Central auditory processing in attention deficit hyperactivity disorder: an Egyptian Study

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Introduction
Attention deficit hyperactivity disorder (ADHD) and central auditory processing disorder (C)APD are two neurodevelopmental disorders that usually result in poor scholastic performance. Both disorders share common symptoms such as poor attention particularly in noisy situations. Several studies suggested that they are the same disorder.

Aim
This study aimed to explore the relationship between ADHD and (C)APD.

Participants and methods
A group of 20 children with ADHD were assessed psychologically using Wechsler Intelligence Scale for Children and Conner's Parent Rating Scale. Then, central auditory function was assessed subjectively using the Scale of Auditory Behavior (SAB) and objectively using the central auditory processing test battery.

Results
It was found that 55% ($n=11$) of children showed abnormality in one or more of the (C)APD test results. SAB scores and Conner's scores did not vary significantly between both the groups. In contrast, Intelligence Quotient Scores were significantly lower in patients with ADHD than in patients with (C)APD. The results showed that pitch pattern sequences, pitch pattern discrimination (PPD), and gap in noise were significantly abnormal in patients with ADHD with affected (C)APD, indicating that the most affected central ability in (C)APD ADHD is auditory temporal processing, namely, 'temporal ordering and sequencing as well as temporal resolution'. In addition, inattention and cognitive problems in Conner's Parent Rating Scale-Long version were statistically significantly associated with (C)APD.

Conclusion
It was concluded that high comorbidity exists between (C)APD and ADHD, with the most affected ability being temporal auditory processing. Inattention and cognitive problems were the only clinical variables correlated to the presence of (C)APD.

Keywords:
attention deficit, hyperactivity, neurodevelopmental disorder, Conner's, reading disability, central auditory processing

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Introduction

Attention deficit hyperactivity disorder (ADHD) is a neurodevelopmental disorder characterized by age-inappropriate poor attention span as well as features of hyperactivity and impulsivity or both [1]. It is the most common neurobehavioral disorder presenting for treatment in childhood. ADHD is often chronic, with prominent symptoms, and impairment spanning into adulthood. It is often associated with cooccurring anxiety, mood, and disruptive disorders, as well as substance abuse [2].

A pathophysiological explanation for ADHD symptomatology relates to deficits in prefrontal cortex-mediated executive brain function, also known as response inhibition [3]. Neuroimaging is allowing researchers to further study the ways in which medications affect neurophysiology, providing more precise insights into ADHD and its etiology, diagnosis, and treatment [4]. Neuropsychological studies have implicated the frontal cortical regions of the brain and the circuits linking them to the basal ganglia as critical to executive function, attention, and the ability to exercise inhibition [5].

There may be a greater likelihood for the causal pathway to be from hyperactivity-inattention symptoms to scholastic deficits. This is consistent with findings showing that inattention symptoms contribute to later reading difficulties [6]. It was found that the severity of ADHD affects academic performance in school, with psychiatric morbidity [7]. Children with ADHD are up to five times more likely to require special needs education than children without ADHD [8,9]

Central auditory processing disorder [(C)APD] is defined as a hearing disorder resulting from impaired brain function and characterized by poor discrimination, separation, grouping, localization, or ordering of sounds. It is a common cause of poor scholastic performance as it is reported to contribute significantly to academic and behavioral dysfunctions among school-aged children [10]. In USA, (C)APD is included in the 'specific learning disability' category under the Individuals with Disabilities Education Act. It is defined under Individuals with Disabilities Education Act as a disability that causes problems in comprehending the social and interpersonal content of language [11].

Since the introduction of (C)APD, there has been a debate about its relation to ADHD. Although the comorbidity of (C)APD with ADHD has been well documented [12], some researchers argued that (C)APD and ADHD may be overlapping but independent disorders [13], whereas other investigators argued that there are similarities between both disorders. There is a similarity between ADHD and (C)APD in symptomatology as well as in psychoeducational and behavioral sequelae [14]. Research findings concluded that a diagnosis of ADHD places the child at risk (50–80%) for (C)APD [15]. Chermak and Museik suggested that understanding the relationship between the attention deficits of ADHD and (C)APD hinges on the interaction between perception and higher-level cognitive processing [16]. Although several studies were conducted to evaluate (C)APD in ADHD, debate still exists on the relation of both disorders [14,17,18]. Accordingly, this study was conducted to explore the relationship between ADHD and (C)APD.

Hypothesis

ADHD and (C)APD are different but overlapping disorders with high comorbidity. The comorbid cases show particular clinical and electrophysiological profiles.The aims of this study were (a) to detect the profile of central auditory processing among ADHD patients and (b) to study the behavioral and psychophysical correlates of comorbid ADHD and (C)APD.

Participants and methods

A convenient sample of 20 children aged 6–12 years fulfilling the diagnosis of ADHD according to the *Diagnostic and Statistical Manual of Mental Disorders*-Fourth Edition (DSM-IV) criteria [19] who were not under medication were recruited from the outpatient clinic of the Institute of Psychiatry, Ain Shams University (Cairo, Egypt). The inclusion criterion was Intelligence Quotient of 85 or more on the Wechsler Intelligence Test for Children, Arabic version [20]; written consent was obtained from one parent to involve his or her child in the study. Children with any other neurological problems, sensory deficit, or receiving psychotropic drugs or auditory training were excluded. Each child was evaluated in two sessions.

During the first session, a proper case history and examination using the child psychiatry clinical sheet of the Institute of Psychiatry, Ain Shams University, was applied to diagnose ADHD and exclude patients on treatment or with comorbidity. Confirmation of the diagnosis according to the criteria was carried out using the DSM-IV [19]. Comorbidity was excluded using the Mini International Neuropsychiatric Interview for children, Kid-Arabic version [21], which is a short structured diagnostic interview based on DSM-IV criteria. General intelligence was assessed by a professional clinical psychologist using the Wechsler Intelligence Scale for Children-Arabic version [20]. The severity of ADHD was assessed using Conner's Parent Rating Scale-revised-Long version (CPRS-L) [22]. It scores the parents' report of their child's behavior during the past month on a 4-point response scoring. It has an excellent specificity for ADHD dimensions (Short-Band Questionnaire).

During the second session, an audiological assessment was made. It included a case history and otological examination, followed by a basic audiologic evaluation that included pure-tone audiometry (air conduction testing) and speech audiometry that consisted of speech reception threshold using Arabic bisyllabic words [23], and a speech discrimination test using Arabic Phonetically Balanced Kindergarten words [23]. Immittanemetry was carried out to assess middle ear function. Patients with abnormal test results were excluded. Patients were then screened for (C)APD using the Arabic version of the SAB Questionnaire [24]. It is a 12-item questionnaire with an average time of administration of 5 min. It scores the parents' report of their child's auditory behavior on a 5-point response. It is used for the screening of (C)APD. The scale was translated from the English form developed by Schow *et al.* [24].

A series of psychophysical central auditory tests were then carried out for the selected patients including the following:

(1) Arabic low-pass-filtered (LPF) test [25]: Assessing auditory closure ability;
(2) Arabic speech intelligibility-in-noise (SPIN) test [25]: Assessing selective auditory attention;
(3) Arabic dichotic digit test [26]: Assessing binaural integration;
(4) Arabic-gap in noise (GIN) test [27]: Assessing temporal resolution;
(5) Pitch pattern sequences (PPS)(PPD) test [28]: Assessing temporal ordering and sequencing;
(6) All tests were scored as percent correct for ears, except the GIN test, which was scored by measuring the Gin threshold in milliseconds (the shortest gap duration for which at least four of six responses are correct [29].

Statistical methods

The data collected were statistically analyzed using Statistical Package for Social Sciences program software version 17.0. (Chicago, Illinois, USA). Descriptive statistics were obtained for numerical parametric data as means, standard deviation, minimum and maximum of the range, and 95% confidence interval, whereas for categorical data, it was expressed as number and percentage. Inferential analyses were carried out for quantitative variables using an independent *t*-test in case of two independent groups with parametric data. Qualitative data were obtained using Fisher's exact test. Correlations were assessed using the Pearson's correlation for numerical parametric data. The level of significance was set at a *P* value of less than 0.05, and nonsignificant otherwise.

Results

Descriptive statistics

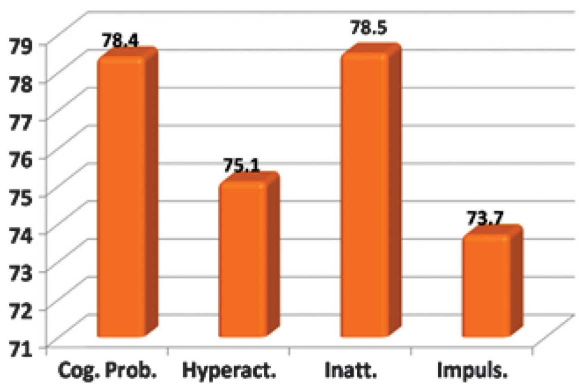
Twenty children with ADHD were included in this study, six children (30%) had ADHD-I (inattentive type) and 14 children (70%) had ADHD-C (combined type). There were six (30%) females and 14 (70%) males. Their mean age was 8.65 years [standard deviation (SD) = ± 1.18)], ranging from 7 to 11 years. The mean verbal intelligence quotient was 101.0 (SD = + 11.4), the mean performance intelligence quotient was 102.9 (SD = + 10.9), and the mean total intelligence quotient was 101.5 (SD = + 10.4). The mean scores on (CPRS-L) are presented in Fig. 1. The mean score on the SAB is 31.8 (SD = ± 5.2), ranging from 23 to 41, and 95% confidence interval was 29.3–34.2.

The diagnosis of (C)APD among patients with ADHD was made on the basis of abnormal scores even in one test according to age-specific norms. Among the entire study sample of ADHD patients, 45% ($n = 9$) showed normal (C)APD test scores, whereas 55% ($n = 11$) showed abnormality in one or more of the (C)APD test results.

Among inattentive-type ADHD, two cases (33.3%) were non-(C)APD and four cases (66.6%) were (C)APD, whereas among combined-type ADHD, seven cases (50%) were non-(C)APD and seven cases (50%) were (C)APD, $\chi^2 = 0.6$, $P = 0.5$.

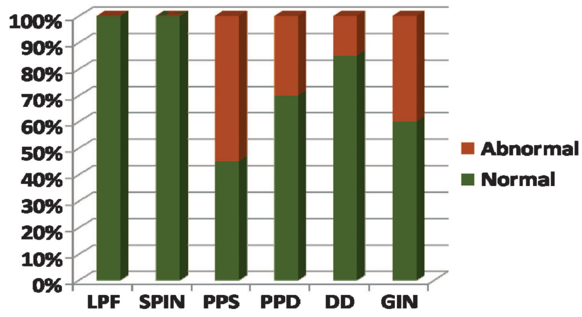
The (C)APD pattern was as follows: 55% showed abnormal scores on PPS, 30% on PPD, 15% on DD, and 40% on GIN tests. None of the patients with ADHD showed abnormality in LPF and SPIN. The results are shown in Fig. 2.

Fig. 1.



Mean scores of Conner's Parent Rating Scale.

Fig. 2.



Percentage of patients with attention deficit hyperactivity disorder showing normal or abnormal central auditory processing disorder test results. DD, dichotic digit; GIN, gap in noise; LPF, low-pass-filtered; PPS, pitch pattern sequences; PPD, pitch pattern discrimination; SPIN, speech intelligibility-in-noise.

Relation between patients with ADHD with (C)APD and patients with ADHD without (C)APD

Demographic variables

Patients with ADHD with (C)APD did not differ significantly from patients with ADHD without (C)APD in terms of age [ADHD with (C)APD, mean age: 8.5 years, SD = ± 1.4 vs. ADHD without (C)APD, mean age: 8.9 years, SD = ± 0.9, $t = 0.81$, $P = 0.42$]. Similarly, sex was not statistically associated with either diagnosis. In the ADHD with (C)APD group, three (27%) were females and eight (72.7%) were males; in the ADHD without (C)APD group, three (33.3%) were females and six (66.6%) were males.

Behavioral variables

Patients with ADHD with (C)APD did not differ significantly from patients with ADHD without (C)APD with regard to their auditory behavior using (SAB) [ADHD with (C)APD mean SAB score: 30 ± 5.1 SD vs. ADHD without (C)APD mean age: 34 ± 4.8 SD, $t = 1.8$, $P = 0.089$). Similarly, there was no statistically significant difference between patient scores on CPRS among patients with ADHD with or without (C)APD, except for the cognitive problem subscale, which was significantly lower in patients with (C)APD [ADHD without C(APD) mean cognitive probability score: 74.4 ± 5.6 SD vs. ADHD with C(APD) mean cognitive score: 81.6 ± 8.2 SD, $t = 2.216$, $P = 0.4$]. In addition, the inattention subscale scores tended to be significantly lower in patients without (C)APD [ADHD without (C)APD inattention score: 75 ± 6.7 SD vs. ADHD with (C)APD mean inattentive score: 81.4 ± 7.7 SD, $t = 1.94$, $P = 0.06$]. The results are shown in Fig. 3.

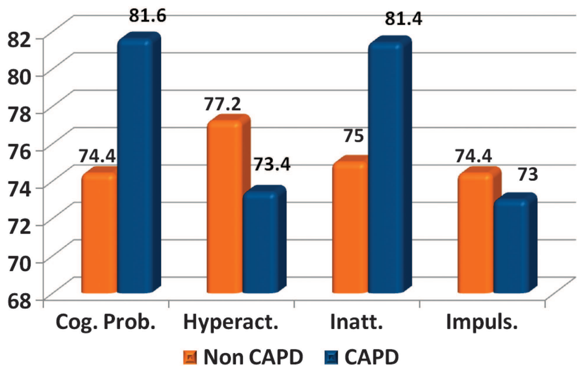
Psychometric variables

However, VIQ and TIQ were statistically significantly higher in patients without (C)APD ADHD compared with patients with (C)APD ADHD . The results are shown in Table 1.

Audiometric variables

Different CAP subsets were tested for a statistically significant association with the presence or absence of

Fig. 3.



Comparison between noncentral auditory processing disorder [(C)APD] and (C)APD attention deficit hyperactivity disorder cases in Conner's scores.

Table 1 Comparison between non-(C)APD and (C)APD ADHD cases in terms of IQ

	Non-(C)APD		(C)APD			
	Mean (SD)	95% CI	Mean (SD)	95% CI	*t*	*P*
VIQ	106.9 (12.4)	97.3–116.4	96.1 (8.1)	90.7–101.5	2.347	0.031*
PIQ	107.9 (10.4)	99.9–115.9	98.8 (10)	92.1–105.5	1.984	0.63
TIQ	106.7 (10.7)	98.4–114.9	97.3 (8.4)	91.6–102.9	2.198	0.041*

ADHD, attention deficit hyperactivity disorder; (C)APD, central auditory processing disorder; CI, confidence interval; IQ, Intelligence Quotient; SD, standard deviation.
**P* value is Sf statistically significant.

Table 2 Association between (C)APD tests and the presence of (C)APD in ADHD cases

	Non-(C)APD ADHD (%)	(C)APD ADHD (%)	*P*
LPF			
Abnormal	0 (0)	0 (0)	CC
Normal	9 (100)	11 (100)	
SPIN			
Abnormal	0 (0)	0 (0)	CC
Normal	9 (100)	11 (100)	
PPS			
Abnormal	0 (0)	11 (100)	<0.001***
Normal	9 (100)	0 (0)	
PPD			
Abnormal	0 (0)	6 (54.5)	0.014*
Normal	9 (100)	5 (45.5)	
DD			
Abnormal	0 (0)	3 (27.3)	0.218
Normal	9 (100)	8 (72.7)	
GIN			
Abnormal	0 (0)	8 (72.7)	<.001***
Normal	9 (100)	3 (27.3)	

ADHD, attention deficit hyperactivity disorder; (C)APD, central auditory processing disorder; CC, could not be calculated; DD, binaural integration; GIN, temporal resolution; LPF, auditory closure; PPD, temporal discrimination; PPS, temporal ordering; SPIN, selective auditory attention.
**P*<0.05 (significant).
***P*<0.01 (highly significant).
****P*<0.001 (very highly significant).

(C)APD among patients with ADHD in an attempt to find a specific marker among them for the presence of (C)APD or to at least detect the specific differentiating pattern of CAP between ADHD and (C)APD.

The results showed that PPS, PPD, and GIN were significantly atypical in patients with ADHD with (C)APD, indicating that the most affected central ability in (C)APD ADHD is auditory temporal processing namely 'temporal ordering and sequencing as well as temporal resolution', which are not affected in ADHD alone (Table 2).

Both groups were then compared in terms of their (C)APD test battery results using an independent-sample *t* test and a highly statistically significant difference was found between them with regard to two of the six tests conducted, namely, temporal ordering and sequencing, being lower in the (C)APD group. Moreover, a statistically significant difference was found on the dichotic test and the GIN test, reflecting poor performance in the (C)APD group on these two tests as shown in Table 3.

Discussion

This study was carried out to determine the rate of comorbidity between ADHD and (C)APD among patients in a clinical setting in our community, which was found to be 55%. No statistically significant association existed between the clinical subtype of ADHD and the occurrence of (C)APD. The (C)APD pattern was as follows: 55% showed abnormal scores on PPS, 30% on PPD, 15% on DD, and 40% on GIN tests. None of the patients with ADHD showed abnormalities in LPF and SPIN. The results are shown in Fig. 2. This is consistent with the result obtained by Tillery *et al.* [15], who found that a diagnosis of ADHD places the child at risk (50–80%) for (C)APD. In addition, Riccio *et al.* [30] found that in 30 children diagnosed with (C)APD, 50% would also fulfill the criteria of ADHD on the basis of a formal diagnosis.

In terms of the sociodemographic characteristics of cases with overlap between ADHD and (C)APD, there is no statistically significant difference between patients with (C)APD and patients without (C)APD as regards age. This might be explained by the fact that both ADHD and (C)APD are neurodevelopmental disorders. Hence, they will go hand in hand with regard to age of presentation. Furthermore, patients are selected according to a limited age range (6–12 years). Similarly, there was no statistically significant difference between both groups with regard to sex. This could be attributed to the higher number of males (high male-to-female ratio) in this study, which might implicate the findings. This result should be interpreted with caution as the sample studied was too small to detect a difference.

The aim of this study was to detect symptom patterns in ADHD both with and without (C)APD. On comparing patients without (C)APD and patients with (C)APD ADHD with regard to the four subscales of (CPRS-L) (Fig. 3), we found that the Cognitive Problem Subscale Score was significantly higher in patients with (C)APD.

Table 3 Comparison between non-(C)APD and (C)APD ADHD patients with regard to scores of the CAP test battery

		Non-(C)APD		(C)APD			
Test	Side	Mean (SD)	95% CI	Mean (SD)	95% CI	*t*	*P*
LPF	Right	97.9 (4.3)	94.6–101.2	100 (0)	100–100	−1.488	0.175
	Left	98.7 (2.8)	96.5–100.8	100 (0)	100–100	−1.414	0.195
SPIN	Right	97.2 (4.4)	93.8–100.6	94.1 (5.8)	90.2–98.0	1.365	0.189
	Left	97.8 (3.6)	95.0–100.6	95.3 (5.9)	91.3–99.2	1.164	0.261
PPS	Right	91.1 (8.9)	84.2–98.0	44.8 (11)	37.4–52.3	10.084	<.001***
	Left	90.6 (9.8)	83–98.1	47.2 (10)	40.5–54	9.656	<.001***
PPD	Right	85.6 (8.8)	78.8–92.3	65.1 (12)	57.0–73.2	4.251	<.001***
	Left	90 (7)	84.5–95.4	61.3 (14.8)	51.4–71.3	5.66	<.001***
DD	Right	96.7 (4.3)	93.3–100.0	95.5 (4.7)	92.3–98.6	0.593	0.561
	Left	95.6 (4.6)	92.0–99.1	85.9 (12)	77.8–94.0	2.267	0.036*
GIN	Right	5.6 (0.5)	5.2–6.0	8.0 (1.9)	6.7–9.3	−3.985	0.002*
	Left	5.6 (0.5)	5.2–6.0	8.4 (2.1)	6.9–9.8	−4.254	<0.001***

ADHD, attention deficit hyperactivity disorder; (C)APD, central auditory processing disorder; CI, confidence interval; DD, binaural integration; GIN, temporal resolution; LPD, auditory closure; PDD, temporal discrimination; PDS, temporal ordering; SD, standard deviation; SPIN, selective auditory attention.
*$P<0.05$ (significant).
**$P<0.01$ (highly significant).
***$P<0.001$ (very highly significant).

Furthermore, the inattention subscale scores tended to be significantly higher (P value = 0.068) in patients with (C)APD compared with patients without (C)APD . Thus, a statistically significant association between the presence of (C)APD comorbidity and severity of cognitive and attentional problems was found in these patients. This is an indication of an area of overlap detected in our study between ADHD and (C)APD symptoms. There are many studies indicating that both disorders overlap clinically [31–37]. Riccio *et al.* [30] postulated that both attention and auditory processing are necessary to perform central auditory processing tasks. Furthermore, Chermak and Musiek [16], Chermak *et al.* [34], and Musiek *et al.* [38] reported that all auditory tasks, from pure tone detection to spoken language processing, are influenced by higher-order, nonmodality-specific factors such as attention, memory, and motivation. Finally, Cacace and McFarland [39] concluded that attention is a major source of contamination in (C)APD testing. Our findings were not consistent with those of Riccio *et al.* [13], who found no significant correlations between measures of attention (i.e. continuous performance test and rating scales for attention problems and hyperactivity and measures of central auditory processing [i.e. the staggered spondaic word and screening test for auditory processing disorders (SCAN)]. This can be explained by the fact that only 72% of their study sample had ADHD, but in this study, the entire sample had ADHD. In addition, their study was retrospective in nature. Thus, it is highly likely that children were medicated; in this study, they were not under medication. Furthermore, not all children of the other study sample were subjected to the same combination of neuropsychological or auditory tests. Finally, they are correlating results of behavioral tests of (C)APD to laboratory measures (the test of variables of attention, which is a computer-administered continuous performance test) and behavioral rating scales of attention. In this study, however, only rating scales were used, which might result in a higher degree of bias.

There was no statistically significant difference between the scores of the SAB questionnaire in both patients without (C)APD and patients with (C)APD ADHD. This indicates an overlap between both groups on evaluation by subjective measures.

In terms of the overlap between ADHD and (C)APD on the investigative level, the most affected ability in patients with ADHD is temporal auditory processing. This finding was supported by the American Speech Hearing and Language Association technical report of coexistence of auditory temporal processing disorder with ADHD [40]. Toplak *et al.* [41] added that children with ADHD have problems in several aspects of temporal information processing, including duration discrimination.

Several studies have applied P300 and mismatch negativity to assess auditory sequential processing speed and temporal information processing [42–46]. Du *et al.* [47] demonstrated a reduction of the voluntary component P300 as well as a reduction of the automatic response component MMN in ADHD cases, which also indicates abnormality of auditory temporal processing.

This study showed no difference between patients without (C)APD and patients with (C)APD ADHD in selective auditory attention as measured by the SPIN test as all the study sample scores were normal according to age-specific norms. This agrees with Dalebout and Fox [48] and Hooks *et al.* [49], who reported that there were no differences between an ADHD and a control group on a selective attention task, and Landau *et al.* [50], who reported that children with ADHD focus less on television in the presence of distraction, but their recall of events is not significantly different from that of children without ADHD.

However, our finding is not consistent with that of Satterfield *et al.* [51], who reported different results on a recall task under conditions of auditory and visual distraction.

Fernandez *et al.* [52], McAlonan *et al.* [53], and Shaw and Rabin [54] reported a delay in cortical maturation in

ADHD and that different clinical outcomes may by associated with different developmental trajectories in adolescence and beyond. In this study, a significantly reduced dichotic digit score in the left ear than the right ear was found in patients with (C)APD compared with patients without (C)APD ADHD. This finding reflects an atypically large right ear advantage (i.e. left ear deficit), indicating possible developmental delay in the maturation of the central auditory nervous system [46]. This finding is supported by Mackie *et al*., who reported that more comorbid presentations of ADHD are associated with a more pronounced delay in brain maturation [55].

Conclusion and recommendations

High comorbidity exists between (C)APD and ADHD, with the most affected ability being temporal auditory processing. The presence of right ear advantage as evidenced by a dichotic digit test confirms maturational delay in patients with ADHD. High inattention and cognitive problem scores on CPRS-L were the only clinical variables correlated to the presence of (C)APD. It is thus recommended to suspect the presence of (C)APD in those patients and subject them to further assessment. Further research is recommended to study temporal processing on a large sample of ADHD children using both psychophysical and electrophysiological measures. Furthermore, neuroimaging is recommended as another investigative tool to delineate the differences between ADHD and (C)APD.

Acknowledgements

Conflicts of interest

There is no conflict of interest to declare.

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المعالجه المركزيه للسمع في عينة من الأطفال المصريين من مرضي اضطراب فرط الحركة و نقص الآنتباه

يعد كل من اضطراب السمع المركزي و اضطراب فرط الحركة و نقص الآنتباه من اضطرابات النمو العصبى و التى تؤدى الى تأخردراسى. يعتبر نقص الأنتباه أحد الأعراض المشتركة بينهما مما دفع عددا من الباحثين الى اعتبارهما نفس المرض. تهدف هذه الدراسة الي بحث العلاقة بينهما. اجري البحث على عينة عشوائية من مرضي اضطراب فرط الحركة و نقص الأنتباه و اظهرت النتائج ان 55% من العينة يعاني أضطراب السمع المركزى. كذلك وجد أن كلا من معامل الذكاء و نتائج بعض أختبارات السمع المركزي تكون أقل بدرجة ذات دلالة أحصائية في وجود اضطراب السمع المركزي المصاحب لاضطراب فرط الحركة و نقص الآنتباه ايضا هناك ارتباط ذو دلالة احصائية بين تشخيص اضطراب السمع المركزي المصاحب لاضطراب فرط الحركة و نقص الآنتباه في حالة وجود نقص الأنتباه و المشكلة المعرفية .