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EFFECT OF EXTENDING THE RESPONSE WINDOW AND OF SUBJECT PRACTICE ON MEASURES OF AUDITORY PROCESSING IN CHILDREN WITH LEARNING OR READING DISABILITY

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Contributions:
A Study design/planning
B Data collection/entry
C Data analysis/statistics
D Data interpretation
E Preparation of manuscript
F Literature analysis/search
G Funds collection

Abstract

Background: This study studied the effect of extending the response window on the auditory processing (AP) test performance of children with a learning disability or reading disability (LD/RD). The study also investigated whether subject practice affected test performance.

Material and methods: Twenty-four children with an LD and 12 typically developing (TD) age-matched peers between 9 and 13 years of age participated in the study. The participants were administered three AP tests – the dichotic digit (DD), duration pattern sequence (DPS), and random gap detection (RGD) test – under two conditions: standard response window and extended response window.

Results: The performance of the LD group on the DD and DPS tests significantly improved using an extended time window whereas the performance of the TD group did not change.

Conclusions: The findings suggest that some children with an LD achieve higher scores on auditory processing tasks if given a longer response window. This has implications for diagnosis and for providing a potential differential diagnosis tool.

Key words: auditory processing • assessment • response window • learning disability • reading disorder • temporal processing

EFECTOS DE LA AMPLIACIÓN DE LA VENTANA DE RESPUESTA Y LA ACTIVIDAD DEL PACIENTE EXAMINADO EN CONTEXTO DEL PROCESAMIENTO AUDITIVO EN NIÑOS CON DIFICULTADES DE APRENDIZAJE Y LECTURA

Resumen

Introducción: Se examinó el efecto de la ampliación de la ventana (tiempo) de respuesta sobre los resultados de la prueba de procesamiento auditivo (AP) en niños con dificultades de aprendizaje (inglés: *learning disability*) o bien dificultades de lectura (inglés: *reading disability*). El objetivo del estudio fue también comprobar si la experiencia del paciente examinado impacta el resultado de la prueba.

Materiales y métodos: 24 niños con dificultades de aprendizaje y 12 niños con desarrollo típico (inglés: typically developing) en un grupo de edad seleccionado (9-13 años). Los participantes se sometieron a tres pruebas de procesamiento auditivo: test de dígitos dicóticos (inglés: *Dichotic Digit Test*), test de patrones de duración auditiva (inglés: *Duration Pattern Sequence Test*) y test de detección de intervalos aleatorios en ruido (inglés: Random Gap Detection Test), en las siguientes condiciones: ventana de respuesta estándar y ventana de respuesta más larga.

Resultados: Los resultados en el grupo con dificultades de aprendizaje para el test de dígitos dicóticos y el test de patrones de duración auditiva mejoraron de forma considerable cuando se amplió la ventana de respuesta, mientras que la eficacia en el grupo de aprendizaje típico no sufrió cambios.

Conclusiones: Los resultados indican que algunos niños con dificultades de aprendizaje obtienen mejores resultados en caso de tareas relativas al procesamiento auditivo si se les da más tiempo para responder. Dichos resultados pueden resultar de aplicación en el diagnóstico y pueden ser una de las herramientas en el diagnóstico diferencial.

Palabras clave: procesamiento auditivo • evaluación • ventana de respuesta • dificultades con el aprendizaje • dificultades con la lectura • procesamiento temporal

РЕЗУЛЬТАТЫ УВЕЛИЧЕНИЯ ОКНА ОТВЕТА И АКТИВНОСТИ ИССЛЕДУЕМОГО В КОНТЕКСТЕ ПЕРЕРАБОТКИ СЛУХОВОЙ ИНФОРМАЦИИ ДЕТЕЙ С ПРОБЛЕМАМИ С ОБУЧЕНИЕМ И ЧТЕНИЕМ

Изложение

Введение: Исследование касалось воздействия увеличения окна (времени) ответа на результаты теста слухового восприятия (AP) у детей с проблемами в обучении (англ. *learning disability*) или проблемами с чтением (англ. *reading disability*). Целью исследования была также проверка, влияет ли опыт исследуемого на результат теста.

Материал и методы: 24 ребёнка с проблемами с обучением и 12 детей, развивающихся типично (англ. typically developing), в возрастной группе 9-13 лет. Участники прошли три теста слухового воприятия (переработки аудиторной информации) – раздельноушный цифровой тест (англ. *Dichotic Digit Test*), тест оценки длительности последовательности тонов (англ. *Duration Pattern Sequence Test*) и тест обнаружения перерывов в шуме (англ. *Random Gap Detection Tes*t) – в следующих условиях: со стандартным окном ответа и увеличенным окном ответа.

Результаты: Результаты группы с проблемами с обучением в раздельноушном цифровом тесте и тесте оценки оценки длительности последовательности тонов значительно улучшились, когда использовалось увеличенное окно ответа, в то время как продуктивность группы типично обучающихся детей не изменилась.

Выводы: Результаты указывают на то, что некоторые дети с проблемами с обучением достигают более хороших результатов в случае заданий, связанных со переработкой аудиторной информации, если им предоставляется больше времени для ответа. Данные результаты могут использоваться в диагностике и могут быть одним из инструментов дифференциальной диагностики.

Ключевые слова: переработка слуховой информации • оценка • окно ответа • проблемы с обучением • проблемы с чтением • предварительная переработка

SKUTKI WYDŁUŻENIA OKNA ODPOWIEDZI I AKTYWNOŚCI BADANEGO W KONTEKŚCIE PRZETWARZANIA SŁUCHOWEGO U DZIECI Z TRUDNOŚCIAMI W UCZENIU SIĘ I CZYTANIU

Streszczenie

Wprowadzenie: Badaniu poddano wpływ wydłużenia okna (czasu) odpowiedzi na wyniki testu przetwarzania słuchowego (AP) u dzieci z trudnościami w uczeniu się (ang. *learning disability*) lub z trudnościami w czytaniu (ang. *reading disability*). Celem badania było również sprawdzenie czy doświadczenie badanego wpływa na wynik testu.

Materiał i metody: 24 dzieci z trudnościami w uczeniu się i 12 typowo rozwijających się (ang. *typically developing*) w dobranej grupie wiekowej 9-13 lat. Uczestnicy zostali poddani trzem testom przetwarzania słuchowego – testowi rozdzielnousznemu cyfrowemu (ang. *Dichotic Digit Test*), testowi oceny długości sekwencji tonów (ang. *Duration Pattern Sequence Test*) oraz testowi wykrywania przerw w szumie (ang. Random Gap Detection Test) – w następujących warunkach: o standardowym oknie odpowiedzi i wydłużonym oknie odpowiedzi.

Wyniki: Wyniki grupy z trudnościami w uczeniu się w teście rozdzielnousznym cyfrowym i teście oceny długości sekwencji tonów znacznie się poprawiły gdy zastosowano wydłużone okno odpowiedzi, podczas gdy wydajność grupy typowo uczących się nie uległa zmianie.

Wnioski: Wyniki wskazują na to, że niektóre dzieci z trudnościami w uczeniu się osiągają lepsze wyniki w przypadku zadań związanych z przetwarzaniem słuchowym, jeśli dano im dłuższy czas na odpowiedź. Wyniki te mogą mieć zastosowania w diagnostyce oraz mogą być jednym z narzędzi diagnostyce różnicowej.

Słowa kluczowe: przetwarzanie słuchu • ocena • okno odpowiedzi • trudności w uczeniu się • trudności w czytaniu • przetwarzanie tymczasowe

Background

Children with a learning disability (LD) are often diagnosed with auditory processing disorder (APD) [1]. Compared with their typically developing peers, children with an LD or reading disorder (RD) perform poorly on auditory tasks, including discrimination, temporal processing, pattern recognition, and performance with competing acoustic signals [1,2]. The nature of this processing deficit is not completely understood and remains a matter of debate [3]. There is no general agreement about whether children with LDs have APD [4,5]. Numerous studies have reported poor auditory processing (AP) abilities among LD children using AP tests [6,7]. Others have questioned whether children with RDs or LDs have APD [8]. However, researchers do agree that children with LDs exhibit deficits on a range of temporal processing tasks (neural timing deficits) when they are called on to process rapidly presented stimuli, and that these temporal deficits are not restricted to the auditory modality.

The American Speech, Language and Hearing Association has recommended a standardized test battery for AP assessment that includes various subjective and objective tests which measure the functioning of a wide variety of auditory processes [9]. To diagnose an individual with APD, the individual must fail at least two tests with a score below two standard deviations (SDs) of the mean or

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at least one test with a score below three SDs of the mean. During the AP assessment, the audiologist should consider the characteristics of the individual, such as language development, motivation level, attention, fatigue, mental age, native language, socioeconomic factors, and cultural factors. The test duration should also be appropriate for the person's attention, motivation, and energy levels [9].

There are many sensitive and well standardized AP tests, but their validity remains questionable [10]. A valid test is one that measures accurately what it purports to measure. In the field of AP, it is presumed that AP tests measure central auditory dysfunction. However, AP tests have also been reported to be sensitive measures of attention [11], working memory [12], and learning abilities [13]. This relationship might explain the high comorbidity of APD with attention deficit hyperactivity disorder (ADHD), LDs, and language impairment (LI).

Performance on AP tests varies with task complexity and practice. Most AP tests are rapid and have short response windows, and scores on these tests can be affected by lapses of attention [14]. Test stimuli with more items and shorter response windows add additional working memory and motor demands. Furthermore, performance improvement with practice on a backward masking task has been reported [15]. Children with LDs require more practice to become familiar with a task [16]. Considering the variation in the amount of practice required, and the memory and motor demands of a particular AP test, performance on each test differs among participants. However, the extent to which working memory and motor demands contribute to performance on AP tests is not yet clear. Sharma et al. [1] studied the nature of AP deficits among children with language and/or reading difficulties and also investigated the link between AP, sustained attention, and short-term memory. They reported that LDs and reading disorders (RDs) co-occurred with APD and that attention and memory influenced performance on some of the auditory tasks but only explained a small amount of the variance in scores.

Some children with LDs fail AP tests because of non-auditory factors (task complexity, rapid presentation of stimuli, and high attentional and working memory demands) and not because of a deficit in the neural processing of the auditory stimuli [14]. It has been reported that children with LD can process better with slower speech tests [17] which facilitate real-time AP [18].

The rapid nature of AP tests, coupled with the linguistic demands of many of them, increase the likelihood that children will fail at least two tests and be diagnosed with APD. The ASHA guidelines emphasize that APD reflects a deficit in processing auditory stimuli (modality specific) and is not due to higher-order language, cognitive, or related factors [9]. Therefore, AP tests need to be administered in a way that minimizes the influence of these higher-order cognitive functions. This requirement underscores the need to develop comprehensive assessment procedures that accommodate children with LDs by reducing the confounding effects of higher-order processing. Thus, it is necessary to modify AP assessment procedures for children with LDs to differentiate children who actually have difficulty processing auditory information from those whose processing difficulty is the result of the attentional, memory, and linguistic demands of the tests.

The purpose of the current study was to investigate the effect of extending the response window on the AP test performance of children with an LD/RD. This study also looks into whether children might perform better on the second half of AP tests than on the first half. Evidence in the literature suggests that the performance of children on AP tasks improves in subsequent administrations of the tests. Children with dyslexia have been reported to perform better with practice on intensity and frequency discrimination, gap detection, and time order judgment tasks [19]. Similarly, Marler et al. [15] reported that children's scores on backward masking tasks improved with practice. The changes in performance with practice in both studies were measured over time in multiple sessions.

Material and methods

Participants

Two groups of children participated in this study. The first group was composed of 24 children (M=18, F=6) who were previously diagnosed with an LD. These children ranged in age from 9.1 to 13.0 years (median age 10.7 years, first quartile 9.65, third quartile 12.00). Thirteen children were diagnosed with dyslexia without ADHD, and 8 were diagnosed with both dyslexia and ADHD. The remaining 3 children showed significant learning problems but were not diagnosed with either dyslexia or ADHD. The second group consisted of 12 typically developing (TD) children (M=7, F=5) between the ages of 9.4 and 12.7 years (median age 10.65 years, first quartile 9.70, third quartile 11.77). All children showed normal hearing sensitivity and could follow the instructions for AP tests. The children who participated in this study were from Mumbai, India. The testing was conducted at the Dhwani Early Intervention Centre, Mumbai. Approval was obtained from the Institutional Review Board at the University of North Carolina at Greensboro; permission to conduct the research was also obtained from the center's authorities. Written consent was obtained from the parents as well as the children who participated in the study after the investigation was fully explained to them.

The inclusion criteria for participant selection were as follows. Each participant had to have or demonstrate:

a) Normal otoscopic examination and normal middle ear function (Type A tympanogram with a peak middle ear pressure between –99 and +50 daPa);
b) Normal hearing sensitivity (hearing thresholds of 15 dB HL or better for frequencies between 250 and 8000 Hz);
c) No medical history of behavioral, emotional, or neurological problems;
d) Normal intelligence level as assessed by an IQ (> 90) evaluation using the Wechsler Intelligence Scale for Children III (WISC III) [20];
e) Normal, or corrected to normal, vision; and

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f) Studying in a school in which English was the primary language of instruction.

The LD group was recruited from intervention centers in Mumbai where services for hearing assessment, speech therapy, special education, and psychiatric and occupational therapy are provided on the premises. These children were assessed and diagnosed with LDs at the B.Y.L. Nair Ch. Hospital and T.N. Medical College, Mumbai. The participants were recruited after they completed the assessment process and were diagnosed with LDs. The LD assessment battery included a patient history, the Woodcock Johnson III Test of Achievement, the WISC III, motor skills assessment, and written communication tests.

The TD group was recruited from private schools in Mumbai. These children demonstrated normal academic performance and were free of LDs and ADHD based on school records.

Procedure and stimuli

The participants were tested in a double-walled, double-floored, sound-treated booth. Pure tone audiometry, immittance audiometry, and the three AP tests – the dichotic digit (DD), duration pattern sequence (DPS), and random gap detection (RGD) tests (under both the standard and extended response window conditions) – were administered in one 120-minute session. The AP tests were pre-recorded on a CD. The CD was played on a Sony CD player and routed through a GSI-61 (Grason-Stadler, Inc.) diagnostic audiometer to TDH-50 earphones.

American normative information was used. The DD and DPS scores were considered 'pass' if the scores were within 2 SDs of the mean (for norms, see [21]). For the RGD, a gap detection threshold of 20 ms or less was regarded as pass [22]. Children who scored 2 SDs below the mean on two tests were classified as having APD [9]. The three tests were administered using the standard test procedure and with a response window extended by 2 seconds. The time-extended test was constructed using Audacity software and recorded on a CD. The three AP tests and two conditions were counterbalanced in terms of their order of presentation.

Auditory processing tests

1) Dichotic Digits (DD): A two-digit dichotic test was administered at a presentation level of 50 dB SL (re: spondee threshold) [23].
2) Duration Pattern Sequence (DPS): The test was administered binaurally at a presentation level of 50 dB SL (re: 1000 Hz threshold) [24].
3) Random Gap Detection (RGD): The test was administered at 55 dB HL binaurally [22].

Data reduction and analysis

Descriptive statistics, including the mean, SD, and median of the scores, were derived for all three tests under both testing conditions. The data was then subjected to statistical testing. A series of 2 (group) ×2 (condition) repeated-measures analysis of variance (ANOVA) was conducted for the three AP tests. The level of significance for the repeated-measures ANOVA was fixed at 0.01. The effect size was measured using eta-squared (η^2). The effect size was considered medium if $\eta^2 \geq 0.13$ and large if $\eta^2 \geq 0.26$. Follow-up analysis was performed using paired *t*-tests to compare the test scores for the standard and extended time conditions. The paired *t*-test analysis was performed for both the LD and TD groups. The level of significance for the paired *t*-tests was fixed at 0.01. The effect size for the paired *t*-tests was measured using Cohen's *d*. The effect size was considered medium if $d \geq 0.50$ and large if $d \geq 0.80$.

Repeated-measures ANOVA was used to compare the first- and second-half test performance. Follow-up analysis was performed using paired *t*-tests to compare the test scores from the 1st and 2nd halves of the test for both the standard and extended time conditions. The paired *t*-test analysis was performed for both LD and TD groups. The level of significance for the paired *t*-tests was fixed at 0.01.

Results

Effect of extended time on AP test scores

Tables 1 and 2 present the means and SDs for the three AP measures (DD, DPS, and RGD) for the LD and TD groups, respectively. The effects of group and condition were analyzed with three 2 (group) ×2 (condition) repeated-measures ANOVA. As expected, the TD group performed significantly better than the LD group on all three measures. On the DD task, the main effect of condition (standard/extended time) was significant, $F(1,34)=26.30$, $p<0.01$, $\eta^2=0.43$, but the group × condition interaction was also significant, $F(1,34)=13.36$, $p<0.01$, $\eta^2=0.282$. The performance of the LD group improved in the extended response window condition, whereas there was no change in the performance of the TD group. A paired *t*-test indicated that the LD group's improvement was significant with a large effect size ($t(23)=-6.64$, $p<0.01$, $d=-1.06$). The effect of condition was significant for the DPS task, $F(1,34)=8.10$, $p<0.01$, $\eta^2=0.19$, indicating that the performance of the participants differed between the two time conditions. However, the interaction between group and condition was not significant, $F(1,34)=1.91$, $p=0.176$. No effect of condition was found for the RGD task.

Differences in scores with extended time

The difference in performance between the standard and extended time conditions was calculated for each participant for the DD and DPS tasks. A 10% change in score was considered a clinically meaningful difference, whereas a 20% change was considered a large difference. For the DD task, a 10% change (10% difference from the mean score for the standard time condition) was equivalent to 7.1%; a 20% change was equivalent to 14.2%. For the DPS task, a 10% change was equivalent to 4.3%, and 20% was equivalent to 8.6%. On the DD task, 16 participants showed at least a 10% improvement, and 11 participants showed a 20% or greater improvement in performance. No participant showed a reduction in score of 10% or more. On the DPS test, 17 participants showed at least a 10% improvement, and 16 participants showed at least a 20% increase in scores in the extended time condition compared with

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Table 1. Effect of an extended response window on AP test scores of the LD group

	DD		DPS		RGD	
	Std	**Ext**	**Std**	**Ext**	**Std**	**Ext**
Mean	71.51	80.83	43.33	50.55	68.28	68.63
Median	71.87	83.12	41.66	51.66	81.94	80.55
SD	10.12	11.25	19.26	23.84	28.71	28.76
N	24	24	24	24	24	24
p	**0.000***					

Values in bold and marked with an * indicate statistical significance $p \leq 0.01$. AP – auditory processing; LD – learning disability; DD – dichotic digit; DPS – duration pattern sequence; RGD – random gap detection; SD – standard deviation; Std – standard time; Ext – extended time.

Table 2. Effect of extended response window on AP test scores of the TD group

	DD		DPS		RGD	
	Std	**Ext**	**Std**	**Ext**	**Std**	**Ext**
Mean	90.93	92.50	83.05	85.55	92.12	91.66
Median	92.5	91.87	81.66	86.66	95.83	97.22
SD	4.58	2.76	7.71	8.32	9.16	9.69
N	12	12	12	12	12	12
p	**0.155**					

Abbreviations as per Table 1.

Table 3. Number of participants who showed a significant change in performance between the normal and extended response window conditions

LD (N=24)	Scores	≥10%	≥20%
DD	Increased	16	11
	Reduced	0	0
DPS	Increased	17	16
	Reduced	6	4
Both DD and DPS	Increased	11	7
	Reduced	0	0

the standard condition. Six participants showed at least a 10% reduction in DPS score, and 4 participants showed at least a 20% reduction (Table 3). Further analysis was performed to measure the number of participants who showed a change in scores for both the DD and DPS tests. Eleven participants showed at least a 10% increase on both tests, and 7 participants showed at least a 20% increase. Because the test order was counterbalanced, the children with LD who performed better under the extended time condition were not the same ones who received this condition second in the test order.

AP test failure and APD diagnosis

Based on their test score and reported age-specific norms, the performance of the children in the LD group on each AP test was classified as pass or fail for both the standard response window and extended response window conditions. More participants failed the DD and DPS tests in the standard response window condition than in the extended response window condition. The RGD test failure rate was the same in both conditions. Twenty-one children failed at least two tests in the standard condition compared to only 14 for the extended response window condition (a difference of 7 children).

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Effect of practice on AP test scores

Scores from the first and second halves of the three AP tests were compared to determine whether there was any learning or practice effect in the two groups and under the two conditions. Descriptive statistics for the scores on the first and second halves of the three tests for the LD and TD groups and for the standard and extended time conditions were measured. A series of 2 (condition: standard/extended) ×2 (test part: first/second) ANOVAs did not identify any significant differences in scores for the TD and LD groups (for the two parts of the three tests under the two conditions).

Discussion

The present study examined whether extending the response window of three AP tests would significantly improve the performance of children with LDs or their typically developing peers. Potential differences between the first and second halves, which might reflect a learning or practice effect, were also examined for the three AP tests.

As expected, the TD group performed significantly better than the LD group on all three AP measures. These findings are consistent with a large body of research showing that children with LDs perform below age level on measures of temporal processing and dichotic listening [1,7]. Comparison of the standard and extended time conditions revealed only one significant difference: the DD task performance of the children in the LD group improved significantly in the extended response window condition. Subsequent analyses of individual subject data showed that the DD and DPS test performance of more than half the children with an LD improved under the extended response window condition. For the DD and DPS tasks, about two-thirds of the children showed a clinically significant (≥10%) improvement in performance. Eleven out of 24 children showed a clinically significant improvement on both the DD and DPS tests. A large improvement (≥20%) in score was observed in 11 participants for the DD test and in 16 participants for the DPS test. Seven participants showed a large improvement on both the DD and DPS tests. Scores on the RGD test did not change with the extended time. Comparing the children's score with age-specific norms also revealed a difference in the test failure rate. Fewer participants failed the AP tests under the extended response window condition than under the standard response window condition.

The findings of this study indicate that the extended time helped children with LDs improve their scores on two out of three AP measures. The findings also suggest that some children with LDs achieve higher scores if they are given more time to complete the task. This may have implications for diagnosis and management and could provide a potential differential diagnosis tool. Not coincidentally, the two tests that showed improvement, the DD and DPS tests, had higher processing demands than the test that showed no improvement, the RGD test. Children with LDs have been shown to have deficiencies in attentional, memory, and language processes [4,14].

Each AP test has different auditory, language, attentional, and motor demands. In the DD test, attention must be switched between the two ears, and four digits (words) must be repeated after each test item. The DPS test requires that three tones be labeled. In contrast to the DD test, which uses speech, the DPS test uses tones, which are non-linguistic stimuli. However, responses on both of these tests require 3 or 4 words.

The test with the greatest processing demands, the DD test, was associated with the largest change in performance in the extended time condition. The test with the fewest processing demands, the RGD test, showed no change in performance in the extended time condition. In the RGD test, a participant must listen to a tone (non-linguistic) and respond with a single word, saying 'one' or 'two'. The combination of fewer stimuli per test item and a shorter response length (one word) makes the test less demanding. Therefore, a significant change in score with extended time was not observed for the RGD test. The largest change in score with the extended time was observed for the test with the greatest demand (the DD test); the next-largest change in score was observed for a test with fewer demands (the DPS test). AP tests are known to be sensitive to non-auditory factors, such as attention and working memory [10–12]. It is difficult to remove these factors completely from the behavioral AP assessment procedures; however, they can be minimized. As the ASHA 2005 position statement on APD notes, APD reflects a deficit in the neural processing of auditory stimuli that is not due to deficiencies in higher cognitive or linguistic abilities. Reducing the higher-level language and cognitive demands of AP tests will improve the diagnostic sensitivity of these tests in identifying individuals with APD.

There was no evidence of an effect of learning or practice when the first and second halves of the test items were compared. This finding is not surprising given that previous research [15,19] has shown that learning and practice effects occur only when AP tests are presented over multiple days and intervals. Due to the small sample sizes of both groups in this study, the application of these findings to a larger population of children with LD may be limited. Future studies may include a larger sample size and observations that are performed longitudinally.

Conclusions

The findings of this study confirmed that extending the response window significantly improved the performance of children with LDs on two out of three AP measures. Using an extended response window may reduce the cognitive and linguistic confounds and could help differentiate children who have APD from those who perform poorly on AP measures due to cognitive and linguistic demands. No difference in performance was found when the two halves of the AP tests were compared. This finding could indicate that for LD children, experience with half the total number of test items is not enough to improve their performance.

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