Central auditory processing and audio-vocal psycholinguistic abilities in children with attention deficit-hyperactivity disorder

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Objective

Central auditory processing disorders and attention deficit-hyperactivity disorders (ADHD) have become popular diagnostic entities for school-age children. P300 (P3) event-related potential (ERP) putatively reflects central auditory dysfunctions associated with ADHD.

Participants and methods

Forty children with a diagnosis of ADHD according to *Diagnostic and Statistical Manual of Mental Disorders*, 4th ed. and 39 normal children were included in the study and were subjected to P300 ERP, audio-vocal items of Illinois test of psycholinguistic abilities.

Results

This study found a significant difference in P300 latency, amplitude, and most of the audio-vocal subtests between the patients and the controls. This difference was obvious in older children for the Illinois test, but was not observed in P300 results.

Conclusion

There was a CAPD in ADHD children as indicated by decreased amplitude of P300 and prolonged latency in such children.

Keywords:

attention deficit-hyperactivity disorder, auditory P300, psycholinguistic abilities

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Introduction

Attention deficit-hyperactivity disorder (ADHD) affects about 3–5% of children. The main symptoms of ADHD are inattention, hyperactivity, and impulsive behavior (American Psychiatric Association, 1994). Auditory processing disorder (APD) may be broadly defined as a deficit in the processing of information that is specific to the auditory modality. It may be associated with difficulties in listening, speech understanding, language development, and learning. In its pure form, however, it is conceptualized as a deficit in the processing of auditory input (Children Jerger and Musiek, 2000).

Central auditory processing disorders (CAPD) and ADHD have become popular diagnostic entities for school-age children. Indeed, there are many behaviors that children with APD and ADHD have in common (Schochat *et al.*, 2002).

Children with ADHD are generally described to have difficulties ignoring irrelevant information, being easily distracted by other stimuli. Therefore, a selective attention deficit may be presumed in these children. Recently, electrophysiologic assessment of auditory selective attention has become possible because of the advent of event-related potential (ERP) studies (Booth *et al.*, 2005).

P300 is the most used auditory ERP. This potential appears around 300 ms and requires attention, auditory discrimination, and memory for its generation. It may provide a general index of cognitive processes, and an abnormally small or delayed P300 probably indicates some cognitive abnormality. Latency is a much more reliable indicator than amplitude, as latency is difficult to alter with attention. Long latency potentials such as the P300 are useful in studying cognitive and attentional functions (Kahn *et al.*, 2004).

Stimulants appear to be a useful treatment for the symptoms of both ADHD and APD, and APD tests might represent a useful measure of ADHD symptomatology and a response to stimulants (Tillery *et al.*, 2000).

Hypothesis and aim

Detection of central auditory processing (higher auditory functioning) as measured by P300 in ADHD children.

Determine the role of stimulants in central auditory processing and P300 in ADHD children for a better understanding of the nature of the deficit in these children.

Participants and methods

Participants

(1) Forty 6–10-year-old patients of both sexes (32 boys and eight girls) were selected from the Phoniatric Unit in Kasr Al Aini Hospital. Parents reported poor academic achievement and hyperactivity in these children. The study was carried out from March 2010 to January 2011. Twenty-one children were

receiving treatment with stimulants (methylphenidate 10–30 mg/day) and the other 19 children were not receiving any medication.

(2) Thirty-nine normal control children (30 boys and nine girls) were included in the study; they were recruited from the pediatric ear, nose, and throat clinic because of acute infections, and fulfilled the inclusion and exclusion criteria, with no history of any psychiatric disorder.

(3) Informed written consent was obtained from the children and their parents, with a full explanation of the steps of the study.

Patient selection criteria

(1) Inclusion criteria
  (a) Average and below average IQ.

(2) Exclusion criteria
  (a) No history of delayed language development.
  (b) No history of hearing or neurological disorders.

Methods

All the patients were referred to a consultant child psychiatrist in The Center of Social and Preventive Medicine (Abou El Reesh Hospital) for the following:

(1) *Psychiatric assessment*: Semistructured psychiatric interview with the child and his/her parents for history taking including personal, prenatal, natal, and postnatal, developmental history, history of childhood illness, and social behavior of the child. A mental status examination was also carried out to confirm that the patients had the diagnosis of ADHD according to the *Diagnostic and Statistical Manual of Mental Disorders*, 4th ed. (DSM-IV) diagnostic criteria (American Psychiatric Association, 1994).

(2) General and neurological examination.

(3) *Psychometric assessment*:
  (a) The Stanford Binet Intelligence Test is a standardized test that assesses IQ and cognitive abilities in children and adults. This was done to exclude borderline IQ and mental retardation (Terman and Merrill, 1960).
  (b) Conners' Parent Rating Scale-Revised, long version (CPRS-R: L), was used to assess the severity of symptoms as reported by parents. This form includes 80 items grouped into different subscales. The CPRS-R: L in the Arabic language was developed by translation and back translation with the permission of the original author (Conners, 2001).

After confirmation of the psychiatric assessment and diagnosis, patients and control children were sent to the Phoniatric Clinic and subjected to the following:

(1) Ear, nose, and throat examination, and language assessment to exclude language delay.

(2) The Illinois Test of Psycholinguistic Abilities (ITPA) Arabic edition (2–10 years) (El-Sadi *et al.*, 1998). In this study, only the audio-vocal items are studied, which include auditory reception, auditory association, verbal expression, grammatical closure, auditory sequential memory, auditory closure, and sound blending (Appendix 1).

Then the patients (medicated and nonmedicated) and control children were sent to the neurophysiology department for the assessment of ERP (P300): A double-blind study was carried out as the clinician in the Neurophysiology Department was not aware of whether or not the patients were taking methylphenidate. The medicated children received a dose of 10 mg of methylphenidate 60 min before P300. P300 was determined using head phone TDH 39. An odd-ball paradigm was used, where the participant was instructed to react to occurrences of a tone (target) presented during 20% of trials and to ignore a frequent tone present on other trials. P300 responses were obtained in response to the target stimuli. P300 amplitude is the difference in microvolt between the point of maximum amplitude of the designated peak and the stimulus baseline. P300 latency was measured from the time of stimulus onset to the point of maximum amplitude of the chosen peak.

Statistical analysis

Data are represented as mean ± SD. Data of the patients and the controls were compared using an independent *t*-test. According to Conners' *T*-subscales, patient data were divided into three groups: group 1 ($T \leq 65$); group 2 ($T = 66–70$); and group 3 ($T > 70$), where the number, validity, and cumulative percent were determined. The Pearson correlation coefficient test was used to correlate patients' Conner *T*-subscales with patients' P300 and Illinois subsets. Two-tailed significant values were considered when *P* value was less than 0.05. Data were analyzed using SPSS for windows, version 11 (IBM, Chicago, Illinois, USA) (Barry *et al.*, 2003).

Results

The mean chronological age of the patient group was 8.1 ± 1.64 years and the mean chronological age of the control group was 8.23 ± 1.38 years ($P = 0.72$). The patient group included 32 (80%) boys and 8 (20%) girls and the control group included 30 (77%) boys and 9 (23%) girls, with a nonsignificant difference ($P = 0.69$).

There was a statistically significant difference between ADHD children and the controls in P300 amplitude and latency ($P \leq 0.001$ and 0.002, respectively) (Table 1).

There were statistically significant differences in auditory reception ($P = 0.006$), auditory association, auditory sequential memory, sound blending, and auditory closure ($P \leq 0.001$) between the cases and the controls (Table 2).

There was a negative significant correlation between P300 latency and the auditory sequential memory ($P = 0.013$) (Table 3).

The following are Conners' subscales: (A) Oppositional, (B) Cognitive Problems/Inattention, (C) Hyperactivity, (D) Anxious-Shy, (H) ADHD Index, (E) Perfectionism, (F) Social Problems, (G) Psychosomatic, (I) Conners' Global Index Restless-Impulsive, (J) Conners' Global Index Emotional lability, (K) Conners' Global Index Total, (L) DSM-IV Symptoms inattentive, (M) DSM-IV Symptoms Hyperactive-Impulsive, and (N) DSM-IV Symptoms Total.

There was a positive correlation between inattention and hyperactivity with P300 latency. Also, there was a negative correlation between Conners' Global Index Restless-Impulsive (I) and both auditory reception and auditory sequential memory (Table 4).

There were highly significant differences in auditory reception, auditory association, verbal expression, grammatic closure, auditory sequential memory, and sound blending. This indicates that older children had more impairment than younger children (Table 5).

There was a longer P300 latency in nonmedicated children than the medicated children, with a significant difference ($P<0.001$) (Table 6).

Discussion

We carried out this study to detect higher auditory function disorder (CAPD) in ADHD children through P300 and the Illinois subtest. ERPs reflect their perceived importance as possibly providing clues to ADHD's underlying pathophysiology; brain-related processes reflecting deficits in inhibitory control have received particular attention in ADHD research (Hinshaw, 2003; Abdel Hamid *et al.*, 2010). P300 amplitude is believed to provide a psychophysiological signature of these deficits (Barry *et al.*, 2003).

The results indicated longer latency and smaller amplitude in ADHD children as compared with their controls (Table 1). Our findings might indicate that the children with ADHD showed signs of late-stage auditory perceptual processing. In agreement with our findings, Satterfield *et al.* (1994) have suggested the existence of abnormal sensory and cognitive information processing in patients with ADHD. They have reported lower amplitudes of the P300 wave, which is related to problems with signal recognition and transduction. A possible explanation was provided by Hoeksma *et al.* (2006), who reported that an abnormally small P300 amplitude is an indication of abnormal functioning of neuronal generators (temporal, parietal, and frontal areas), as these neuronal generators need to be intact for the P300 to attain normal levels. Another explanation was provided by Barry *et al.* (2003), who found that the P300 component is partly associated with frontal function, and the most accepted interpretation is that it relates to the involvement of executive and attentional resources. In agreement with our findings, a small P300 amplitude in ADHD children is in agreement with the findings of Van der Stelt *et al.* (2001), but others have reported that they are equivalent (Rothenberger *et al.*, 2000).

In the present study, the delayed latency might indicate that more time was required to complete stimulus evaluation in the auditory modality at the higher processing level. Jonkman *et al.* (1997) reported significantly longer latencies in ADHD children, which is in agreement with our results.

In terms of the audio-vocal subtests of Illinois, there was a highly significant difference between cases and controls in the studied items, except in verbal expression and grammatical closure (Table 2).

In the present study, auditory reception was impaired in the ADHD = children. We observed that the children did not recognize or identify sounds in their environment, did not have listening attitude, were not able to attach meaning to words, and were also not able to follow consecutive speech. This can be attributed to defective attention in these children.

Table 1 P300 in children with attention deficit-hyperactivity disorders and controls

	Mean ± SD		
P300	Cases ($n=40$)	Control ($n=39$)	*P* value
Amplitude	6.95 ± 4.11	31.22 ± 20.41	< 0.001
Latency	395.76 ± 59.64	362.58 ± 28.14	0.002

Table 2 Performance of children with attention deficit-hyperactivity disorders and controls on Illinois subtests

	Mean ± SD		
	Cases ($n=40$)	Control ($n=39$)	*P* value
Auditory reception	7.14 ± 2.04	8.24 ± 1.29	0.006
Auditory association	6.70 ± 1.94	8.18 ± 1.30	< 0.001
Verbal expression	6.99 ± 2.10	7.08 ± 1.92	0.842
Grammatic closure	6.56 ± 2.02	7.12 ± 1.90	0.205
Auditory sequential memory	5.70 ± 2.01	8.16 ± 1.49	< 0.001
Sound blending	5.97 ± 1.99	8.14 ± 1.35	< 0.001
Auditory closure	6.09 ± 2.01	8.15 ± 1.35	< 0.001

Table 3 Correlates of P300 with Illinois subtests

	Illinois subsets						
P300	Auditory reception	Auditory association	Verbal expression	Grammatic closure	Auditory sequential memory	Sound blending	Auditory closure
Amplitude	0.052 (0.752)	0.124 (0.448)	0.057 (0.728)	0.166 (0.307)	0.203 (0.209)	0.183 (0.259)	0.19 (0.234)
Latency	− 0.141 (0.384)	− 0.266 (0.097)	− 0.171 (0.290)	− 0.162 (0.319)	− 0.55 (0.013)	− 0.293 (0.066)	− 0.27 (0.085)

Table 4 Correlation between Connors' subscales, P300, and Illinois subtest

	P300		Illinois subsets						
Conners' *T*-subscales	Amplitude	Latency	Auditory reception	Auditory association	Verbal expression	Grammatic closure	Auditory sequential memory	Sound blending	Auditory closure
A	−0.001	−0.107	0.025	−0.007	0.047	0.093	−0.030	−0.008	0.002
B	0.035	0.350*	0.018	−0.018	−0.060	0.012	−0.085	−0.077	−0.028
C	−0.126	0.327*	0.090	0.022	0.045	0.129	−0.018	0.035	0.078
D	0.000	−0.169	0.001	0.067	0.037	0.036	0.049	0.045	0.063
E	−0.197	−0.106	−0.068	−0.025	−0.006	0.002	−0.119	−0.080	−0.037
F	−0.122	−0.007	−0.022	0.019	−0.059	−0.021	−0.060	−0.019	0.024
G	−0.181	−0.149	−0.065	−0.111	−0.114	−0.065	−0.176	−0.125	−0.064
H	0.203	0.031	0.242	0.198	0.147	0.225	0.182	0.183	0.212
I	−0.085	−0.039	−0.315*	0.284	0.268	0.211	−0.315*	0.227	0.228
J	0.206	−0.028	0.035	0.080	0.109	0.116	0.063	0.092	0.101
K	−0.006	−0.028	0.285	0.273	0.282	0.318	0.205	0.232	0.237
L	0.120	−0.061	0.201	0.160	0.076	0.149	0.094	0.064	0.112
M	−0.074	0.003	0.163	0.105	0.111	0.195	0.076	0.099	0.137
N	0.004	−0.020	0.197	0.139	0.099	0.197	0.079	0.081	0.132

*Means of statistical significant correlation.

Table 5 Age differences among the studied patients in the P300 and Illinois subtests

	>8–10 years (*n*=23)	6–≤8 years (*n*=17)	*P* value
P 300			
Amplitude	6.98±4.86	6.92±3.58	0.96
Latency	392.70±59.55	397.86±60.94	0.79
Illinois subsets			
Auditory reception	8.70±1.66	5.99±1.44	<0.001
Auditory association	8.35±1.39	5.49±1.29	<0.001
Verbal expression	8.72±1.67	5.71±1.33	<0.001
Grammatic closure	8.23±1.48	5.32±1.38	<0.001
Auditory sequential memory	7.10 ± 1.81	4.66±1.47	<0.001
Sound blending	7.49±1.61	4.85±1.43	<0.001

Table 6 Effect of medication (methylphenidate) on P300 and Illinois subtsets in the patient group (*n*=40)

	Medicated children (*n*=21)	Nonmedicated children (*n*=19)	*P* value
P 300			
Amplitude	6.87±4.30	7.03±4.01	0.90
Latency	366.28±40.47	461.35±41.07	<0.001
Illinois subtests			
Auditory reception	7.35±2.06	6.91±2.04	0.50
Auditory association	7.06±2.02	6.31±1.83	0.23
Verbal expression	7.19±2.11	6.77±2.05	0.54
Grammatic closure	6.77±2.05	6.32±2.01	0.48
Auditory sequential memory	6.11±2.06	5.24±1.90	0.17
Sound blending	6.50±2.05	5.38±1.79	0.07
Auditory closure	6.64±2.05	5.48±1.82	0.07

Auditory association was also significantly impaired in ADHD children in comparison with the controls. It was found that the children had difficulty holding more than one concept in mind and consider the relation between them. This finding can be attributed to the short-term memory defects in these children. Barkley (2003) has reported that children with ADHD cannot hold a concept as well as the semantic representation of the auditory stimulus applied to them and recall other concepts related to it.

Auditory sequential memory was impaired in children with ADHD in comparison with the controls. These results can be attributed to memory deficit in ADHD children. Auditory sequential memory is considered a complex item of Illinois test that is a processing-based problem; thus, its defect might indicate CAPD. Several studies have reported memory deficiencies in children diagnosed with attention problems (Brocki *et al.*, 2008; Shaheen *et al.*, 2011). Martinussen *et al.* (1987) have found that working memory, both verbal and spatial, was impaired in ADHD children. Gomarus *et al.* (2009) have reported that the Central Executive of working memory was impaired in ADHD children.

Auditory closure was also defective in ADHD children compared with the control group. In the current study, it was observed that the child had to listen hard sometimes to be aware that part of the word is missing. Yet for some children, it was observed that the word could be unrecognizably changed. Auditory closure and sound blending defects are because of the presence of defects in the phonological storage and recall of the articulatory loop of words, especially the newly acquired ones (Shaheen *et al.*, 2011). As such, phonological short-term memory is integrally involved in the development and acquisition of academic skills. Shibasaki and Miyazaki (1992) have found that a defect in these abilities may also be attributed to defective central auditory processing because of the concern that ADHD may be frequently comorbid with, or even indistinguishable from, CAPD, which may impact on the child's educational achievements.

Grammatic closure and verbal expression values showed a nonsignificant difference between patients and controls. This can be explained by the selection of the patients; their main complaint was poor academic achievement, with no language problem.

In the present study, there was also positive correlation between P300 latency and inattention and hyperactivity subscales of Conners' Parents Rating Scale. This can be attributed to the fact that the child cannot sit still as there is increased distractibility in children with ADHD; thus, the stimulus takes a longer time to be processed. There was a negative correlation of auditory sequential memory and P300 latency, which can be attributed to the longer time required for the stimulus to be processed (Booth *et al.*, 2005).

In terms of the age difference in the results of this study (Table 5), it was found that there was no difference in P300 results in the two age groups, despite the presence of a highly significant difference in the results of Illinois tests. This result was not in agreement with the findings of Shibasaki and Miyazaki (1992) of a decrease in latency and an increase in amplitude with age. In our study, a significant difference between the two age groups in the Illinois subtest scores with considerably impaired abilities in older children might reflect their poor academic achievement.

The results of the present study on the effect of medication on amplitude and latency indicated that nonmedicated ADHD children had longer P300 latencies than children medicated with methylphenidate. Some studies have reported an increase of the P300 amplitude with stimulant medication in ADHD (Seifert *et al.*, 2003). However, there is still controversy in terms of their effect on the P300 latency. However, Schochat *et al.* (2002) have pointed that methylphenidate did not have a significant effect on any of the central auditory processing measures, although it was found that their performance improved significantly on the attention/impulsivity test. It should be noted that an improvement in the child's attentive ability facilitates the evaluation of AP, with less stress on the child.

Conclusion and recommendations

There was a CAPD in children with ADHD (as indicated by Illinois subtests) and higher auditory central cognitive function (indicated by decreased amplitude of P300 and prolonged latency in such children).

Audio-vocal abilities are more defective in older children (8–10 years) than in younger children.

Children with ADHD should be assessed for CAPD and a rehabilitation program for their deficits should be implemented.

Stimulants may decrease the P300 latency and hence improve the attentive ability and auditory process.

Acknowledgements

Conflicts of interest

There are no conflicts of interest.

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Appendix 1. Illinois test

Auditory reception: The ability to attain meaning from the auditory received stimuli. The 'yes or no' response (normally develops at the chronological age of 2 years)

Auditory association: The ability to relate the auditory received stimuli in a meaningful manner (42 verbal analogues).

Verbal expression: The ability to convey ideas in words, that is the child's response to an open-ended question.

Grammatical closure: The ability to use oral language in acquiring habits for handling syntax and grammatical inflections.

Auditory sequential memory: The ability to produce from memory immediately after representation sequence of stimuli which have been auditory received. It is limited to short-term memory.

Auditory closure: The ability to recognize and reproduce words by filling in the missing parts that are omitted or distorted during presentation. Grammatical form is one form of auditory closure.

Sound blending: The ability to synthesize two or more discrete and isolated sounds into a whole (Cary, 2002).

The audio-vocal items can be arranged according to the structural complexity of items of the test as follows (Hinshaw, 2003; Abdel Hamid *et al.*, 2010).

(1) *Simple items*: (knowledge dependent) auditory reception, verbal expression, grammatical closure, auditory association, and auditory closure.
(2) *Complex items*: (processing dependent) auditory sequential memory and sound blending.