DIAGNOSTIC DUPLICITY: AN EYE-TRACK STUDY TO EVALUATE THE DIFFERENTIABILITY OF AUDITORY PROCESSING DISORDER AND SPECIFIC-LANGUAGE IMPAIRMENT

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Abstract

Auditory processing disorder (APD) is a language impairment that exists without any peripheral hearing obstruction; the disorder lies not in that a child cannot hear, but that the child cannot properly interpret what he or she hears. Specific-language impairment (SLI) is diagnosed when a child’s language capabilities are not on par with those expected for his or her age. Controversy exists within the field on whether or not APD deserves its own diagnostic distinction. In this study, seventeen children between the ages of eight and eleven were recruited for language testing in order to evaluate language processing in children with APD and SLI. Test subjects underwent CELF-4, PPVT-IV, TONI-3, and Eye-Tracking, the benefits of which have been proven by research. This is the first study to utilize Eye-Tracking to study a population of subjects with APD. The only observed difference between APD and SLI is a slightly lesser proportion of correct answers, which could be attributed to APD being a more severe form of SLI. The results of this study (ANOVA p < 0.02) reveal that the typology of errors in children with APD and SLI is remarkably similar. APD and SLI may be one and the same.

Keywords: auditory processing disorder, specific-language impairment, Eye-Track, Tobii, audiology, speech-language diagnosis, speech-language etiology, APD, SLI
Diagnosis Duplicity: An Eye-Track Study to Evaluate the Differentiability of Auditory Processing Disorder and Specific-Language Impairment

INTRODUCTION

1. Central Auditory Processing Disorder

1.1. The Problem

In recent years, the amount of documentation and methods of treatment for auditory processing disorders has substantially increased. Some may see this upsurge in a positive light, but to others, there is a profound need for refinement and greater specificity in both diagnosis and treatment. Furthermore, the definitions for various auditory disorders overlap, and the means of classification are troublingly complex. Oftentimes, when dealing with school-aged children, intervention is neglected based on numerous shortcomings in the test battery (American Speech-Language Hearing Association, 2005; Dawes and Bishop, 2007; Deevy and Leonard, 2004). One of these disorders, central auditory processing disorder (CAPD), also known as just auditory processing disorder (APD), is in fact not due to any peripheral hearing impairment. The nature of the disorder refers to the manner in which, qualitatively, the central nervous system (CNS) utilizes auditory information. It is not that one cannot hear; rather, the brain of one afflicted by CAPD interprets the auditory information in a manner other than that which was modally intended.

1.1.2. Difficulties and Symptoms

In children, CAPD often leads to learning problems in the school environment. Difficulties as a result of CAPD apply to verbal and nonverbal signals, and affect many functions including speech and language. These difficulties may include sound localization and lateralization, auditory discrimination, auditory pattern recognition, temporal aspects of audition, including: temporal resolution, temporal masking, temporal integration, temporal ordering, auditory performance decrements with competing acoustic signals, and auditory performance decrements with degraded acoustic signals. By American Speech-Language-Hearing Association definition, a central auditory processing disorder is an observed deficiency in one or more of the above behaviors (American Speech-Language Hearing Association, 2005). Because of the prevalent controversy surrounding diagnosis and treatment of APD, educational intervention is once again a difficult matter. Without a standardized test battery, many different methods of diagnosis exist and are often dependent upon the independent conclusions of the audiologist.

1.1.3. Discrimination

Many studies have put forth the idea that disorders of auditory perception lead to or function as a cause of learning disabilities (Cacace and McFarland, 1998; Haggerty and Stamm, 1978; Katz and Wilde, 1985; McCroskey and Kiddler, 1980; Pinhiero, 1977; Willeford, 1977). What separates CAPD from most other auditory disorders and learning disabilities is the fact that CAPD does not result from higher order language, cognitive, or related factors, and is a deficit in processing of auditory stimuli. One topic of particular debate is the fact that CAPD is considered modality-specific. Many diagnostic criteria of CAPD require that a perceptual deficit be demonstrated exclusively in the auditory system (American Speech-Language Hearing Association, 2005). The scientific community is yet to come to consensus on definition, identification, treatment, and intervention of CAPD. In its most basic form, auditory processing can be seen as "what we do with what we hear" (Katz, et al., 1992), and CAPD a disorder in the processing thereof without any peripheral hearing impairment.

1.1.4. Testing and Diagnosis

There is no universally accepted method of screening for CAPD; however, it is evident to parents, teachers, and peers when a child is afflicted by such a speech-language disorder (American Speech-Language Hearing Association, 2005). Though the child is able to hear without any impairment, the audio is not properly processed neurologically. A word may be interpreted as another term starting with the same letter, or starting with the same syllable. As previously stated, these difficulties apply to both verbal and nonverbal signals. CAPD is considered to be a "modality-specific perceptual dysfunction," which means that these difficulties will not apply to cognitive,
high-order functions such as language-based or attentional problems (Cacace and McFarland, 2005). In a school environment, the effects of CAPD can be extremely detrimental. Of course, a careful and accurate diagnosis must be performed to confirm that the disorder is in fact CAPD. At the current time, one of the most popular tests for identifying an auditory processing disorder in a child in America (testing varies in other English-speaking countries due to accentual bias) is the SCAN-C test. This test assesses the perception stage of auditory processing in children between the ages of five and eleven, asking the child to repeat certain words or phrases presented to him or her. The test consists of two separate parts, each focusing on two subtests: Filtered Words and Auditory Figure Ground, and Competing Words and Competing Sentences. In the first section, the stimulus item is distorted to make it harder for the child to hear and discriminate. In the second section, words are presented simultaneously, or in a dichotic manner. Concerns have been voiced that this test is solely applicable to speakers of American English, and thus there still exists no universal standard for assessing CAPD (Cohen, et al., 2005).

1.1.5. Treatment

At the present time, there is no certain remedy for CAPD; however, methods of treatment do exist to better the life of the child. It must be noted that the success of these methods of treatment will vary by the child, and that there is no panacea for CAPD. Some clinicians may suggest environmental modifications, such as various electronic devices, that improve the access the child receives to auditory information. Other compensatory strategies assist the child in strengthening higher-order language processes in order to overcome the difficulties presented by the auditory disorder. Amelioration of the disorder can only be achieved by intervening in such a way as to allow the child to become an active participant in his or her communicatory success.

1.2. Specific-Language Impairment

1.2.1. The Problem

Like many speech-language disorders including APD, the diagnosis of specific-language impairment (SLI) is rooted in exclusionary criteria. As scientific research into speech-language disorders is still relatively young, definitions of disorders based on exclusion historically have arisen from early definitions of childhood aphasia (Aram, et al., 1992; Benton, 1964; Eisenson, 1972; Tomblin, et al., 1996). As research progressed, language disorders were differentiated from autism, then from each other, and then finally from other neurological conditions, based on development, impairment, and manifestation (Schwartz, 2009). Furthermore, a diagnosis of SLI requires that a discrepancy be evaluated proving the existence of a nonconformity between the child’s achieved language status and some standard of expectation for the child’s language status. In the scientific community, coming to an agreement on the demonstration of a significant language discrepancy tends to conjure up a slight degree of discord.

1.2.2. Difficulties and Symptoms

From an early age, difficulties and language deficits are prominent in children affected by SLI. Though a baby’s first word is often a crowning moment for his or her parents, the family of a child with SLI will most likely have to wait longer than the average family for a first word to emerge. These children have limited vocabularies and demonstrate particular difficulty with verbs, especially those having to do with physiological conditions (Johnston, et al., 2001). Verb morphology is often restricted in numerous ways, such as producing solely a bare stem infinitive form of a verb (e.g. the boy run to the store). Difficulty seems to increase directly with syntactic complexity. Long-distance dependencies, such as antecedents and wh-questions (such as “who,” “what,” “where,” etc.), are oftentimes prone to comprehension difficulties (Deevy and Leonard, 2004). Much of this research has additionally been conducted with children with SLI who speak languages other than English and it appears to be a global deficit (Håkansson and Hansson, 2000; Schwartz, 2009).

1.2.3. Discrimination

SLI is considered an exclusive language disorder, meaning that it is a standalone impairment not in the presence of any hearing loss or adverse neurological condition. Approximately 7% of the population is affected by SLI, and current research has demonstrated a convincing degree of possible genetic transmission (Tomblin, et al., 1997). Children
afflicted by SLI demonstrate limitations in general auditory and speech perceptions, along with deficits in central cognitive domains including memory, attention, and executive functions (Schwartz, 2009). Though the process of linking these limitations to SLI remains controversial, it is clear that their exact nature must be discovered in order to determine the most logical method of intervention to better the lives of children with this disorder.

1.2.4. Treatment

At the present time, intervention is one of the least researched aspects of SLI. Current means of intervention are primarily grammatical studies disguised as play. Various means of pedagogy exist, with some encouraging the use of the child’s parents as the primary intervention agents, while others encouraged a clinician-only approach (Fey, et al., 1997; Kaiser and Hancock, 2003). In addition, a piece of commercial software entitled Fast ForWord claimed to have a positive impact on children’s language age scores, though this data has recently been refuted by independent studies (Cohen, et al., 2005; Friel-Patti, et al., 2001; Gillam, et al., 2008).

1.3. Developmental Implications

Parents of children with learning disorders will often apply for what is often known as a 504 educational plan (Section 504 of the Rehabilitation Act of 1973). Students receiving accommodations through a 504 plan may be placed in an alternative classroom, receive extra time on examinations, or receive special education services, etc. In theory, a parent must simply write a written request for a 504 plan to his or her child’s school in order to navigate the standardized qualification process; however, children with SLI and APD may have a significantly more difficult experience receiving proper accommodations than children with ADHD, which is profoundly well-researched.

According to current legislation, to qualify for a 504 plan, a student must be demonstrated to “(1) have a physical or mental impairment that substantially limits one or more major life activities; or (2) have a record of such an impairment; or (3) be regarded as having such an impairment” (“Protecting Students with Disabilities”). As a result of the high-frequency of ADHD diagnoses in the current generation of school-aged children, especially notable when compared to SLI and APD, ADHD may be instantly seen as an impairment to major life activities as noted above, whereas SLI and APD require further investigation before a determination can be made.

1.4. Similarities between APD and SLI and Other Speech-Language Disorders

Both APD and SLI are characterized by a strikingly ambiguous definition of exclusion. Researchers cannot say what these disorders are – but they can say what they are not, in order to separate them from other perceptual impairments and hearing deficits. One proposal maintains that children with SLI have significant deficiencies in procedural memory (how something is done), and that when procedural memory is lacking, declarative memory (rote facts not generated by rule) will compensate. This means that aspects of language that are usually processed by a rule-based system, such as the regular past tense, will instead be produced on a case-by-case basis with no system of procedure (Schwartz, 2009). This component of language processing, along with many others, can be analyzed through a technique known as Eye-Tracking.

Given that 7.42% of the population of the Midwestern United States is afflicted with a speech-language disorder, it is shocking and concerning that the general public’s awareness is so minimal (Edwards and Munson, 2009). For such a prevalent hardship, it is bewildering to consider the little body of research surrounding the treatment of speech-language disorders.

Though only proposed in 2004, the “quadrant system” put forth by Bishop and Snowling to describe and distinguish between and among sub-groups of children with SLI and dyslexia (Figure 1) has been readily applied to also model APD and ADHD [Figure 1]. Researchers have acknowledged the fact that the two have overlapping symptomology; however, professionals claim to use behavioral indicators to distinguish between the two. Figure 2 displays the results of a behavioral analysis of APD and ADHD simultaneously to highlight the similarities between what was thought to be their defining difference (Chermak, et al., 1999) [Figure 2]. The suggestion that what textbooks
label as two separate disorders may actually be the same disorder seems to have resulted from the re-conceptualization of language disorders in the early 2000s. “Developmental dyslexia and specific language impairment (SLI) were for many years treated as distinct disorders but are now often regarded as different manifestations of the same underlying problem, differing only in severity or developmental stage” (Bishop and Snowling, 2004).

2. MATERIALS AND METHODS

The Tobii 1750, the machine used to perform Eye-Tracking, is a device utilized for both market and scientific research and uses infrared scanners to trace the path of one’s eyes as he or she views a digital computer screen. Eye-Tracking has never before been administered to children with APD for the purpose of language processing evaluation. The Tobii 1750 is enclosed in a soundproof room consisting of a comfortable chair for the subject, the equipment itself, and a chair for the experimenter to press the button corresponding to the subject’s response to each on-screen prompt.

“Eye tracking works by reflecting invisible infrared light onto an eye, recording the reflection pattern with a sensor system, and then calculating the exact point of gaze using a geometrical model. Once the point of gaze is determined, it can be visualized and shown on a computer monitor. The point of gaze can also be used to control and interface with different machines. This technique is referred to as eye control” (“What is Eye Tracking?”).

The experiment was designed using a program called E-Prime and progresses fluently without intervention by the experimenter, whose only task besides monitoring the experiment is to press the button of the response that the subject chooses. It consists of a brief set of trial prompts followed three sets of forty prompts posed on screen. For each prompt, a pre-recorded preamble is played over the speakers introducing the pictures on screen. An example preamble might say, “Here are some chickens and some balls.” Then four pictures will appear on the screen with a calibration cross in the middle. The prompt might be, “The chicken on the ball is brown”, and then the child will respond verbally with the number of the response choice that he or she chooses. One of the four pictures is the correct response (a brown chicken on a ball), one is a hierarchical error (a chicken on a brown ball), one is a preposition-change error (a ball on top of a brown chicken), and the other is a reversal error (a brown ball on top of a chicken). In addition to a predicate attachment question such as the one just described, two different kinds of reflexive questions were included in the experiment. One of them contained a preposition in an attempt to add more information to the subject’s working memory, and the other did not contain a preposition.

A total of seventeen children between the ages of eight and eleven were recruited for this study according to each of the following groups: auditory processing disorder (APD), specific-language impairment (SLI), and typical language development (TLD). There were three children in the APD group, two of whom were female and one of whom was male; six children in the SLI group, four female and two male; and eight children in the TLD group, four female and four male. The children were recruited using various online and e-mail ads, phone calls to former subjects, and flyers posted in various audiologists’ offices and around local parks. To evaluate language processing in these groups, two standardized language diagnostic tests were administered, in addition to a standardized non-verbal intelligence test, a screener evaluation for APD, and an Eye-Track analysis. The main data that was utilized for this study comes from the Eye-Tracking, while the other tests serve primarily to qualify the subjects for the study (by verifying their status as typically developing or language-impaired) and additionally to further interpret the data.

The children each underwent four separate tests for a total of approximately three hours: Clinical Evaluation of Language Fundamentals 4 (CELF-4), Peabody Picture Vocabulary Test IV (PPVT-IV), Test of
Nonverbal Intelligence (TONI-3), and Eye-Tracking. The SCAN-C-R was administered to confirm the presence of APD in all of the subjects in the APD group. For the purposes of this study and based on principle, a child is determined to fall into the SLI group if he or she scores more than 1.25 standard deviations below the mean on any two subsections of the CELF-4 assessment. Informed parental consent and child assent was gained prior to beginning the testing.

3. RESULTS
3.1 Behavioral Analysis

Figure 3 is an analysis of the behavioral data produced from the Eye-Tracking component of the study [Figure 3]. This behavioral data tells us if the child responded correctly or incorrectly to the prompts during the testing.

Each child was given a total of 120 statements – to which they would have to determine the corresponding picture on the screen – in three segments of forty prompts with a short break (a minute or two for the child to stretch) in between each. Three different kinds of statements were posed, in no specific order, to the child: predicate attachment, reflexive, and reflexive with preposition. A predicate attachment prompt would follow the format of “The chicken on the ball is brown,” while a reflexive prompt would be “The girl is washing herself,” and the reflexive with preposition prompt would be “The man on the ladder is looking at himself.”

As seen in Figure 3, errors were not an uncommon occurrence for any group in the Eye-Tracking. As each prompt had four possible choices, the three possible errors were hierarchical, preposition change, and reversed. By analyzing the type of errors committed most often for each prompt, we can understand how the language processing occurs in children of all three testing groups. As explained earlier, if the prompt is “The chicken on the ball is brown,” the child may respond incorrectly with a hierarchical error (a chicken on a brown ball), a preposition-change error (a ball on top of a brown chicken), or a reversal error (a brown ball on top of a chicken). Figure 4, Figure 5, and Figure 6 analyze the typology of errors for each of the three groups [Figure 4] [Figure 5] [Figure 6].

3.2. Gaze Analysis

A repeated measures, mixed-model ANOVA was performed on the data for the two experimental groups and the control. As a result, Figure 7 was computed in reference to the proportion of looking times by each of the groups at the correct vs. error answer choices [Figure 7].

The results are divided into prompt class in order to allow the results to be analyzed in respect to the amount of load placed on the working memory. F-values test the fact that the means are significantly different between groups, while P-values are the observed significance of this difference. As opposed to the behavioral data, the gaze data analyzes the children’s eye-movements between answer choices in response to the audio prompt.

4. DISCUSSION

Both of the language-impaired populations demonstrate staunch differences from the control group. Clearly, a cascading effect of correct answers is evident in each of the subject groups (Figure 3). The fact that the amount of correct answers decreases across the three categories of prompts, and that this decrease remains constant across the three populations, implies there is a lesser working memory load on the predicate attachment prompts, followed by the reflexive prompts, and then finally the reflexive with preposition prompts bear the heaviest working memory load. In many different ways, the children with APD demonstrate similarities to the children with SLI; however, it must be noted that the APD group does have a lower percentage of correct answers than the SLI group.

At first glance, many of these errors vary noticeably between the control group and the two language-impaired populations. For the base working memory load prompts (the predicate attachment and reflexive series), the majority of errors are preposition errors for the TLD group, while for both of the language-impaired groups, the majority of errors are hierarchical errors (for predicate attachment) and reversal errors (for reflexive). A hierarchical error suggests that the subject’s memory did not
connect the subject of the sentence, ablated by the preposition, with the description at the end of the prompt. Instead, if the subject had heard “The chicken on the ball is brown,” the sentence was processed simply in the order it was received – producing a chicken on a brown ball. It makes sense that a reversal error would take place of a hierarchical error in reflexive prompts, being that the order of the sentence changes and a reversal error would occur if the sentence were to be incorrectly processed in the order it was received. What this may suggest is that the procedural memory is not as ready or equipped to process complex sentences or phrases with antecedents in children with language impairments.

In all three of the groups, reversal errors were the most common errors for the reflexive with preposition class. This suggests that this type of statement overloaded the working memory of even the control group, and thus the sentence was incorrectly processed in the order it was received.

For the most part, the typology of errors in children with APD and SLI were remarkably similar. If two groups of children with different disorders exhibit the same difficulties in language processing, and the definitions of both disorders are based on the nature of these difficulties, then it can be inferred that proper diagnosis of these disorders might be rendered difficult – if there even are two disorders at all. One thing that can be definitively stated from the data is that the two language-impaired groups are readily distinguishable from the control group; however, the language-impaired groups’ typology of errors is too similar for them to be distinguished from each other.

In terms of gaze data, the children across groups had similar proportions of overall gaze time toward the correct pictures for the short sentences with reflexives and for the predicate attachment sentences. However, for the long sentences with reflexives, which have a greater working memory load, the children with APD and with SLI spent proportionally less time than the children with TLD looking at the correct picture; F(2,14) = 4.89 p < 0.02. The portion of looking time towards the incorrect pictures was also examined. For the short reflexive sentences, there were no differences among the groups in their looking time towards the error pictures; F(6,24) = 0.76 p > 0.05 and F(6,24) = 1.3 p > 0.05, respectively. Even so, there was a small trend for the children with APD to look longer at hierarchical pictures than did the children in the other groups. For the long reflexive sentences, there was a significant difference in the pattern across groups; F(6,42) = 2.8575 p < 0.03. This was caused primarily by the SLI children who looked at reversed pictures longer than at hierarchical pictures, which were, in turn, looked at longer than the predicate pictures. Thus, the SLI children were similar in most respects to the APD children, with a hint of a possible distinction.

The results of this study suggest that there is no surefire method to distinguish between APD and SLI; however, it is possible to distinguish language-impaired from the control group. The proportion of correct answers was significantly less for both of the language-impaired groups. The margin between the control and the experimental groups grew with the increase in working memory brought about by different prompt types. From the data collected, the only observed difference between APD and SLI is a slightly lesser proportion of correct answers, which could be attributed to APD being simply a more severe form of SLI. The difficulties, as assessed by the error analysis graphs (Figures 5 and 6), match up very closely. Both APD and SLI are defined by the difficulties associated with them, and from these data, these difficulties appear to be identical. Judging from the data, it seems implausible to distinguish APD from SLI in terms of difficulties with language processing. One other notable piece of analysis is that there becomes a point at which the child’s working memory, regardless of whether he or she was in the TLD, APD, or SLI group, becomes overloaded (reflexive with preposition) and the processing of the sentence begins to break down.

5. CONCLUSIONS AND FUTURE WORK
Considering the limited research currently surrounding the exact nature and forms of treatment of speech-language disorders, and the potential similarities among the disorders, there is an imperative need for further research.
The implications of proper academic accommodations for children are relative today, and it is necessary to know how to treat children with speech-language disorders so that they get an equal opportunity in the education system. As far as this study goes, more children are being recruited for all three of the control groups for further data collection and fine-grain gaze data analysis.

References


28. “What is Eye Tracking?". Tobii. 7.27.2010


Tables

*Table 1:* ANOVA analysis of the gaze data in respect to each question class.

<table>
<thead>
<tr>
<th></th>
<th>Correct F(2,14)</th>
<th></th>
<th>Error F(6,24)</th>
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<td>Predicate Attachment</td>
<td>Reflexive</td>
<td>Reflexive with Preposition</td>
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<td>NSDBG</td>
<td>NSDBG</td>
<td>NSDBG**</td>
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</table>

NSDBG = No significant difference between groups.

*With no difference between APD and SLI but with TLD difference for both.

**However, there was a trend for the children with APD to look longer at hierarchical pictures than the children in the other groups looked at hierarchical pictures.

***This was caused primarily by the SLI children who looked at reversal pictures longer than hierarchical pictures that were in turn looked at longer than the predicate pictures.
Figure Captions

Figure 1. A two-dimensional model of the relationship between dyslexia and specific-language impairment (SLI) as proposed by Bishop and Snowling in 2003.

Figure 2. A correlative scatter plot of behavioral characteristics of APD and ADHD as presented by Chermak et al. in 2002.

Figure 3: The percentages of correct and incorrect answers in each of the three types of questions asked across the three subject populations.

Figure 4: Analysis of the typology of errors in the Eye-Tracking of the TLD population.

Figure 5: Analysis of the typology of errors in the Eye-Tracking of the SLI population.

Figure 6: Analysis of the typology of errors in the Eye-Tracking of the APD population.
Figures

Figure 1

A: classic dyslexia

B: no impairment

C: classic SLI

D: poor comprehenders

nonphonological language skills

phonological skills
Figure 2
Figure 3

Eye-Tracking: Percentage of Correct and Incorrect Answers

- SLI
  - Correct: 87.78%
  - Incorrect: 12.22%

- TLD
  - Correct: 94.17%
  - Incorrect: 5.83%

- APD
  - Correct: 82.22%
  - Incorrect: 17.78%
Figure 4
Figure 5

Predicate Attachment

Types of Errors: SI

Reflexive

Reflexive with Preposition
Figure 6

Predication Attachment

Types of Errors: APD

Reflexive

Reflexive with Preposition