0.184   | -0.254   | -0.520*          | -0.067          | -0.145          | -0.372          | -0.205          |
| Inattention | -0.214   | -0.098   | -0.211   | -0.614**         | -0.165          | -0.147          | -0.420          | -0.358          |
| JHT        |          |          |          |                  |                 |
| TB/TA      | -0.376   | -0.492*  | -0.612** | -0.201           | 0.067           | 0.299           | -0.278          | -0.305          |
| Error Category | -0.436   | -0.434   | -0.346   | 0.348            | 0.374           | 0.534*          | 0.118           | 0.318           |
| FDT        |          |          |          |                  |                 |
| Inhibition | 0.175    | 0.187    | 0.367    | 0.596**          | 0.470*          | 0.244           | 0.599**         | 0.258           |
| Flexibility | 0.216    | 0.225    | 0.272    | 0.551*           | 0.415           | 0.053           | 0.664**         | 0.259           |
| BRIEF      |          |          |          |                  |                 |
| WM         | -0.298   | -0.343   | -0.358   | -0.632**         | -0.241          | -0.006          | -0.508*         | -0.355          |
| 11 years old|          |          |          |                  |                 |
| POI        | 0.360    | -0.216   | -0.351   | -0.189           | 0.431           | 0.233           | -0.441          | -0.751**        |
| IQ         | 0.265    | -0.101   | -0.133   | 0.304            | 0.390           | 0.030           | -0.376          | -0.614*         |
| JHT        |          |          |          |                  |                 |
| B Part - TE | 0.028    | 0.319    | 0.091    | -0.179           | 0.129           | -0.303          | -0.792**        | -0.731*         |
| BRIEF      |          |          |          |                  |                 |
| Inhibition | 0.503    | -0.004   | 0.704*   | -0.197           | -0.111          | -0.043          | 0.403           | 0.225           |
| EC         | 0.159    | 0.159    | 0.713*   | -0.577           | -0.258          | 0.047           | 0.324           | 0.191           |
Table 5 (Continued)

| Variable | MLD | GIN | PPS | DD - Integration | DD - Separation |
|----------|-----|-----|-----|------------------|-----------------|
|          | RE  | LE  | RE  | LE               | RE              | LE             |
| BR       | 0.159 | 0.159 | -0.611 | -0.157 | 0.158 | 0.277 | 0.178 |
| Metacognition | -0.291 | 0.388 | 0.389 | -0.727* | -0.438 | -0.009 | 0.189 | 0.004 |
| GEC      | -0.053 | 0.309 | 0.519 | -0.774* | -0.253 | 0.141 | 0.227 | 0.085 |

Abbreviations: BR, behavior regulation; BRIEF, behavior rating inventory of executive function; DD, digit dichotic; EC, emotional control; FDT, five digit test; GEC, global executive composition; GIN, gaps in noise; IQ, total intelligence quotient; JHT, junior Hayling test; LE, left ear; MLD, masking level difference test; POI, perceptual organization index; PPS, pitch pattern sequence; PSI, processing speed index; RE, right ear; SAAAT, sustained auditory attention ability test; TA, time part A; TB, time part B; TE, total errors; VCI, verbal comprehension index; WISCIV, Wechsler intelligence scale for children; WM, working memory; WMI, working memory index.

Note: * p ≤ 0.05; ** p ≤ 0.01.

Due to the different scoring criteria used in the hearing and cognitive tests, negative correlations were expected. Some tests indicate better performance when their rates are low and others when their rates are high. As in the negative correlation found between PPS and SAAAT (p = -0.513; p = < 0.001), indicating the association of the occurrence of the lowest number of errors in the SAAAT subtests with the highest number of correct answers in the PPS. However, the positive correlation identified between MLD and BRIEF indicates that when there is a better perception of the difference in the level of masking in MLD, there are higher rates of emotional control and behavior regulation. High levels in BRIEF suggest the inefficiency of the executive functions.

**Discussion**

In the last decades, many debates have been taking place among researchers about the interference of cognitive performance in hearing tests, and there is a growing number of studies that seek to understand the association between these functions, with memory and attention functions being the most studied.

The present research aims to verify the possible associations between auditory skills (binaural interaction, temporal resolution, temporal ordering and sequence, binaural integration and binaural separation) and cognitive functions (intelligence, sustained auditory attention, working memory, inhibitory control, and flexibility) in schoolchildren.

Statistical analyses demonstrate the moderate association between sustained auditory attention and auditory skills of temporal order/sequence, integration, and binaural separation, corroborating with the data obtained in other studies that related different CPTs that evaluate sustained auditory and/or visual attention and DD, and also with other auditory tests, such as Staggered Spondaic Word (SSW) that was not used in this study. However, Riccio et al. and Stavrinos et al. did not find this correlation. In the present research, as in other studies, no associations were identified between sustained auditory attention and the MLD and GIN tests. Sustained auditory attention ability showed stronger and more significant correlations with hearing tests than the other correlations. This result is essential, and difficulties of sustained hearing attention should be considered during the application of hearing tests that evaluate CAP.

The temporal resolution hearing ability evaluated using GIN shows a significant correlation with executive functions: inhibitory control, processing speed, and planning. The task required in GIN requires the subject to respond to interruptions that occur within seconds during a continuous stimulus of white noise. The hypothesis for this association with the inhibitory control function, which was the most statistically significant correlation, is the need to control the impulse to respond to the stimulus even when there is no interval, waiting for stimulus interruption to occur. Self-control is an aspect of inhibitory control in which it is necessary to resist stimuli (external or internal) in order not to act impulsively or prematurely. Processing speed and planning may also be required in the task, as stimulus interruption may not occur, or may occur between 1 and 3 times with each presentation, with brief time intervals (2 to 20 seconds), requiring quick and planned responses. The literature does not report similar analyzes involving these tests, which makes it impossible to compare these findings. Studies using the GIN test have made associations with auditory and/or visual attention, as previously reported, and some studies have found possible associations with intelligence using tests that assess non-verbal IQ but found no significant correlations.

The ordering ability/temporal sequence evaluated with the task of naming the PPS, in addition to presenting the association with sustained auditory attention, demonstrated association with working memory, cognitive flexibility and inhibitory control evidenced in correlation with phrase categorization errors in the JHT, that is, by evocation patterns and strategies used to inhibit automatic response during the test. Such associations may be justified by the presence of three stimuli that differ in frequency patterns, which must be memorized and associated with acute/severe concepts (requiring activation of previously stored information recall areas for subsequent naming). Cognitive flexibility that involves shifting or shifting the focus of information, action, or thought processing to suit environmental requirements is also required, since the sequence of stimuli presented in the PPS changes with each presentation.
The data found in the present study also show the statistically significant correlation between working memory and dichotic listening (DD). Understanding that short-term memory involves the temporary storage of information, while working memory implies a combination of storage and manipulation, in the presence of two or more simultaneous stimuli, the participation of the central executive component, which acts as a data supervisor, is required. Thus, it is inferred that the task required in DD, dichotic listening, involves both types of memory since two stimuli are presented simultaneously in each ear, requiring the central executive component’s participation in the maintenance of these stimuli so that they can be repeated accordingly. Maerlender et al. found a strong association between DD and short-term memory, and a more modest association with working memory, reinforcing this hypothesis. Other studies also point to associations between working memory and hearing skills, although using different tests to assess working memory, having found significant correlations with DD, and PPS and SSW. Murphy et al. did not find significant associations between temporal processing tests (PPS and GIN) and working memory tests.

In addition to WMI, other associations were identified between DD and intelligence indexes measured with WISC-IV, such as total IQ, POI, and VCI. Correlations are significant only for the right ear binaural integration task. The advantage of the right ear is because hemispheric areas of language expertise in most individuals are in the left hemisphere, and the functions required for the tasks involved in determining indices also involve the left hemisphere, which may justify the correlation found. Gyldenkærne et al. and Tomlin et al. found significant correlations between left ear dichotic listening tasks in DD and nonverbal IQ tests. Other researches did not identify associations between nonverbal IQ and hearing skills. Weihing et al. found significant correlations between PPS and total WISC-IV IQ, but found no association with other WISC-IV indices. This association between WISC-IV, PPS, DD, and total IQ was also observed by Brenneman et al., who, by including individuals with language and/or cognitive deficits, identified a higher degree of association also with other WISC-IV indices, such as perceptual organization and working memory.

The DD was also associated with inhibitory control and cognitive flexibility. In the executive function model described by Diamond, inhibitory control involves self-regulation and interference control (selective attention), which may justify the findings, since the tasks involved in DD require divided attention (when repeating the four stimuli; two on each side) and directed attention (by repeating only the two stimuli presented in the right ear and then those in the left ear). Stavrou et al. found significant correlations between tests that evaluate divided auditory attention and DD, and recommend caution when using and analyzing this test in the CAP assessment battery due to the interference of attentional aspects evidenced in the results found in the research.

The positive and significant correlation evidenced between MLD, emotional control, and behavior regulation (BRIEF) was unexpected, since it indicates that better responses are expected in MLD when there are higher levels of emotional control and behavior regulation in the inventory, indicating alteration of these components. Considering that emotional control is related to the impact of executive function problems on emotional expression as the individual controls his emotional responses, and that behavior regulation is also related to emotional modulation through appropriate inhibitory control, it can be inferred that the task required in performing MLD may not require these functions. Although the consulted literature did not show studies using this correlation, studies conducted with MLD associated with other cognitive functions, such as intelligence, attention, and memory, did not find significant correlations, showing that this test seems to suffer little interference from the cognitive functions. Further studies are needed for a better understanding of this association.

There is a growing body of literature aimed at understanding the nature of CAPD, but most studies are conducted with relatively small samples. The exception is the work of Moore et al., who conducted a study of 1,469 schoolchildren aged between 6 and 11 years old with normal hearing who were randomly selected from schools in different regions of the United Kingdom. The results showed significant correlations between cognitive tests and tests that assess central auditory functions, and the conclusion was that CAPD is primarily a problem of attention, as poor performance in hearing tests was associated with a generalized attention deficit. However, the researchers used an unusual battery of tests to evaluate core auditory functions (frequency discrimination, backward masking, simultaneous masking, speech in noise testing), which precludes generalizing these results with other auditory tests that may require less attention.

Considering the results of the present study, it is possible to state that cognitive functions, especially attention and executive functions (working memory, inhibitory control, and cognitive flexibility), are related to some tests that assess central auditory functions and may interfere with the performance of individuals during these tests. Stavrou et al. suggest that the CAPD diagnostic criteria need to be reconsidered as they do not include cognitive diagnostic measures. Despite the small sample and weak to moderate associations, the data from the present research reinforce this statement and the recommendation of multidisciplinary assessment in the assessment of CAPD for differential diagnosis among other neurodevelopmental disorders, identifying the presence or absence of comorbidities. Research with larger samples and the use of different instruments to investigate cognition, especially executive functions, is necessary, since the literature is still scarce on the subject.

**Conclusion**

The associations evidenced in the present study between auditory skills and cognitive functions, although weak to moderate, notably demonstrate that the isolated interpretation of CAP tests can be difficult, since the interference of
cognitive functions, especially sustained auditory attention and hearing impairments, is susceptible. Executive functions (working memory, inhibitory control, and cognitive flexibility) had the strongest correlations with the different hearing tests used. Thus, caution is suggested when interpreting the data obtained in the CAP assessment tests, considering the possible interferences of cognitive functioning.

Further research is needed to better understand the practical implications of the unexpected associations between binaural interaction auditory ability and emotional component executive functions (emotional control and behavior regulation), since no similar studies were found in the literature.

The results of the present study reinforce the need for multidisciplinary assessment, with an investigation of cognitive aspects, to better understand the hearing difficulties evidenced in the CAP tests, allowing the differential diagnosis, the optimization of the therapeutic intervention and the reduction of the impact of hearing deficits and/or cognitive disorders in schoolchildren.

Conflict of Interests

The authors have no conflict of interests to declare.

References

1. American Speech-Language-Hearing Association (ASHA) (Central) Auditory Processing Disorders. [Technical Report]. 2005. Accessed Feb. 15, 2019 at: http://www.asha.org/policy
2. Bellis TJ, Bellis JD. Central auditory processing disorders in children and adults. In: Aminoff MJ, Boller F, Swaab DF. (Series Eds.), Celesia GG, Hickok G. (Vol. Eds.), Handbook of clinical neurology - The human auditory system: fundamental organization and clinical disorders. Oxford: Elsevier; 2015:537–556
3. Mccullagh J, Bamiou D-E. Measures of binaural interaction. In: Musiek FE, Chermak GD (Eds.). Handbook of (central) auditory processing disorder: auditory neuroscience and diagnosis. San Diego: Plural; 2014:435–469
4. Hugdahl K, Helland T. Central auditory processing as seen from dichotic listening studies. In: Musiek FE, Chermak GD, (Eds.). Handbook of (central) auditory processing disorder: auditory neuroscience and diagnosis. San Diego: Plural; 2014:153–189
5. Musiek FE, Chermak GD. Auditory neuroscience and central auditory processing disorder: an overview. In: Musiek FE, Chermak GD (Eds.). Handbook of (central) auditory processing disorder: auditory neuroscience and diagnosis. San Diego: Plural; 2014:3–15
6. Alvarez AMMC, Sanchez ML, Carvalho IAM. – Neuroaudiologia e linguagem. In: Fuentes D, Malloy-Diniz LF, Camargo CHP, Cosenza RM (Orgs.). Neuropsicologia teoria e prática. Porto Alegre. Art Med; 2008:136–150
7. Krishnamurti S. Monaural low-redundancy speech tests. In: Musiek FE, Chermak GD, (Eds.). Handbook of (central) auditory processing disorder: auditory neuroscience and diagnosis. San Diego: Plural; 2014:349–367
8. Shinn JB. Temporal processing tests. In: Musiek FE, Chermak GD, (Eds.). Handbook of (central) auditory processing disorder: auditory neuroscience and diagnosis. San Diego: Plural; 2014:405–434
9. American Academy of Audiology (AAA) Guidelines for the Diagnosis, Treatment and Management of Children and Adults with Central Auditory Processing Disorder. American Academy of Audiology, (August). 2010. Accessed February 15, 2019 at: https://audiology-web.s3.amazonaws.com/migrated/CAPD%20Guidelines%202010.pdf
10. Bellis TJ. The nature of central auditory processing disorder. In: Musiek FE, Chermak GD (Eds.). Handbook of (central) auditory processing disorder: auditory neuroscience and diagnosis. San Diego: Plural; 2014:211–230
11. Canadian Interorganizational Steering Group for Speech-Language Pathology and Audiology (CISG) Canadian guidelines on auditory processing disorder in children and adults: assessment and intervention. The Canadian Interorganizational Steering Group for Speech-Language Pathology and Audiology 2012. Accessed February 15, 2019 at: http://www.sac.oac.ca/sites/default/files/resources/Canadian-Guidelines-on-456Auditory-Processing-Disorder-in-Children-and-Adults-English-2012.pdf
12. Chermak GD, Bamiou D-E, Vivian Iliaidou V, Musiek FE. Practical guidelines to minimise language and cognitive confounds in the diagnosis of CAPD: a brief tutorial. Int J Audiol 2017;56(07):499–506
13. Iliaidou VV, Ptok M, Grech H, et al. A European perspective on auditory processing disorder-current knowledge and future research focus. Front Neurol 2017;8(622):1–7
14. Iliaidou VV, Sirimanna T, Bamiou D-E. CAPD is classified as H93.25 and hearing evaluation - not screening - should be implemented in children with verified communication and/or listening deficits. Am J Audiol 2016;25(04):368–370
15. de Wit E, van Dijk P, Henekamp S, et al. Same or different: the overlap between children with auditory processing disorders and children with other developmental disorders: a systematic review. Ear Hear 2018;39(01):1–19
16. British Society of Audiology (BSA) Position Statement Auditory processing disorder. British Society of Audiology, (March), 1–9 2011. Accessed May, 22, 2019 at: http://www.thetheba.org.uk/wp-content/uploads/2014/04/BSA_APD_PositionPaper_31March11_FINAL.pdf
17. British Society of Audiology (BSA) Position Statement and Practice Guidance: Auditory processing disorder (APD). British Society of Audiology, (February), 5–19 2018. Accessed May, 22,2019 at: http://www.thetheba.org.uk/wp-content/uploads/2018/09/Position-Statement-and-Practice-Guidance-APD-2018.pdf
18. Cacace AT, McFarland DJ. The importance of modality specificity in diagnosing central auditory processing disorder. Am J Audiol 2005;14(02):112–123
19. DeBonis DA. It is time to rethink central auditory processing disorder protocols for school-aged children. Am J Audiol 2015;24(02):124–136
20. Moore DR. Editorial: auditory processing disorder. Ear Hear 2018; 39(04):617–620
21. Wilson WJ. Evolving the concept of APD, Int J Audiol 2018;57(04):240–248
22. Bellis TJ. Assessment and management of central auditory processing disorders in the educational setting from science to practice. New York: Delmar Learning; 2003
23. Musiek FE, Bellis TJ, Chermak GD. Nonmodularity of the central auditory nervous system: implications for (central) auditory processing disorder. Am J Audiol 2005;14(02):128–138, discussion 143–150
24. Kreisman NV, John AB, Kreisman BM, Hall JW, Crandell CC. Psychosocial status of children with central auditory processing disorder. J Am Acad Audiol 2012;23(03):222–233, quiz 234
25. Zimmermann N, Cardoso CO, Moraes AL, Prando ML, Fonseca RP. Funções executivas e linguagem na infância: conceitos e relações entre componentes cognitivos para a interpretação neuropsicológica e neuropsicolinguística. In: Fonseca RP, Prando ML, Zimmermann N. Tarefas para avaliação neuropsicológica: avaliação de linguagem e funções executivas em crianças. São Paulo: Mennon; 2016:15–25
26. Chermak GD, Bellis TJ. Differential diagnosis of central auditory processing disorder and Attention-Deficit/Hyperactivity disorder. In: Musiek FE, Chermak GD (Eds.). Handbook of (central) auditory processing disorder: auditory neuroscience and diagnosis. San Diego: Plural; 2014:557–590
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