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Attend to This: The Relationship between Auditory Processing Disorders and Attention Deficits

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Abstract

Background: Children clinically diagnosed with auditory processing disorders (APDs) are often described as easily distracted and inattentive, leading some researchers to propose that APDs might be a consequence of underlying attention difficulties or a subtype of attention disorders.

Purpose: The aim of this study was to investigate the link between AP and attention by determining the relationship between performance on an auditory and visual sustained attention task and performance on a common APD test battery.

Research Design: This study was a cross-sectional correlation study of school-aged children.

Study Sample: Participants were a clinical group of 101 children considered by their parents or teachers to have listening difficulties, and a control group of 18 children with no suspected listening difficulties. All children were 7–12 yr old.

Data Collection and Analysis: All children passed a standard peripheral audiologic assessment and were assessed using a clinical APD test battery and reading accuracy, nonverbal intelligence, and visual and auditory continuous performance tests.

Results: There were significant correlations within the APD test scores except for masking level difference values, which did not correlate significantly with any other measure. Dichotic Digit and Frequency Pattern scores also correlated significantly with Nonverbal Intelligence and Sustained Auditory and Visual Attention scores. Within the clinical group, there were twice as many children outside normal limits on both the APD test battery and the attention tests as there were children who were outside normal limits on only the APD test battery or only the attention tests. Significant predictors of reading ability were the Frequency Pattern, Gaps In Noise, and Nonverbal Intelligence scores.

Conclusions: The degree of correlation between the APD and attention measures indicates that although deficits in both AP and sustained attention co-occur in some children (more than would be expected from chance alone), and the two conditions may have similar symptoms, they are separate, largely independent conditions.

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Key Words: Auditory processing disorder, sustained attention, correlation

Abbreviations: AAA = American Academy of Audiology; ACPT = Auditory Continuous Performance Test; ADD = attention-deficit disorder; ADHD = attention-deficit/hyperactivity disorder; AP = auditory processing; APD = auditory processing disorder; ASust = auditory sustained attention; CPT = Continuous Performance Test; DDT = Dichotic Digits Test; FPT = Frequency Pattern Test; GIN = Gaps In Noise; IVA+Plus = Integrated Visual and Auditory Continuous Performance Test; MLD = Masking Level Difference; SCAN = Screening Test of Auditory Processing Disorders; SSW = Staggered Spondaic Word Test; TONI = Test of Nonverbal Intelligence; TOVA = Test of Variables of Attention; VCPT = Visual Continuous Performance Test; VSust = visual sustained attention; WARP = Wheldall Assessment of Reading Passages

INTRODUCTION

Children with auditory processing disorders (APDs) and children with attention disorders can be difficult to differentiate through behavioral observation. Both groups of children may present as being inattentive or easily distracted; they may ask for instructions to be repeated and find listening in a high level of background noise to be difficult. This similarity in behavior has led to uncertainties in the differential diagnosis of APDs and attention disorders (Chermak et al, 1999; Keller and Tillery, 2002; Gascon et al, 1986; Cook et al, 1993). Uncertainties could lead to inappropriate management as attention difficulties are currently primarily treated medically (using stimulant medications such as methylphenidate) (Storebø et al, 2012; Greenhill et al, 2006; National Institute for Health and Clinical Excellence, 2009), whereas APD is typically managed with a behavioral listening approach (Ferre, 1998; Chermak and Musiek, 2002; Hayes et al, 2003; Musiek et al, 2007; Cameron and Dillon, 2011; Sharma and Purdy, 2012). The presence of either an APD or an attention disorder, being theoretic concepts or underlying traits, must be inferred from a set of test results that display a pattern similar to that expected for the underlying disorder to be present.

From an international standpoint, there is a lack of consensus regarding both the definition of APD and how its diagnosis should be linked to specific test results (American Academy of Audiology [AAA], 2010; British Society of Audiology, 2011; Nickisch et al, 2007; Neijenhuis et al, 2002; Moore et al, 2012). There are numerous different criteria for diagnosis (Wilson and Arnott, 2013) with little to suggest that one is better than the other. For instance, the British Society of Audiology (2011) and Moore et al (2012) advocate nonspeech stimuli, whereas the AAA (2010) suggests inclusion of both linguistic and nonlinguistic tests. Another approach suggests a test battery that encompasses multimodal assessments in order to diagnose auditory-specific difficulties (Cacace and McFarland, 2005; 2013). Similarly, there are multiple points of view regarding attention difficulties (Anderson, 2011), although clinical diagnosis based on the *Diagnostic and Statistical Manual of Mental Disorders, Fourth Edition* (DSM-IV), criteria is widely used (American Psychiatric Association, 2000). The DSM-IV criteria are clinical ratings of symptoms and not based on objective measures such as continuous performance tests (CPTs). Gazzaniga and colleagues stated that "attention is a cognitive brain mechanism that enables one to process relevant inputs, thoughts, or actions while ignoring irrelevant or distracting ones" (Gazzaniga et al, 2002, p. 247). Sustained attention is believed to be a combination of attentional processes involving different cognitive processes (Sarter et al, 2001) and is defined as "the ability to direct and focus cognitive activity on specific stimuli" (DeGangi and Porges, 1990).

APD assessments involve active, sustained participation because completion of most tasks in current APD test batteries requires 10–15 min of listening and attention per task, and most batteries have several such tasks. Hence, a certain degree of attention is required to successfully complete an APD assessment (Chermak, 2002), making the differential diagnosis of APD and attention disorders even more challenging.

Some studies investigating the differential diagnosis of APD and attention disorders have focused on measuring effects of attention-deficit/hyperactivity disorder (ADHD) medication (methylphenidate) on APD test performance for children with behaviorally and observationally diagnosed ADHD (Tillery et al, 2000; Cook et al, 1993; Gascon et al, 1986; Keith and Engineer, 1991). Gascon et al (1986) compared performance on neurodevelopmental attention tests (motor impersistence, finger localization, face-hand extinction, visual tracking, and pointing span of objects in sequence), two auditory processing (AP) tests (Willeford battery of tests: Willeford, 1977; Willeford, 1985; Staggered Spondaic Word Test [SSW]: Katz, 1962), and parent/teacher questionnaires of 19 children diagnosed with attention-deficit disorder (ADD) before and after treatment with methylphenidate. Most children (79%) improved on both attention and AP tasks in the medicated condition. This led the authors to suggest that APD may be the same as ADD and that the AP measures used in their paradigm are sensitive indicators of ADD (Gascon et al, 1986) as, once the ADD was medically managed, the AP difficulties reduced or disappeared in their participants.

Similar results were found by Keith and Engineer (1991), who investigated the effect of methylphenidate on AP, auditory vigilance, and receptive language abilities in 20 children with ADHD. An Auditory Continuous Performance Test (ACPT) was used to measure the children's auditory attention (vigilance); the Screening Test of Auditory Processing Disorders (SCAN; Keith, 1986) and the token test (DiSimoni, 1978) were used to assess AP and memory. A significant improvement on the auditory attention task was found as well as improvements on two out of three of the SCAN subtests (Filtered Words and Competing Words) and the token test in the medicated condition, consistent with the findings by Gascon et al (1986).

Neither Gascon et al (1986) nor Keith and Engineer (1991) included a control group of children without attention difficulties or a group of children with poor AP, but no attention difficulties. An alternative conclusion from these two studies might be that attention plays a role in AP test performance in children with a clinical diagnosis of ADHD, but this does not mean that all children with APDs have poor attention, or that ADHD and APDs are the same conditions. These two studies do highlight the possible misdiagnosis of ADHD as APD if clinicians are not careful to manage the child's attention when administering AP assessments. For example, clinicians need to have a person-centered approach where breaks are given as needed, and the duration of the appointment is kept as short as possible, so that the child's attention during testing is optimized.

Cook et al (1993) compared the performance of 15 boys diagnosed with ADD with 10 boys without ADD in a double-blinded, placebo-controlled study of methylphenidate using parent/teacher questionnaires and an APD test battery (speech perception in quiet and in noise, SSW, Willeford Test battery). The participants were tested in three sessions: at baseline, after 3 wk, and after 6 wk. The 15 boys with ADD performed poorer on the APD test battery compared with the control group, but improved on all measures during treatment. Their results supported previous studies and were interpreted as suggesting that ADD and APD are either singular disorders or are two commonly comorbid disorders. This interpretation is problematic because the fact that children with ADHD do poorly on APD tests does not imply that all children who do poorly on APD tests have ADHD, nor that methylphenidate is an appropriate treatment of all children who demonstrate deficits in APD tests.

A similar study by Tillery et al (2000) comparing two groups of 16 children, both with ADHD, produced different results. Participants were tested twice, once medicated with methylphenidate and once with placebo, with the group differences only in the order with which medication and placebo were randomly assigned. All children were assessed using three AP measures (SSW, phonemic synthesis, speech-in-noise) and on an ACPT (Keith, 1994). For the ACPT, 20 monosyllabic words familiar to the child are presented randomly and the child is asked to lift a hand every time the word "dog" is heard. The test lasts for 15 min, and a total of 576 words are presented (Tillery et al, 2000). Both groups showed an improvement in ACPT performance only in the medicated condition; performance on the AP tests was not significantly affected by the medication. This led Tillery et al (2000) to suggest comorbidity of APD and ADHD, rather than viewing these as a singular disorder.

Comorbidity of APD and attention disorders in some children has been suggested by other experimental results (Riccio et al, 1994; Sharma et al, 2009). Riccio et al (1994) explored the comorbidity of ADHD and APD in a group of 30 children. They used an APD test battery consisting of the SSW (Katz, 1962), low-pass filtered speech test (Willeford, 1977), pitch pattern test (Pinheiro, 1977), and the Seashore Rhythm Test (Seashore et al, 1960). A criterion of poor performance on at least two of the four tests was set as a minimal requirement for an APD diagnosis, although the authors acknowledged that poor performance on any one test can be evidence for an auditory impairment in that particular area (Ludlow et al, 1983; Katz, 1985). Notably, 16.7% of the children in the study failed all subtests in the APD test battery, which is not typical of APD (Sharma et al, 2009; American Speech-Language-Hearing Association, 2005; AAA, 2010) and may instead reflect the effects of fatigue, poor attention, or lack of motivation (Silman et al, 2000).

Riccio et al (2005) investigated correlations between attention measured using a Visual Continuous Performance Test (VCPT), AP measures (SCAN: Keith, 1986; SSW: Katz, 1962), and various psychoeducational measures including memory and parent-and-teacher behavior ratings of the children. The VCPT used was the Test of Variables of Attention (TOVA) (Greenberg and Crosby, 1992), which is a computer-based test that requires the child to press the space bar every time an "X" is seen on the screen. The test measures: (a) commission errors (the number of times the participant responds to some letter other than "X"); (b) omission errors (the number of times the participant does *not* respond when an "X" is presented); (c) reaction time (the time lapse between presentation of the "X" and the response); and (d) reaction time variability across the duration of the task. A total of 36 children referred to an outpatient clinic participated in the study. Greenberg and Crosby found significant correlations within the APD test battery, but no significant correlations were found between performance on the APD tests and the different TOVA measures. Thus, although AP measures involve attentional processes and memory, this study suggests that the children also assess separate processes, consistent with the view by Tillery et al (2000) that deficits in AP and attention can co-occur but are not the same. The findings by Riccio et al (2005) of no association between visual CPT and AP performance is in contrast to their earlier 1996 study, which found a correlation between performance on one AP measure (SSW) and ACPT errors. These two studies did, however, use different modalities for the continuous performance test (ACPT versus VCPT). The findings by Riccio and colleagues are consistent with the view that ADD/ADHD reflects multimodal (auditory and visual) attention difficulties (Barkley, 1997b), and APD is typically associated with attention difficulties in the auditory modality only (Chermak et al, 1999).

Sharma et al (2009) used the Integrated Visual and Auditory Continuous Performance Test (IVA+Plus) (Sandford and Turner, 1995) to determine the association between attention and performance on a standard APD test battery including the Dichotic Digits Test (DDT) (Musiek, 1983); Frequency Pattern Test (FPT) (Musiek, 1994); Random Gap Detection Test (Keith, 2000); compressed and reverberant words (Boothroyd and Nittrouer, 1988); and Masking Level Difference (MLD) (Aithal et al, 2006); and different psychoeducational assessments (language, reading accuracy, phonologic awareness, and auditory memory). Correlation analyses showed that auditory sustained attention (ASust) was significantly ($p < 0.01$) associated with FPT and DDT ($r = 0.30$ and $r = 0.44$, respectively). These correlations are sufficiently low that other factors must be involved as well. One possibility may be that attention affects test scores to a greater degree than it affects real-life listening ability. Another possibility is that attention affects AP ability in real life, beyond the tests per se. Given the confusion in the literature about the association between attention disorders and APD and the conflicting views about whether these are singular or separate, often co-occurring, disorders, it is worthwhile scrutinizing how attention may affect performance on APD tests and, hence, affect our inference about an underlying APD. We present three possible connections between attention disorders and AP: (a) attention disorders may be the primary cause of poor APD scores; (b) attention disorders and APD may be separate, independent disorders; or (c) the two disorders may tend to co-occur because they have some common underlying cause such as a delay or widespread abnormality in neurologic development.

The literature so far surveyed appears to suggest the co-occurrence of APD and attention disorders, rather than attention difficulties as the cause of APD or APD as the cause of attention difficulties. A recent study (Moore et al, 2010), however, provides new evidence that failure on APD tests may reflect a problem with attention. Moore et al (2010) assessed 1469 school-aged children (ages 6–11 yr) with normal hearing randomly selected from schools in four regional areas across the United Kingdom. The study used different AP and cognitive measures to investigate "intrinsic" and "extrinsic" attention. The test battery was atypical (Emanuel, 2002; Chermak et al, 2007) and consisted of adaptive tests of backward masking, simultaneous masking, and frequency discrimination as well as a vowel-consonant-vowel speech-in-noise test. Intrinsic attention—which is indicative of the child's ability to sustain attention—was measured by the threshold "track" width for the adaptive auditory discrimination procedures in the AP test battery. Performance variability within each task indicated by "track" width was viewed as indicative of the child's ability to sustain attention on the task. Extrinsic attention is the process we tap into when performing repetitive auditory tasks, also known as phasic alertness (Sturm and Willmes, 2001). Phasic alertness is the ability to enhance the level of response readiness following external cues and is determined by comparing the reaction time with cued and noncued auditory and visual target stimuli (Riley et al, 2009; Sturm and Willmes, 2001). Moore et al (2010) determined the reaction time between presentation of target and response for cued and noncued targets for both auditory and visual stimulation.

Moore et al (2010) found that cognitive performance (as defined in their study: IQ, memory, language, and literacy) and response variability on AP measures (intrinsic attention) were significantly associated with listening and communication assessed using questionnaires, and speech-in-noise skills. Performance on two AP tests (backward masking and frequency discrimination) differed significantly ($p < 0.01$) between participants with typical and poorer visual extrinsic attention (phasic alertness). Moore et al (2010) concluded that poor performance on auditory tasks was related to a "general" inability to maintain attention rather than a specific auditory deficit. It is unknown to what extent this conclusion generalizes to other auditory tests, or even these same auditory tests administered within a shorter test battery where the ability to sustain attention may be less likely to affect APD scores.

With the exception of Sharma et al (2009) and Moore et al (2010), most studies investigating the relationship between APD and attention disorders have used relatively small sample sizes (<40 in total), making it difficult to generalize to a larger population. Most medication studies have recruited children diagnosed with ADHD and assessed their AP abilities (e.g., Cook et al, 1993; Gascon et al, 1986) in an attempt to answer important questions about the APD diagnosis, instead of recruiting children with a primary concern of APD. Inattention may be a result of exhaustion when testing is prolonged or a sensation arises because the child has poor AP, language, and/or learning difficulties. Thus, it is important to consider how testing is conducted, and the basis on which the children were recruited, when attempting to explain the overlap between APD and attention difficulties (Riccio et al, 1996). Given the complexity of attentional processing, it is also important that specific aspects of attention are explored rather than global attention measures.

This study aimed to further investigate the association between APD and attention by comparing performance on a current, commonly used APD clinical test battery, reading, nonverbal intelligence, and the

IVA+Plus (Sandford and Turner, 1995), which measures sustained attention in both visual and auditory modalities. The aim of including a sustained-attention test was not to diagnose children with attention disorders, but to quantify the children's attention capacity. The focus of the study is on understanding the relationship between these test results and by inference of how they are affected by the underlying abilities of the children, rather than attempting to unambiguously diagnose children as "having" or "not having" APD.

METHODS

Participants

A total of 119 children in the age range of 7–12 yr were included in this study. Participants with listening concerns were recruited from the caseload of an APD clinic (n = 56) and from an advertisement recruiting children with listening difficulties (n = 45). Responses were received from teachers, parents, or other professionals. In addition to this experimental group, a smaller number of children (n = 18) for whom there were no listening concerns were also recruited to the study as controls.

All participants were screened to ensure that they had hearing within normal limits bilaterally with pure-tone air-conduction thresholds of 15 dB or less at octave frequencies from 500 Hz to 4 kHz, type A tympanograms (Jerger, 1970), and present contralateral acoustic reflexes at 2000 Hz (Silman and Gelfand, 1981).

Participants included 73 boys (61%) and 46 girls (39%) with a mean age of 9.2 yr (SD = 1.5, age range: 6.8–12.8 yr).

Approximately one third of the children had a history of multiple ear infections (n = 42), based on parent report. Two children had been diagnosed with ADHD and were taking medication, and five children suspected to have attention disorders were referred by a pediatrician for APD assessment. None of the children had any known history of motor-skill difficulties.

We assessed handedness by asking the children to write their name on a piece of paper. The children were also asked whether they always used the same hand for all tasks and what foot they would kick a ball with. On the basis of this assessment, 105 children (88.3%) were right handed; 12 (10%) were left handed; and 2 (1.7%) were classed as being ambidextrous, as they used different hands and feet for different tasks.

Procedure

Each child was tested in one 2-hr session involving audiologic screening, APD testing, and psychoeducational assessment. Participants had multiple breaks within the session. All children with a performance of 2 SD or more below the normative mean for one or both ears on any of the APD tests were invited to return for reassessment (n = 58) within 3 mo to verify the results for diagnostic purposes. Of 58 families, 19 returned for reassessment. The better scores of the two sessions were used for the purpose of this study.

Behavioral AP Tests

Four behavioral tests were used to test a range of auditory processes, as recommended by the American Speech-Language-Hearing Association (2005) and AAA (2010): DDT v2 (Musiek, 1983), the FPT (Musiek, 1994; Noffsinger et al, 1994), Gaps In Noise (GIN; Musiek et al, 2005), and MLD (Wilson et al, 2003) (see description of tests in Table 1). These tests were chosen based on the minimal test battery described by Jerger and Musiek (2000). Three of the four tests have no linguistic loading.

Pure-tone audiometry and behavioral AP tests were administered using a NOAH-compatible Auricle audiometer and TDH-39P headphones. Test materials were presented at 60 dB HL using a CD player (RCA RP-7920A) through the Auricle. APD tests are typically presented at a comfortable listening level of 50 dB HL or SL, but it has been suggested that the level is not critical provided that the presentation level is at least 15 dB SL above the threshold level (Musiek, 2002). A presentation level of 60 dB HL was used for APD testing to ensure good audibility. For the FPT and GIN tests, stimuli to right and left ears were presented separately, with the starting ear randomized. For the DDT and MLD tests, the right and left ears were tested dichotically.

The performance on the AP tests were considered to be a "pass" if the scores were within 2 SDs of the mean (for norms, see Kelly, 2007; Musiek et al, 2005; Aithal et al, 2006). For FPT and GIN, scores were regarded as abnormal only if this occurred in both ears because ear differences are not expected.

Psychoeducational Tests

Children were tested using the Wheldall Assessment of Reading Passages (WARP), which measures reading accuracy and fluency. WARP test norms based on school year were adopted from Madelaine and Wheldall (2002).

The Test of Nonverbal Intelligence (TONI-3) was also included in the psychoeducational part of the assessment to measure the child's nonverbal intelligence, abstract thinking, and problem solving without any verbal instructions (Brown et al, 1997). The test is norm-referenced, and a standard score of 80 (9th percentile) was used as the cutoff value for inclusion in the study.

Sustained attention: Auditory and Visual

The children were tested on the IVA+Plus (Sandford and Turner, 1995) to assess their continuous performance

Table 1. Description of Behavioral Test Procedures Used for AP and Reading Assessments

Test	Description
DDT (Norms: Kelly, 2007)	This test evaluates how well the child hears competing speech signals presented simultaneously to the two ears. For each test item, two words (the numbers "1" to "9, " excluding "7") were presented sequentially to one ear at the same time as two numbers were presented sequentially to the other ear. Children were asked to repeat all four numbers without paying attention to the order or ear in which they were heard.
FPT (Norms: Kelly, 2007)	Three tones were presented at either of two frequencies (low or high pitch). The child described the pitch sequence verbally (e.g., "high–high–low," "low–high–low").
GIN (Norms: Musiek et al, 2005)	This test detects how well a child can detect short silent breaks of 3–20 msec in a segment of continuous noise (white noise). The children give a signal every time they hear a gap in the noise.
MLD (Norms: Aithal et al, 2006)	This test determines how the two ears function together to detect a sound in the presence of a masking signal. A 500 Hz pure-tone signal is presented in phase at the two ears at different signal-to-noise levels, in the presence of noise presented out of phase at the two ears in one condition, and in phase at the two ears in the other condition.
WARP (Norms: Madelaine and Wheldall, 2002)	This test has three short passages, and the child is asked to read each passage as accurately as he or she can within 1 min (without skipping any words). The test measures the number of words read accurately. The score is an average over the three passages. The norms are provided for each grade 2–6.
TONI-3 (Brown et al, 1997)	The child has to match one out of six pieces as the missing piece in a pattern. It is a normative test of cognitive abilities including nonverbal intelligence, abstract thinking, and problem solving for individuals ages 6–89 yr.
Sustained auditory and visual attention – BrainTrain (Sandford and Turner, 1995); results based on standard scores	The BrainTrain assesses the child's ability to maintain attention for a period (15 min). The child sees and hears the numbers "1" and "2" presented pseudorandomly and has to press the button every time the number "1" is seen or heard. Number "2" should be ignored.

on the same auditory or visual task presented 500 times for a period of 15 min. The test was presented on a laptop with the sound set to a comfortable level. The numbers "1" and "2" were presented pseudorandomly as either a visual or an auditory stimulus, and the children were instructed to click the button on the mouse every time they saw or heard the number "1" and ignore the number "2." No feedback was provided during the testing; however, encouragement to continue was given in rare cases. Scores of 2 SD or more below the mean standard score were considered abnormal. This study used the IVA+Plus scores of auditory and visual sustained attention (VSust; Sandford and Turner, 1995).

Analysis

All standard scores (TONI-3, IVA+Plus) and raw scores (APD tests, WARP) were converted into z-scores (i.e., age-appropriate population SD units). The conversion from raw scores removed age effects where they existed. All APD test scores for which the raw score were in percent correct were normalized using an arcsine-transform (Studebaker, 1985) before calculation of z-scores (Tomlin et al, in press).

The main aim of this study was to investigate the influence of attention on performance on the APD test battery. APD test results are usually reduced to a dichotomous variable (APD positive versus negative); in the current study, APD performance data were treated as continuous variables so that correlation analyses could be performed. A secondary aim was to determine the overlap in the number of children with listening concerns who would be diagnosed as having APD and/or poor attention. For this aim, children were classified as having APD if the scores were poorer than 2 SDs below the mean on two or more scores (AAA, 2010).

Correlation analyses were conducted to investigate the association between performance on the auditory and VSust tests and performance on the APD test battery.

RESULTS

Subsets of participants were created based on the results on the APD test battery, reading accuracy, and sustained attention abilities. A total of 41 children passed all tests in the battery, of which 23 were participating in the study because of parental and/or teacher concern about listening and academic performance. The other 18 children presented no concerns.

Figure 1 shows the distribution of the 119 participants based on the performance on the behavioral test battery.

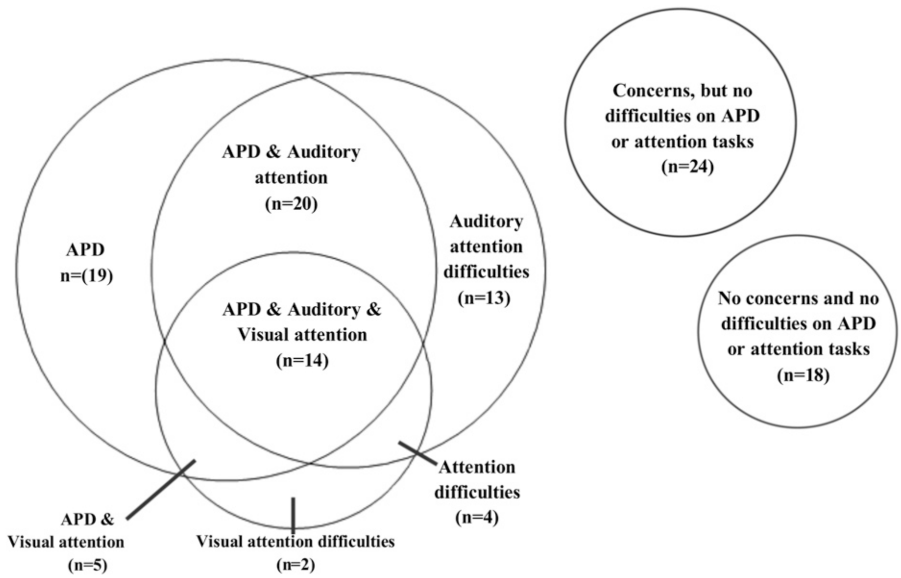

Figure 1. Distribution of patterns of test results across the 119 participants. Participants were categorized as having "APD" or "attention difficulties," as appropriate, if their score was poorer than 2 SDs below the age-appropriate mean on any one test, as described in the text.

Means, SDs, and ranges of scores for the APD, psychoeducational, and sustained attention tests are listed in Table 2.

On the basis of a diagnostic criterion of 2 SD below the mean on any one test (both ears for FPT and GIN), we found that 19 children would be classified as having APD without any attention deficits. Another 19 children presented with attention deficits without APD. Thus APD and attention deficits occurred separately in these children, who comprised 38% of the clinical group. An additional 39 children would be classified as having both APD and attention difficulties.

Of the 58 children with attention difficulties (with or without APD), approximately one half showed auditory difficulties only (n = 33), a few (n = 7) had visual difficulties only, and 15 children had both auditory and visual difficulties. Attention disorders typically involve multimodal (auditory *and* visual) attention difficulties

Table 2. Means, SDs, Medians, and Range of Scores of the No-Concern Group (n = 18) and the Group of Children with Listening Concerns (n = 101) for the AP Tests, Psychoeducational Tests, and Sustained Attention Scores

Test	Test Ear	Group	Mean	SD	*p* value	Median	Range
DDT (%)	Left	No concerns	93.3	6.9		95.0	68–100
		Concerns	83.5	12.0	< 0.0001	87.5	50–100
	Right	No Concerns	97.1	3.3		97.5	88–100
		Concerns	90.7	9.1	< 0.0001	92.5	50–100
FPT (%)	Combined	No concerns	88.0	13.5		90.0	47–100
		Concerns	52.6	25.3	< 0.0001	50.0	0–100
MLD (dB)		No concerns	9.1	1.5		8.0	8–12
		Concerns	8.7	1.8	0.31	8.0	0–14
GIN (msec)	Combined	No concerns	4.8	0.8		5.0	3–6
		Concerns	5.3	1.8	0.06	5.5	0–10
TONI (ss)		No concerns	120.0	17.8		119.0	88–146
		Concerns	94.9	12.9	< 0.0001	92.0	72–141
WARP (word/min)		No concerns	153.5	33.54		164.5	79–201
		Concerns	92.7	44.4	< 0.0001	100.1	16–203
Sustained attention	Auditory	No concerns	100.2	15.9		95.5	79–128
		Concerns	66.2	30.9	< 0.0001	70.0	0–120
	Visual	No concerns	99.9	11.9		100.0	79–120
		Concerns	78.0	33.9	< 0.0001	88.0	0–121

Note: P values indicate the probability of test scores for the children with listening concerns arising from the same distribution as for the children with no listening concerns. ss = standard score.

(Barkley, 1997a, 1997b; Greenberg and Crosby, 1992; Hooks et al, 1994; Seidel and Joschko, 1990). Very few (4%) of the children were found to have VSust difficulties (without an accompanying auditory attention difficulty) alongside APD. The presence of visual attention difficulties in only a small percentage of children with APD is consistent with other reports of visual processing difficulties in children with APD (e.g., Bellis et al, 2011).

Correlation analysis was conducted using the data from all 119 children to investigate the relationship between AP measures (DDT, FPT, MLD, and GIN), reading accuracy, nonverbal intelligence, and sustained attention (see Table 3). Because left- and right-ear test scores for each of the FPT and GIN correlated so highly ($r = 0.77$ and $r = 0.84$, respectively), the results for each were averaged across ears for all remaining analyses. Scores of the DDT correlated with FPT ($r = 0.29$ and $r = 0.49$ for right and left ear, respectively). Scores for FPT also correlated with GIN ($r = 0.32$). MLD results did not correlate significantly with any of the other AP measures. The largest magnitude correlation found between MLD and any other APD score was a correlation of 0.07 with the DDT right ear score. The 95% confidence interval around this is from –0.25 to +0.25, so we can be certain that even a moderate correlation between the MLD scores and other APD scores is not possible. Although scores for a number of AP tests are correlated, none of the correlations are very strong, suggesting that these are assessing different AP abilities.

The psychoeducational measure of nonverbal intelligence (TONI) correlated significantly ($p < 0.01$) with DDT for the left ear ($r = 0.37$) and FPT ($r = 0.39$). The measure of reading rate (WARP) showed correlations with FPT ($r = 0.38$) and GIN ($r = 0.34$). Correlation was also found between the two psychoeducational measures ($r = 0.50$).

Correlation ($r = 0.55$) was found between auditory and visual attention, indicating that some common factor underlies, at least in part, attention in the auditory and visual modalities. Significant correlations ($p < 0.01$) were found between APD test scores and sustained attention. Auditory and VSust both showed correlation with left DDT (auditory: $r = 0.29$; visual: $r = 0.25$), right DDT (auditory: $r = 0.25$; visual: $r = 0.27$), and FPT (auditory: $r = 0.33$; visual: $r = 0.28$). Correlations ($p < 0.01$) were also found between sustained attention and psychoeducational performance: ASust and TONI ($r = 0.33$), ASust and WARP ($r = 0.31$), VSust and TONI ($r = 0.31$), and VSust and WARP ($r = 0.33$).

Multilinear regression was used to examine the extent to which reading ability (WARP scores) could be predicted from those variables shown in Table 3 that individually correlated significantly with the WARP measure (DDT [left], FPT, GIN, TONI, ASust, and VSust). Predictors with regression coefficients significantly different ($p < 0.05$) from zero were FPT ($\beta = 0.26$, $p = 0.012$), GIN ($\beta = 0.18$, $p = 0.035$), and TONI ($\beta = 0.26$, $p = 0.006$). The adjusted R^2 value was 0.41.

Table 3. Correlations between AP Tests, Psychoeducational, and Sustained Attention Measures

	DDT_L	DDT_R	FPT	MLD	GIN	TONI	WARP	ASust	VSust
DDT_L	1.00	**0.43***	**0.49***	0.04	0.21	**0.37***	0.23	**0.29***	**0.25***
DDT_R		1.00	**0.29***	0.07	0.13	0.10	0.07	**0.25***	**0.27***
FPT			1.00	−0.04	**0.32***	**0.39***	**0.38***	**0.33***	**0.28***
MLD				1.00	0.05	0.12	−0.07	−0.03	0.15
GIN					1.00	0.10	**0.34***	0.17	0.02
TONI						1.00	**0.50***	**0.33***	**0.31***
WARP							1.00	**0.31***	**0.33***
ASust								1.00	**0.55***
VSust									1.00

Notes: DDT_L = Dichotic Digits Test (left ear); DDT_R = Dichotic Digits Test (right ear). *$p < 0.01$ (shown in bold). FPT and GIN indicate the average of both ears.

DISCUSSION

Differential diagnosis between APD and attention disorders is a recurrent topic in the literature (e.g., Chermak et al, 2002; Keller and Tillery, 2002; Riccio et al, 2005; Sharma et al, 2009; Cook et al, 1993; Gascon et al, 1986; Chermak et al, 1999), with a recent article by Moore et al (2010) reigniting the discussion about the links between AP and attention deficits. The aim of this study was to investigate the link between AP and attention by determining the relationship between performance on an auditory and VSust task and performance on a commonly used APD test battery.

Theoretic Model

The relationship between APD and auditory attention can be further examined by simplifying the data in Figure 1 as shown in Table 4.

As can be seen, close to one half of the children failed the APD test and close to one half failed the auditory attention test. If these attributes (AP and attention) were independent, then the number expected to fail both tests would be 51*58/101, which is 29 children. Our data showed that, in fact, 34 children failed both tasks. A χ^2 test confirms ($p = 0.06$) that, within this population of children who were suspected to have APD on the basis of listening concerns or poor academic performance, the numbers within the four cells of Table 4 are entirely consistent with the probability of failing the APD battery being independent of the probability of failing the sustained auditory attention test. The same conclusion is reached if we define a fail on the attention test as a fail in either auditory or visual attention.

These children with listening concerns are not, however, at all representative of the general child population,

Table 4. Categorization of Children with Hearing Concerns According to Whether They Passed or Failed the APD Test Battery, and Whether They Were Inside or Outside the Normal Range of the Test of Sustained Auditory Attention

	APD Passed	APD Failed	Total No.
Auditory attention passed	26	24	50
Auditory attention failed	17	34	51
Total no.	43	58	101

and we need to view the full picture before concluding anything about the independence of attention and AP. We recruited these 101 children through an advertisement targeting children with listening concerns or through them initiating a visit to our clinic because of listening concerns. Suppose that, instead, we had found these same children by testing a large number of randomly selected children, most of whom would have no listening concerns and who would be within normal limits (by definition) on the tests used. The vast majority of these children, with no listening concerns, will fall in the top left box of Table 4, as did all 18 of the control children we tested.

Table 5 shows a hypothetic sample of 1000 children comprising the 101 children with concerns assessed in this study, plus 899 children with no deficits. If the two conditions were independent, how many children should fail both APD attention tests? On the basis of data from the current study, the expected number would be 51*58/1000, which is 3 children (only 0.3%). The actual number of children failing both tests in the current study is, however, 34 children (3.4%). This number is 10 times greater than expected if these abilities are independent, and a χ^2 test indicates that the difference from the expected proportion is highly significant ($p < 0.0001$), indicating that AP and attention are not independent. This result is consistent with the finding of significant correlations between some AP and attention measures. This conclusion is by no means the same as saying that APD deficits always reflect attention deficits, or vice versa. In fact, of the experimental group children who had either or both deficits, two thirds of them had only one of these deficits.

This association between performance on APD tests and auditory attention is consistent with the results of the correlation analysis. For the correlation analysis, we more realistically do not categorize children as "having" or "not having" APD or an attention deficit but, rather, examine the strength of their AP and auditory attention abilities, as quantified by their z-scores on each test. Both auditory and VSust correlated significantly with the dichotic digit performance (both ears), FPT, and the GIN performance. Correlation coefficients were in the range of 0.25–0.33. Although these correlations are large enough to reach significance, attention "explains" only 8% of the variance in the APD test scores. Consequently, there are no grounds for viewing the APD performance as primarily the consequence of attention, although unquestionably some relationship exists between the two apparently different attributes.

This view is also consistent with the results of the multilinear regression used to relate potential predictors to the children's reading ability. FPT, GIN, and TONI scores all contributed significantly. It was noteworthy that attention scores did not contribute significantly, although individually they correlated significantly with reading ability. Presumably, they failed to reach significance in the multilinear regression because of the variance they shared with the APD measures or with nonverbal intelligence. When the two attention scores were used as the only predictors of reading speed, only VSust reached significance. In summary, attention, nonverbal intelligence, and the APD measures have sufficient variance in common that when the APD measures and nonverbal intelligence were used to predict reading ability, no significant additional contribution was made by either visual or ASust.

We can consider three possible options for the (co)existence of sustained attention difficulties and APD:

(a) Only attention disorders exist and they cause children to perform poorly on APD tests, which would result in a high correlation between APD and sustained attention scores, and in children diagnosed with one condition nearly always being diagnosed with the other.

(b) Attention disorders and APD occur independently of each other, which would result in no correlation between the APD and sustained attention scores, and in an extremely small proportion of children having both disorders.

(c) Some common factor (which may be attention) contributes to, but does not solely determine, performance on tests of APD and tests of attention, which would result in a significant but imperfect correlation between the APD and sustained attention scores, and in there being an appreciable proportion of children with both types of disorders.

The data from this experiment lead us to favor the third interpretation over the first two interpretations. The low but significant correlation between APD scores

Table 5. Sample of 1,000 Children Comprising the 101 Children with Concerns Assessed in This Study Plus a Theoretic 899 Children (See Text) with No Deficits or Concerns

	APD Passed (%)	APD Failed (%)	Total No. (%)
Auditory attention passed	925 (92.5)	24 (2.4)	949 (94.9)
Auditory attention failed	17 (1.7)	34 (3.4)	521 (5.1)
Total no.	942 (94.2)	58 (5.8)	1000 (100%)

and sustained attention scores, and the nearly 50% of children in the experimental group who had either APD or an attention deficit, but not both, establishes that poor performance on an APD test may not just be a consequence of an attention deficit. Test-retest error will limit the magnitude of the correlation that is possible but seems insufficient to cause correlations as low as those observed, given the high correlation between ears observed in the FPT and GIN test scores.

Conversely, the statistically significant correlations between APD and attention scores, and the one quarter of children in the experimental group who had test results indicative of both types of disorders, establishes that attention deficits and APD test scores are not totally independent conditions that co-occur only occasionally and only by chance.

There are, however, two different contexts in which a partial correlation of attention and APD scores can come about. The first context is that some common factor, such as an underlying delay or abnormality in executive function, contributes to a deficit in both AP ability and attention (as suggested by Moore et al, 2010). As a result, the scores assessing these different abilities correlate significantly, but the correlation is low because other independent factors also contribute to either or both of the abilities. The second context is that the APD test, in itself, requires sustained attention, so that children with poor attention are more likely to obtain poor APD test scores, but the variation in test scores caused by differences in attention has no relevance to the child's AP ability in everyday life. As an extreme example, when conducting an AP test that lasts for 1 hr, only children with the greatest ability to sustain attention would score well on the test. In such an example, a low score on such a test would not be an indication of poor AP ability. The same issue, to a lesser degree, may well be in play for shorter AP tests. The data in this experiment do not enable us to decide between the two contexts underlying interpretation (c).

Our findings are in agreement with previous studies using CPT measures (Riccio et al, 1994; Sharma et al, 2009), which found modest correlations between ASust and performance on APD tests, especially DDT and FPT. On the other hand, our results are in contrast with the findings by Riccio et al (2005) of no significant correlations between their APD test battery and the performance on a *visual* CPT task (Riccio et al, 2005). Overall, it appears that performance outside normal limits on APD tests is often accompanied by, and perhaps caused by, performance outside normal limits on tests of sustained attention. However, abnormal performance on APD tests also often occurs despite sustained attention being within normal limits.

Caveats

The results of this study are applicable to populations like that studied: children whose parents or teachers suspected a hearing loss, listening difficulties, or an AP disorder on the basis of an apparent difficulty in taking in information, or because of poor academic performance without other causes being apparent. The conclusion that there is a significant correlation between the attention and APD scores is also specific to the two APD measures for which this was true: the dichotic digit test and the FPT. Attention may well play no role in some other tests of APD, and this does seem to be the case for the MLD and GIN tests used in this experiment. A limitation of the approach taken is that measurement error on the sustained attention test is not known for children (despite the test being commercially available and its creators describing its test-retest reliability as "excellent"). Measure error in any measure will cause correlations with this measure to be attenuated relative to the correlations that exist between the underlying ability and other underlying abilities. Finally, the only cognitive measures studied in this experiment were nonverbal intelligence and sustained attention. It is possible that other cognitive abilities, especially auditory memory, and possibly other types of attention, could underlie some of the correlations found (such as between APD test scores and reading ability) or that even higher correlations may be found between APD test scores and these other aspects of cognitive ability.

CONCLUSIONS

This study investigated the correlation between APD and multimodal sustained attention difficulties. The dichotic digit and FPT scores were each significantly correlated ($p < 0.01$; $r = 0.25$–0.33) with each of auditory and VSust, as well as with nonverbal intelligence. This trend suggests that performance on these APD tests (which are very frequently used in APD test batteries) may be affected by cognitive deficits, or that both the APD scores and the cognitive scores are affected by some other underlying trait. The small size of the correlations, however, argues against the view that poor AP is merely a reflection of attention deficits. This concept is important to consider because the current treatment and management approaches for the two disorders are very different.

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