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Exploring the relation between the central auditory processing functions and language development among Arabic-speaking children with attention deficit hyperactivity disorder

Mona Abdel-Fattah Hegazi[1], Ghada Moharram Khalil[2], Sarah Mosaad Mohamed[3] and Mona Sameeh Khodeir[1*]

Abstract

Background Debate still exists on the effect of central auditory processing disorder (CAPD) on the language of children with attention deficit hyperactive disorder (ADHD). This study aimed to explore the deficits of the central auditory processing (CAP) functions and their relation to language development and ADHD symptoms in 30 Egyptian Arabic-speaking children with ADHD between 4 and ≤ 7 years old. ADHD symptoms were rated by Conners' Parent Rating Scale–Revised. Language development was assessed by the Modified Pre-school Language Scale (PLS) 4th edition, the Arabic version, and the Egyptian Arabic Pragmatic Language Test. CAP functions were tested by the Pediatric Speech Intelligibility (PSI) test (Arabic version).

Results Sixty percent of the ADHD children had comorbid CAPD with predominance among ADHD children of combined type. There was a significant positive correlation between all PSI subtests assessing the monotonic auditory closure and dichotic auditory separation abilities in both ears and the language ages by the modified PLS-4. There was also a significant positive correlation between scores of the Egyptian Arabic Pragmatic Language Test (EAPLT) and the monotonic auditory closure ability in both ears and auditory separation ability in the right ear only.There was a non-significant mild difference in scores of the modified PLS-4 in favor of the ADHD children with normal CAP functions.

Conclusion Not all children with ADHD have central auditory processing disorder as both ADHD and CAPD are independent disorders. Better central auditory processing functions are associated with well-developed language and higher pragmatic skills in ADHD children.

Keywords Attention deficit hyperactive disorder, Central auditory processing disorder, Language deficits in ADHD

*Correspondence:
Mona Sameeh Khodeir
mona.khodeir@med.asu.edu.eg; dr.mona.khodair@gmail.com
Full list of author information is available at the end of the article

Background

Although the comorbidity between attention deficit hyperactive disorder (ADHD) and central auditory processing disorder (CAPD) is well documented, the relationship between both disorders is still complex and is not clearly understood. The explanation of one disorder as causal to another remains unclear and the understanding of the interaction between both disorders needs to be studied thoroughly. ADHD is an iceberg disorder, where the symptoms of ADHD represent only the tip. Under the tip of this iceberg, ADHD individuals often have associated and/or comorbid disorders that impact their ability to function successfully [1]. Research studies showed that as much as 65% of children with ADHD will have one or more comorbid conditions at some point in their lives. The common co-occurring disorder within study samples of ADHD has been language impairment and CAPD [2, 3]. The close relationship between attention deficit disorder and auditory processing disorder (APD) is an important subject of discussion in the literature and both disorders have become popular diagnostic entities for school-age children [4]. Since the possible conjunctive relationship between ADHD and CAPD is based on neurodevelopmental perspectives, there is a dysfunction of the interhemispheric transfer of auditory information by the corpus callosum, in both ADHD and CAPD.

Despite the agreement that CAPD and ADHD are independent disorders, there are similarities between both disorders. Attention and listening problems, maladaptive behavior, distractibility, instruction following difficulty, and increased time required to complete tasks are characterizing behaviors exhibited by individuals with CAPD and ADHD [5]. The two behaviors (namely, inattention and distractibility) are ranked alternatively as the sixth and seventh symptoms for CAPD, and first and second for ADHD. Hence, children with CAPD present clinical profiles that can be distinguished from the profile of ADHD [6].

The understanding of the relationship between the attention deficits of ADHD and CAPD hinges on understanding the interaction between perception and higher-level cognitive processing [7]. Dissimilarities between CAPD and ADHD have been reported because of the nature of attention deficits and behavioral differences. Attention deficits in ADHD have been reported to be pervasive and supra-modal affecting more than one sensory modality, whereas in CAPD it affects auditory modality only [8]. Thus, the primary difference between CAPD and ADHD is that CAPD is a sensory-based disorder, while ADHD is a behavioral problem in which the individual cannot self-regulate.

The reason an ADHD child is inattentive is due to a physiological difficulty with attention because of poor execution or response programming [9]. Conversely, the reason a child with CAPD is inattentive is because s/he has trouble processing auditory input. In a visual task, a child with CAPD can focus and be attentive since the visual processes are intact [10]. Also, the inattentiveness noted in children with CAPD is associated with selective attention deficits, associated language difficulties, and processing deficits.

In CAPD, the auditory perceptual deficits impede the operation of executive functions hence such executive dysfunction is difficult to assess thoroughly. The major concern in CAPD is the difficulty in listening or understanding acoustic signals which further makes it difficult for the children to perform higher demanding functions of execution [10]. Executive functions that occupy a higher hierarchy in the tasks get affected due to improper organization, monitoring, and understanding of acoustic signals thereby reflecting the limited use of executive tasks. Hence, executive function difficulties are secondary to listening deficits. Unlike CAPD, ADHD is considered a primary clinical concern. The primary link of executive function deficits in ADHD has been highlighted based on the common grounds of rule-governed behavior, executive function, and self-control. Poor executive functioning has been considered significant in understanding the cause of language deficits, poor problem-solving, and pragmatics in ADHD [11].

One of the current pressing issues is whether CAPD is a unique clinical entity that can be regarded as an unimodal auditory-specific disorder or whether the listening problems are related to or caused by another impairment, for example, language or attention difficulties [12]. There is also a correlation between language development and central auditory processing (CAP) functions. CAP functions are related to the ability to perceive and process rapid changes of spectral characteristics along the auditory pathway, within a time interval in the order of milliseconds, this being an essential process for the development of language.

Although several studies were conducted to evaluate CAPD and language disorders in ADHD, debate still exists on the relationship between CAPD and language impairment in children with ADHD. Accordingly, this study is conducted to explore the deficits of CAP functions among ADHD children and its relation to ADHD symptoms and language development in those children.

Methods

This study is a cross-sectional analytical study that included 30 children between 4 and 7 years old who were diagnosed as having ADHD according to the diagnostic criteria of the Diagnostic and Statistical Manual of Mental Disorders-Fifth Edition (DSM-V) criteria

[13]. Children were selected conveniently from the outpatient clinics of the Phoniatrics and Audiology units. Children with average IQ and normal mental age as assessed by the Stanford-Binet intelligence scale, the Arabic version (5th edition) [14] were included. Children with speech, voice disorders, autism spectrum disorder, or any other neuro-developmental disorders were excluded. Children selected were checked to have normal peripheral hearing by.

a) Pure tone audiometry including air and bone conduction (age-based hearing threshold determination).
b) Speech audiometry including Speech Reception Threshold using Arabic bisyllabic words for children and Speech Discrimination using Arabic Phonetically balanced kindergarten "PBKG" [15].
c) Immittancemetry including tympanometry and acoustic reflex threshold.

Parents of the ADHD-selected children were asked to complete the Conners' Parent Rating Scale–Revised (CPRS-R) [16]. CPRS-R is a parent report scale appropriate for parents with children at the age of 3–17 years. It focuses on behaviors directly related to ADHD and its associated behaviors and it reflects recent knowledge and developments concerning ADHD. The degree of severity of ADHD is dependent on the child's T-score; T-scores (0–45) are average, (46–60) are slight, (61–65) are mild, and (66–80) are significant.

The included children were subjected to an assessment of language development by (1) The modified Preschool language scale-4, the Arabic version (Modified PLS-4) [17], to determine the language ages (total, receptive, and expressive language ages), and hence calculate the language deficits, and (2) Pragmatic language assessment by the Standardized Egyptian Arabic Pragmatic Language Test (EAPLT) [18] to determine the 5th and 95th percentile ranks of the child's total score and his/her scores in each subset of the EAPLT. This test also determines the pragmatic language deficits in correlation to the child's chronological age.

The central auditory processing (CAP) functions were assessed by the Pediatric Speech Intelligibility (PSI) test (Arabic version) [19] which is a linguistically and cognitively simplified central auditory processing test. It is a valuable tool in assessing central auditory abilities namely auditory closure and binaural separation in children as young as 3 years. Also, PSI tests can be used in language-impaired populations. This is because of its closed message sets which overcome expressive language difficulties [20].

In the PSI paradigm, the Ipsilateral Competing Message "ICM" represents a degraded monotonic task, this task requires Auditory closure (figure-ground auditory ability). while the Contralateral Competing message "CCM" represents a dichotic task using the binaural auditory separation ability. Each subtest was presented in two levels of difficulty by modifying the signal-to-noise ratio "SNR", (SNR + 4 and 0) and (SNR 0 and − 20) for PSI-ICM and PSI-CCM, respectively with an intensity level of 40 dBSL (reference of speech reception thresholds "SRT").

Recorded speech material was presented via headphones after calibration using a carrier tone of one KHz for 30 s. Only word lists were used in this study as sentences were found to be difficult for younger children. All four picture response cards (one through four) were used for each child. The child was seated in the sound-treated room with a picture identification response card on his/her lap. The parent was seated next to him/her to help change the response cards and make the child more comfortable. After familiarization with the items on each card, the examiner then instructed the child to point to the picture he/she heard and ignore the distracting voice. A listening trial was administered in quiet first (no competing message) before the competing message started.

Test timing and scoring

Each child was examined in one or two sessions lasting about one hour with multiple breaks when needed. Reinforcement by smiling, verbal compliments, and candy was done frequently to encourage the child to carry on the lengthy procedure. Scoring was done by calculating % correct at each S/N ratio (by counting the number of correctly identified words) and recording this in the specially designed scoring sheets.

Statistical measures and analysis

The data were collected, revised, coded, and entered into the Statistical Package for Social Science (IBM SPSS) version 23. The data were presented as numbers and percentages for the qualitative data, mean, standard deviations, and ranges for the quantitative data with parametric distribution, and median with interquartile range for quantitative data with non-parametric distribution.

Paired *t*-test was used to compare the effect of superiority of the right to the left ear according to the results of the Pediatric Speech Intelligibility (PSI) (Arabic version) among the studied ADHD children (p value < 0.01 is highly significant). Spearman correlation coefficient test was used to (1) correlate scores of the subsets of the Pediatric Speech Intelligibility (PSI) with the chronological age of the participated children, (2) correlate scores of the inattention, hyperactivity, and impulsivity symptoms by the Conners' Parent Rating Scale–Revised "CPRS-R" with the scores of the subsets of the PSI test (Arabic Version), and (3) correlate scores of the subsets of the PSI test (Arabic Version) to scores of the modified Preschool Language Scale – 4 "PLS-4" (Arabic Version) and total score of the Egyptian Arabic Pragmatic Language Test "EAPLT". The confidence interval was set to 95% and the margin of error accepted was set to 5%. So, the p value < 0.05 was considered significant and the p value < 0.01 was considered highly significant. The independent t-test was used to compare between scores of the modified Preschool Language Scale–4 "PLS-4" (Arabic Version) and the total score of the Egyptian Arabic Pragmatic Language Test "EAPLT" among the ADHD with CAPD and ADHD children with normal CAP functions (p value < 0.01 is highly significant).

Results

The demographic data and the characteristics of the studied children regarding chronological age, gender, mental age, IQ, total, receptive, and expressive language age, pragmatic language age and percentile age range, degree of severity of ADHD symptoms, and the distribution of subtypes of ADHD among the participated children are reported in Table 1. Mean (± SD) and 95% confidence intervals for each subtest of PSI were calculated in Table 2. The results of the participating ADHD children were considered abnormal if they were not within the age-specific normative data of the normal healthy control Egyptian children [19, 20].

According to age-specific normative data (95% confidence intervals) reported by Tawfik et al. [19], the participating ADHD children were classified into three groups: ADHD children with normal CAP functions (13.3%), ADHD children with CAPD affecting both auditory figure-ground (AFG) and auditory dichotic separation abilities (60%), and the third group included ADHD children with deficits in only one CAP ability (either auditory figure-ground ability "36.7%" or abnormal dichotic separation "26.7%") and those children were considered borderline or at risk for CAPD for further assessment and follow up (Fig. 1). Case-by-case and intra-test analysis indicated that most of the ADHD children with abnormal scores on the PSI test were less than 5 years and those children had a higher significant mean score in the right ear compared to the left ear in all tasks (Table 3). Results

Table 1 Demographic data and characteristics of the studied ADHD children

Demographic data		ADHD children (*n* = 30)	
Chronological age (in years)	Mean ± SD	5.48 ± 1.09	
	Age range	4–7	
Gender (No. %)	Male	24 (80%)	
	Female	6 (20%)	
Stanford-Binet Intelligence Scale (5th edition)	Mental age (in years) (mean ± SD)	5.00 ± 1.18	
	IQ	91.73 ± 7.60	
Language ages (in years) ** (mean ± SD, age range)[a]	Total	4.97 ± 1.23 (2.6–6.9)	
	Expressive	4.92 ± 1.35 (2.4–7)	
	Receptive	5.03 ± 1.17 (2.9–6.7)	
Score of EAPLT[b] (mean ± SD	61.90 ± 28.06		
Pragmatic language percentile rank[b], No. (%)	Below the 5th percentile	Above the 5th percentile	At the 5th percentile
	21 (70.0%)	9 (30.0%)	0 (0.0%)
Degree of severity of ADHD[c]	High	Mild	Slight
Inattention	24 (80.0%)	3 (10.0%)	3 (10.0%)
Hyperactive	20 (66.7%)	4 (13.3%)	6 (20.0%)
Impulsivity	21 (70.0%)	4 (13.3%)	5 (16.7%)
Distribution of subtypes of ADHD[c]	Inattentive (ADHD-IA) No. (%)	Hyperactive/impulsive (ADHD-HI) No. (%)	Combined (ADHD-C) No. (%)
	5 (16.7%)	4 (13.3%)	21 (70%)

[a] Scores of the modified Preschool Language Scale–4 (The Arabic version) [17]

[b] *EAPLT* = The Egyptian Arabic Pragmatic Language Test [18]

[c] Scores of Conners' Parent Rating Scale-Revised [16]

Table 2 Results of subsets of the Pediatric Speech Intelligibility (PSI) test (Arabic version) that was applied to the studied ADHD children to assess the auditory processing functions

Subsets of PSI test–the Arabic version			The participating ADHD children ($n=30$)		
			Mean (±SD)	95% Confidence interval of the difference	
				Lower	Upper
ICM*	Right ear	+4	54.33 (±24.023)	45.36	63.30
		0	27.67 (±20.625)	19.97	35.37
	Left ear	+4	49.67 (±23.116)	41.03	58.30
		0	27.00 (±21.995)	18.79	35.21
CCM**	Right ear	0	82.67 (±21.804)	74.53	90.81
		−20	54.33 (±33.803)	41.71	66.96
	Left ear	0	65.33 (±32.455)	53.21	77.45
		−20	38.33 (±33.434)	25.85	50.82

PSI Pediatric Speech Intelligibility

[*] *ICM* ipsilateral competing message

[**] *CCM* contra-lateral competing message

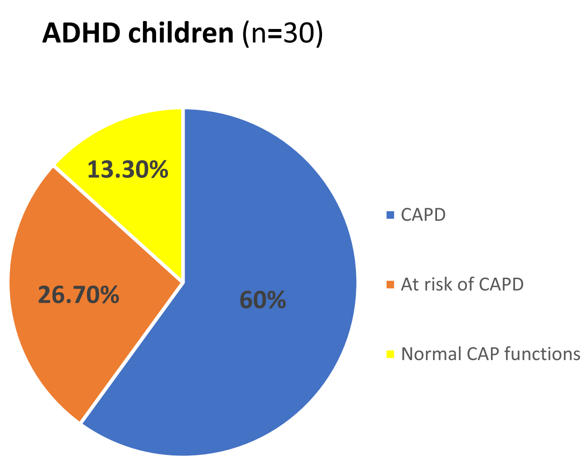

Fig. 1 Classification of the participated ADHD children according to the PSI test (Arabic version)

indicate also that 72.2% of the studied ADHD who had CAPD are of the combined type of ADHD (inattentive-hyperactive type) (Table 4).

By using the Spearman correlation coefficient test, a highly significant positive correlation between Ipsilateral SNR+4 (ICM+4) right and left with the age of participated ADHD children. There was also a highly significant positive correlation between the chronological age and scores of all contralateral (CCM) SNR tests (p values were <0.01). This indicates that the figure-ground auditory and dichotic listening separation abilities get better as the ADHD child gets older (Table 5).

Table 3 Comparing the effect of superiority of the right to the left ear according to the results of the Pediatric Speech Intelligibility "PSI" test (Arabic version) among the studied ADHD children using the paired *t* test

The participating ADHD children ($n=30$)					
Subsets of PSI test–the Arabic version		Right ear	Left ear	Paired *t* test	
		Mean (±SD)	Mean (±SD)	*t* value	*p* value
ICM*	+4	54.33 (±24.023)	49.67 (±23.116)	1.316	0.000*
	0	27.67 (±20.625)	27.00 (±21.995)	0.250	0.000*
CCM**	0	82.67 (±21.804)	65.33 (±32.455)	3.184	0.012*
	−20	54.33 (±33.803)	38.33 (±33.434)	3.413	0.000*

PSI Pediatric Speech Intelligibility

[*] *ICM* ipsilateral competing message

[**] *CCM* contra-lateral competing message

Paired samples test: *p value <0.01 is highly significant

Table 4 Distribution of subtypes of ADHD according to the scores of the Conners' Parent Rating Scale-Revised (CPRS-R) among the participated ADHD children with CAPD

ADHD children with combined CAPD ($n=18$)		
Inattentive (ADHD-IA) No. (%)	Hyperactive/impulsive (ADHD-HI) No. (%)	Combined (ADHD-C) No. (%)
3 (16.6%)	2 (11.1%)	13 (72.2%)

Table 5 Correlation of scores of the subsets of the Pediatric Speech Intelligibility "PSI" test (Arabic version) with the chronological age of the participated ADHD children, using the Spearman correlation coefficient test

The participating ADHD children ($n=30$)				
Subsets of PSI test–the Arabic version			Chronological age $N=30$	
			R	*p* value
ICM*	Right ear	+4	0.473**	0.008
		0	0.108	0.570
	Left ear	+4	0.434*	0.017
		0	0.164	0.387
CCM**	Right ear	0	0.475**	0.008
		−20	0.691**	0.000
	Left ear	0	0.494**	0.006
		−20	0.568**	0.001

PSI Pediatric Speech Intelligibility, **ICM* ipsilateral competing message, ***CCM* contra-lateral competing message

Spearman correlation coefficient: *p value <0.05 is significant, **p value <0.01 is highly significant

As shown in Table 6, there was a non-statistically significant positive correlation between inattention and all the studied PSI test subtests (except for one PSI-ICM SNR 0 in the left ear). This indicates that when symptoms of inattention increase, the figure-ground auditory ability gets worse. Also, there was a statistically significant negative correlation between hyperactivity and PSI-CCM SNR-20 in both ears. This indicates that when symptoms of hyperactivity increase, the dichotic listening separation ability gets worse. There was also a statistically high significant negative correlation between impulsivity and PSI-CCM SNR-20 in both ears and a significant negative correlation between impulsivity and PSI-ICM SNR 0 right test. This indicates that when symptoms of impulsivity increase, both the figure-ground auditory and the dichotic listening separation abilities get worse.

The correlational results between scores of the PSI test (Arabic version) and scores of modified PLS-4 (Arabic version) indicated a statistically highly significant positive correlation between the ICM SNR + 4 and ICM SNR 0 (right and left ears) and the language ages (total, receptive, and expressive) (Table 7). This indicates that the

Table 6 Correlation of scores of the inattention, hyperactivity, and impulsivity symptoms by the Conners' Parent Rating Scale–Revised "CPRS-R" with the scores of the subsets of the Pediatric Speech Intelligibility "PSI" test (Arabic version) using Spearman correlation coefficient

Scores of "CPRS-R" regards the ADHD symptoms							
Subsets of the PSI test (Arabic version)		**Inattention**		**Hyperactive**		**Impulsivity**	
		r-	***p* value**	***r-***	***p* value**	***r-***	***p* value**
ICM SNR + 4 *	Right	0.335	0.070	0.220	0.243	0.223	0.236
	Left	0.227	0.228	−0.287	0.124	−0.054	0.778
ICM SNR 0	Right	0.356	0.054	0.309	0.097	−0.376*	0.041*
	Left	−0.430*	0.018*	0.138	0.467	0.298	0.109
CCM SNR 0**	Right	−0.142	0.454	−0.297	0.111	−0.336	0.070
	Left	−0.085	0.657	−0.311	0.094	−0.396*	0.030*
CCM SNR-20	Right	−0.207	0.273	−0.418*	0.022*	−0.415*	0.023*
	Left	−0.136	0.475	−0.449*	0.013*	−0.492**	0.006**

PSI Pediatric Speech Intelligibility, **ICM SNR* ipsilateral competing message-signal-to-noise ratio, ***CCM SNR* contra-lateral competing message-signal-to-noise ratio

Spearman correlation coefficient: **p* value < 0.05 is significant, ***p* value < 0.01 is highly significant

Table 7 Correlation of scores of the subsets of the Pediatric Speech Intelligibility "PSI" test (Arabic Version) with scores of the modified Preschool Language Scale–4 "PLS-4" (Arabic Version) and total score of the Egyptian Arabic Pragmatic Language Test "EAPLT" using the Spearman correlation coefficient test

The participating ADHD children (*N* = 30)										
Subsets of the "PSI" test (Arabic Version)			**Scores of the modified PLS-4 (Arabic Version)**						**The total score of the EAPLT**	
			Receptive language Score		**Expressive language Score**		**Total language Score**			
			r-	***p* value**	***r-***	***p* value**	***r-***	***p* value**	***r-***	***p* value**
ICM*	Right ear	+ 4	0.690**	0.000**	0.695**	0.000**	0.660**	0.000**	0.490**	0.006**
		0	0.377*	0.040*	0.396*	0.030*	0.366*	0.046*	0.388*	0.034*
	Left ear	+ 4	0.670**	0.000**	0.621**	0.000**	0.643**	0.000**	0.384*	0.036*
		0	0.411*	0.024*	0.364*	0.048*	0.362*	0.049*	0.477**	0.008**
CCM**	Right ear	0	0.421*	0.020*	0.407*	0.026*	0.440*	0.015*	0.285	0.126
		− 20	0.491**	0.006**	0.521**	0.003**	0.555**	0.001**	0.394*	0.031*
	Left ear	0	0.324	0.081	0.335	0.071	0.310	0.096	0.080	0.673
		− 20	0.419*	0.021*	0.432*	0.017*	0.433*	0.017*	0.322	0.083

PSI Pediatric Speech Intelligibility, **ICM* ipsilateral competing message, ***CCM* contra-lateral competing message

Spearman correlation coefficient: **p* value < 0.05 is significant, ***p* value < 0.01 is highly significant dichotic listening separation ability gets better in ADHD children with well-developed language.

Regarding pragmatic language, the results point to a significant positive correlation between the total score of the EAPLT and the scores of ICM SNR 0 right and left as well as ICM SNR + 4 right and left, while there is a significant positive correlation between total pragmatic scores and scores of the CCM SNR − 20 in the right ear only (Table 7). This means that the figure-ground auditory ability is better among ADHD children with better pragmatic language.

The results of the modified PLS-4 (Arabic version) and the EAPLT were compared in the ADHD with CAP disorders (18 children) and those with normal CAP functions (4 children). The results point to a mild difference in favor of the children with normal CAP functions. However, this difference was statistically non-significant (Table 8).

Discussion

With the rising evidence concerning the association of ADHD and CAPD, there was a need to explore the auditory processing deficits among children with ADHD, aiming to figure out the relation of CAPD to symptoms of ADHD and its effect on language development among ADHD children. In general, the comorbidity of ADHD with other disorders was estimated to be between 60 and 80% [21] and this essentially created confusion about the definition of a "true" ADHD diagnosis. Besides, the symptoms of ADHD and other comorbid disorders frequently overlap and affect the ability of individuals with ADHD to function successfully. This makes differential diagnosis and the identification of comorbidity essential to the effective management of ADHD [21].

Because of the challenging nature of the CAP tasks and their considerable performance variability among young children, CAP was assessed in this study by the PSI test (Arabic version). The two subtests of PSI; PSI-ICM, and PSI-CCM, examine the figure-ground auditory and the dichotic listening abilities, respectively. Its closed message sets were established to overcome any expressive language difficulties. Besides the good test–retest reliability of the PSI test, its available age-specific norms for younger children make APD testing suitable for children as young as 3 years old [19]. The PSI test (Arabic version) together with the objective electrophysiological tests, these youngsters can, at least, be identified as being "at-risk" for APD and be eligible for a response to intervention [12].

This study reported that 60% of the evaluated ADHD children had deficits in auditory processing functions. Since the auditory figure-ground ability helps to pick out important sounds from a noisy background, children who struggle with auditory figure-ground discrimination are unable to filter background conversations and noises and focus on what is important. Moreover, problems in dichotic listening affect the ability to understand what is heard and affect the capacity for selective attention.

Although all subtypes of ADHD could have APD as reported by Hong et al. [22], this study found that 72.2% of the co-morbid ADHD with APD children are of the combined inattentive-hyperactive type. This confirms that problems in attention are the core shared symptom between children with ADHD and those with CAPD. Children with CAPD find difficulties in paying attention, their attention is easier to be distracted. Although children with CAPD can hear, they find it hard to understand what is said to them. On the other hand, children with ADHD can hear and understand what is said to them, but they find it hard to pay attention and stay focused on what is said to them, especially if they are not interested in it (hyperfocus attention). This also explains the overlap between ADHD and CAPD in symptomatology and psychoeducational and behavioral sequelae. These results match with that by Effat et al. [23] who reported 55% of ADHD Children had co-morbid CAPD and Tillery et al. [24] who found also that a diagnosis of ADHD places the child at 50–80% risk for CAPD. A study by Riccio and

Table 8 Comparison between scores of the modified Preschool Language Scale–4 "PLS-4" (Arabic Version) and total score of the Egyptian Arabic Pragmatic Language Test "EAPLT" of ADHD with CAPD and ADHD children with normal CAP functions, using the independent *t*-test

		ADHD children with CAPD ($n = 18$)	ADHD children with normal CAP functions ($n = 4$)	*t*-	*p* value
Scores of Language ages by the Modified PLS-4, (Arabic version) (mean ± SD)	Receptive	5.55 ± 1.56	5.35 ± 1.71	0.326	0.723
	Expressive	5.26 ± 1.73	6.24 ± 2.97	0.889	0.365
	Total	4.99 ± 1.42	5.88 ± 1.41	− 1.130	0.272
The total score of the EAPLT (mean ± SD)		59.11 ± 29.52	82.75 ± 16.38	− 1.530	0.142

Independent *t*-test: *p value < 0.01 is highly significant

Hynd [25] stated that the performance of ADHD children was significantly lower than normal children in the SCAN test (one of the screening tests of auditory processing), and the auditory figure-ground subtest alone could accurately classify children with ADHD 64% of the time. This confirms that children with ADHD may have extremely specific auditory processing deficits, or they may have increasing levels of attention deficit that are reflected in tasks requiring careful listening. The explanation is that ADHD in general, has decreased connectivity in a wide neural network linking the frontal, striatal, and cerebellar regions of the brain compared to normal children, and the combined type of ADHD (inattentive-hyperactive type) has the least neural connectivity compared to other subtypes. This was also reported by Ahmed [26] and Murdoch [27].

The current study reported that most of the studied ADHD children were less than 5 years old and had a better right ear performance over the left ear indicating delayed auditory maturation. The depressed scores in the left ear suspect the incomplete myelination of the corpus callosum at an early age and the developmental delay in the maturation of the central auditory nervous system [28]. It may take auditory regions of the cerebrum 10 to 12 years of age or more to become fully myelinated [29], also the left ear performance on dichotic processing tests shares a similar maturational time course [30]. However, there is considerable variability in myelin development across individuals. These findings are supported by Mackie et al. [31] who reported that more comorbid presentations of ADHD are associated with a more pronounced delay in brain maturation. Thus, consideration of age-related variations in normative values is important when interpreting test results for children. This also matches the results of this study that revealed that figure-ground auditory and dichotic listening separation abilities get better as the ADHD child gets older. This is because the central auditory processing abilities improve with age like all cognitive abilities which increase with the increase of age. Cognitive processes get more mature by the age of adolescence [32] and studies have shown that younger children need higher SNRs than older teens/adults when listening to speech in conditions that place demands on top-down processes [33]. To minimize confusion about auditory development, age-specific normative data were used to diagnose CAPD. Besides, the low linguistic load of the PSI test makes it proper for the age group being tested [34].

Regards the relationship between CAPD and the language development in the participating ADHD children, this study reported that ADHD children with a well-developed language and a better pragmatic language had better figure-ground auditory and dichotic listening separation abilities. This is supported by the fact that language disorders are the result of multiple factors that act synergistically, and these factors include auditory processing, language processing, and higher cognitive functions [35]. Moreover, evidence supports the interactions between motor, auditory, and somatosensory systems that involve the formation of neural mappings. Smith [36] believes that there may be a close relationship between APD and speech disorders because the first interferes with the stability of the phonemic representation in the brain and with speech perception, making the learning of phonology, syntax, and semantics difficult.

Several studies reported the co-existence of language impairment among children with ADHD. The range of comorbidity of ADHD and language disorders ranges between 50 to 90% of children with ADHD as mentioned by Trautman et al. [37]. The relationship between APD and language deficits is the most debated in the literature [38]. Auditory processing functions were found to influence language development, particularly pre-literacy skills [39]. With conflicting results on the issue of the association between auditory processing and language development, it was agreed that language impairments and APD may stem from common developmental substructures, rather than causality [40]. Thus, the coexistence of ADHD and CAPD is expected to have great inflections on the language development of young children, since problems of perception, linguistics, and cognition coexist in these two disorders. Unexpectedly, this study found no significant difference between ADHD children with comorbid CAPD and those with isolated ADHD in the development of the different language domains. However, ADHD with comorbid CAPD and those with isolated ADHD had exclusively pragmatic language deficits, which were clearer in ADHD children with comorbid CAPD, although the difference was statistically insignificant. These results suggested that pragmatic language deficit among ADHD children seems to be the main effect of ADHD on children's language. This could highlight the fact that the core deficit of CAPD, ADHD, and pragmatic impairment among ADHD children, is the executive functions deficit. Poor executive functions are considered the primary clinical concern in ADHD, and it explains the cause of any existing language deficits, poor problem-solving, and poor pragmatic skills in ADHD as mentioned by Chermak et al. [9]. The primary link of executive function deficits in ADHD has been highlighted based on the common grounds of rule-governed behavior, executive function, and self-control. Moreover, the pragmatic and metacognitive behavior associated with communication is also rule-governed and language-based and this explains pragmatic deficits in ADHD. CAPD has been referred to as an input disorder (impeding selective and dividing auditory attention) while ADHD has been reported to be an output disorder in response to programming and execution that leads to sustained attention deficits through different modalities.

Recommendations

Further research is recommended to study central auditory processing using both psychophysical and electrophysiological measures. Neuroimaging is also recommended as another investigative tool to delineate the differences between ADHD and CAPD. A detailed analysis of language functioning in children with ADHD is essential. This is because of the potential role language deficits play in explaining some of the basic underpinnings of ADHD as suggested by the recent theoretical information.

Conclusion

The figure-ground auditory ability gets worse when symptoms of inattention increase while both the figure-ground auditory and the dichotic listening separation abilities get worse as symptoms of impulsivity increase. Sixty percent of the ADHD children had deficits in CAP functions and 72.2% of them had a combined type of ADHD. CAP functions are better among ADHD children with a well-developed language and a better pragmatic language with a better performance of the right ear over the left ear. ADHD children with normal CAP functions had better language than ADHD children with comorbid CAPD.

Abbreviations

ADHD	Attention deficit hyperactive disorder
AFG	Auditory figure-ground
CAP	Central auditory processing
CAPD	Central auditory processing disorder
CCM	Contra-lateral competing message
CPRS-R	Conners' Parent Rating Scale-Revised
EAPLT	Egyptian Arabic Pragmatic Language Test
ICM	Ipsilateral competing message
IQ	Intelligence quotient
MCR	Message competition ratio
PBKG	Phonetically balanced kindergarten
PFC	Prefrontal Cortex
PLS-4	Preschool language scale-4
PSI	Pediatric Speech Intelligibility
SNR	Signal-to-noise ratio
SRT	Speech reception thresholds

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Authors' contributions

SM collected independently the study data from the selected children. MK, GM, and MH analyzed the collected data and interpreted these data. MK and MH were major contributors to writing the manuscript. All the authors read and approved the final manuscript.

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Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate

Informed consent was obtained from all parents of the children before enrollment in the study and the study protocol was approved by the Faculty of Medicine of Ain Shams University's Research Ethical Committee (REC) on August 25th, 2019. The protocol registration number was "FMASU MS 237/2019".

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

Author details

[1]Unit of Phoniatrics, Otorhinolaryngology Department, Faculty of Medicine, Ain Shams University, Lotfy Elsayed Street, AbbassiaCairo 11566, Egypt. [2]Unit of Audiology, Otorhinolaryngology Department, Faculty of Medicine, Ain Shams University, Lotfy Elsayed Street, AbbassiaCairo 11566, Egypt. [3]Unit of Phoniatrics, Otorhinolaryngology Department, El-Khanka Psychiatric Hospital, Egypt Ministry of Health and Population, Cairo, Egypt.

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