JSLHR, Volume 40, 694–703, June 1997

Vocal Reaction Times of Children With CAPD, Age-Matched Peers, and Young Adults to Printed Words

Paul A. Dagenais
Michele Cox
University of South Alabama
Mobile

M. Helen Southwood
Stephen C. Smith
University of Alabama at
Birmingham

The purpose of this study was to determine if there were differences between children identified in a clinical setting as having Central Auditory Processing Disorder (CAPD), an age-matched peer group, and young adults when tested using a vocal reaction time (VRT) format. The children with CAPD were matched by gender and age to peers between the ages of 8 and 10 years. All speakers were presented visually with printed third-grade-level one- and two-syllable words (e.g., *boy*, *mother*) as well as the syllable "uh." Participants spoke each word according to the criteria of seven separate conditions, which included immediate naming tasks (0 s delay), a short delay before speaking (M = 1.5 s), and a longer delay before speaking (M = 4.0 s). Speakers' VRTs were measured, and production errors were recorded. All speakers took longer to respond in the immediate-response conditions than the delayed-response conditions. Statistically significant differences were found for the immediate-response conditions, with means for the children with CAPD reflecting slower performance than that of their peers. The peer group was slower than the adults. For the delayed conditions, both groups of children responded with significantly longer VRTs than the adults. The two groups of children did not differ for these tasks. The children with CAPD produced a significantly greater number of errors than their peers, specifically for the long-delay conditions. The adults showed no performance differences across the immediate response conditions nor across the delayed conditions. These results suggested that children with CAPD may have processing difficulties with visual stimuli.

KEY WORDS: central auditory processing, central auditory processing disorder, reaction time, vocal reaction time

Central Auditory Processing Disorder (CAPD) is defined as an observed deficiency in one, or more, of the auditory functions of sound localization and lateralization, discrimination, pattern recognition, ability to process competing or degraded acoustic signals, as well as such temporal aspects as masking, integration, temporal resolution, and ordering (Task Force on Central Auditory Processing Consensus Development, 1996). Martin (1994) further states that individuals with CAPD typically have normal intelligence and normal hearing sensitivity. Although this general definition is accepted by most audiology and speech-pathology professionals, there is still much discussion and controversy over the exact dynamics of central auditory processing and thus CAPD (Bloom & Lahey, 1978; Cook et al., 1993; Katz, Stecker, & Henderson, 1992; Rees, 1981; Task Force on Central Auditory Processing Consensus Development, 1996). This controversy is reflected in the lack of conformity in defining characteristics of CAPD. In addition to

 1092-4388/97/4003-0694

problems with sequencing and organization of thoughts and speech, Katz et al. (1992) included difficulties with reading, writing, spelling, and poor penmanship as direct symptoms of CAPD. Howard and Hulit (1992) stated that only expressive, not receptive, language suffers as a result of CAPD. Rees' (1981) statement that the CAPD label often is used incorrectly as a catchall diagnosis for unrelated learning, language, articulation, and reading problems continues to be supported (Martin, 1994).

It is difficult to determine the particular characteristics of CAPD that may differentiate it from other disorders. It has overlapping symptomatology with other disorders, such as attention deficit hyperactivity disorder (ADHD), language disorders, and learning disorders (Cook et al., 1993; Oberklaid, Harris, & Keir, 1989). Short-term memory problems also have been included by some researchers as symptoms of CAPD (Oberklaid et al., 1989). However, it has not been determined if CAPD has a cause/effect relationship with these disorders or merely coexists with them.

It may be possible that an auditory processing problem is actually one affected modality of a broader processing disorder (Task Force on Central Auditory Processing Consensus Development, 1996). Testing through the auditory channel alone can show only those central processing problems that are auditory in nature. Current diagnostic procedures that employ tests with primarily auditory input as stimuli do not account for the possibility of other affected modalities (Stecker, 1992). Because other stimulus-response paradigms have not been adequately explored in the diagnosis of CAPD, it may be possible that CAPD is not exclusively an auditory processing disorder. If the presence of other processing deficits is identified or eliminated, a more distinct definition of CAPD could be determined.

One way to evaluate further the scope of CAPD would be to add a nonauditory task. An example would be timing a verbal response to orthographically presented stimuli. It is known that children with CAPD typically take longer to respond to auditory stimuli than children without CAPD (Keller, 1992). In contrast, how well children with CAPD produce verbal responses to orthographic stimuli as compared to their peers is unknown.

Reaction time is defined as the amount of time between presentation of a stimulus and a speaker's response. Typically, reaction time is not measured during a CAPD evaluation. However, the use of reaction time measures might be of benefit in determining the presence of CAPD. Webster and Ryan (1991) stated that reaction times, whether manual or vocal, are dependent upon neuromotor variables, information processing, and demand characteristics of the task. However, authors do not agree always as to what reaction times are measuring when used to assess the processing of responses to stimuli. For example, Webster and Ryan (1991) used manual reaction times to differentiate people who stutter from those who don't when the tasks had differing information-processing complexities. They found that differences between speaker types were not dependent upon decision complexity but upon aspects of spatial and temporal coordination (i.e., the physical component of the response, not the linguistic complexity, differentiated speaker types). In contrast, Wulfeck (1993) measured manual reaction times of children of two different ages when judging word order and grammatical agreements. Conclusions from this study suggested that the use of real-time paradigms (such as reaction times) would permit a determination of how linguistic forms become more accessible with development. Wulfeck did not report on any attempt to compare her two groups of children on a strictly motor response to account for differences that might be due to differing motor abilities in her children. Differing motor abilities or development could have accounted for her findings.

Fletcher, Smith, and Hasegawa (1985) used a vocal reaction time (VRT) paradigm to determine differences between children with and without hearing impairment in how well they recognized words of increasing phonetic complexity. They interpreted their results of faster VRTs for the children with normal hearing as suggesting that these children had better "central phonetic processing" skills than children with hearing loss.

Edwards and Lahey (1993) measured vocal response times to auditory stimuli for two age groups of children and a group of adults. The stimuli were real words, nonwords, and a 1000-Hz tone. Once the differences for nonlexical responses across ages were accounted for, the authors stated that there were no group differences for the speed of lexical processing. That is, the response characteristic that separated speakers had less to do with central processing than it did with motor programming and execution. This type of finding could be summarized by the statement by Grandori et al. (1994) that VRTs "offer reproducible, reliable, and quantitative information about the operational times required for speech planning and production" (p. 204). Grandori et al. (1994) used VRTs to determine differences in "perceptual, programming and motor execution" of healthy younger and older adults and patients with Parkinson's disease. When comparing younger and older healthy adults, they used an immediate-response reaction time measure and a delayed-response reaction time measure. Because the younger adults did better than the older adults on the immediate-response condition only, Grandori et al. interpreted their results to indicate that the older adults required more "processing" time, not motor execution responding time. The VRTs of the patients with Parkinson's disease were delayed in both conditions.

Sternberg, Monsell, Knoll, and Wright (1978) reported on simple reaction time studies in which the speakers were informed of the utterances to produce but had to wait for a signal to do so. As the identities of the stimuli were known before the actual response was given, Sternberg et al. (1978) proposed that the reaction measures obtained were the result of motor programming and execution, not information processing. They found that when reciting lists of words, listeners' reaction time increased proportionally with the size of the list. They accounted for this by proposing a motor program buffer into which a motor program (and its subunits) would be placed before execution. Once signaled to respond, the execution would be delayed by the amount of time needed to process the entire utterance. The longer the utterance, the more time is needed to process it before the vocalization is made.

Summarizing these findings, it can be said that when responding to linguistic stimuli of varying complexity reaction time disparities across ages may be due to the motor aspect of the tasks when the speaker waits for a signal to respond. When the speaker is presented with a stimulus and is required to respond immediately, some internal processing must be completed that would precede the motor execution. Further, varying the delays before a response is made may indicate what aspect of the response, "internal processing" or "motor complexity," is responsible for the resulting reaction time measure. As CAPD procedures purportedly measure varying aspects of internal processing, it is unusual that response-time paradigms are not used more commonly to assess the general or specific aspects of processing of the acoustic stimuli.

Although studies exist that show differences in vocal response times for adults of different ages and deficits (e.g., Connor & Abbs, 1991; Grandori et al., 1994), there are limited studies that compare the response time differences and accuracy of responses between children and adults. Edwards and Lahey (1993) showed that there were age-related differences between two groups of children and adults for vocal response tasks. Although vocal response times decreased with age, Edwards and Lahey (1993) determined that the differences were related to nonlexical factors. Dagenais, Southwood, and Watts (1995) investigated the differences between normally developing children and adults on vocal response times to orthographic stimuli and manual response times to words presented auditorily. An immediate response format was used. They found that the children had significantly slower manual reaction times to auditory stimuli and that the children made significantly more production errors than the adults on the vocal response task. This suggested that there are differences between children and adults in their abilities to respond quickly and accurately to speech materials. However, the use of only an immediate format limited findings in that it was not possible to suggest whether differences were motor-based or motor-plus-processing-based. Information about the relative response abilities between normally developing children and adults could have implications for evaluating any differences between normally developing children and children with CAPD. That is, comparisons of child performance to adult performance could provide a response range for rating any deficits noted for children identified with CAPD. Differences between normally developing children and those with CAPD might not appear large or relevant when compared to child-adult differences.

This study investigated the possibility that additional, different, or slower processes may be evident in children with CAPD as compared to normally developing peers and adults, and that these differences could be determined using a nonauditory-based modality. A comparison was completed for VRTs between children with CAPD, age matched peers, and young adults using immediate-response and delayed-response paradigms. The number of spoken errors for the orthographic stimuli was also determined. It was expected that the VRTs for the children with CAPD would be slower than their peers' VRTs and that the children with CAPD would produce more errors. It was also predicted that the children with CAPD would evidence greater delays during immediate-response conditions because these conditions would be dependent upon both processing and motor responses for the VRT recorded. If the children with CAPD responded to this nonauditory task with notable delays and errors, it is possible that the CAPD label might be representative of a more central disorder. It was anticipated that both child groups would perform more slowly than the adults.

Method

Speakers

Speakers consisted of three groups of 10: one group of children diagnosed with Central Auditory Processing Disorder (CAPD), a second group of normally developing children who acted as matched controls, and a group of young adult controls. All speakers met the following criteria:

1. Passed a pure tone audiometric screening at 1 kHz and 2 kHz, both at 20 dB HL and 4 kHz at 25 dB HL (ANSI, 1989)

2. Passed a vision screening by correctly identifying letters on a standardized eye chart with a criteria of 20/20 vision

3. No other known physical, psychological, or cognitive problems

4. Normal development as reported by parents or self-reported by the adults

Children with CAPD were chosen from the University of South Alabama (USA) Speech and Hearing Clinic's CAPD program. These children are identified when they are referred to the clinic for a CAP evaluation because of reported academic difficulties that include reading and/or writing problems and difficulty understanding or following directions in the classroom. The typical test battery used to identify CAPD children includes the Staggered Spondaic Word Test (SSW; Katz, 1977), portions of the Willeford Test Battery (Willeford, 1977), Phonemic Synthesis Test (Katz, 1983), and the Screening Test for Auditory Processing Disorders (SCAN; Keith, 1986). Other tests may be added depending upon the particular child. The children identified as having CAPD and who participated in this study failed at least two of the four tests cited. Typically, these children showed left-ear deficits on the SSW, normal- to below-grade scores on the Willeford Competing Sentences test, below-grade scores on the Binaural Fusion test, and below-normal scores for Phonemic Synthesis.

Child peers were matched by age and gender (3 girls and 7 boys) with the children with CAPD. In order to identify any possible CAPD symptoms, the peers were required to pass the SSW (Katz, 1977). Of all possible tests, the SSW was chosen because it is incorporated routinely in the test battery used at the USA clinic. The group with CAPD had a mean age of 8:7 (years:months) (*SD* = 0.66), and the peers had a mean age of 8:9 (*SD* = 0.67). Mean academic grade averages based on a 100-point scale were 92% for the CAPD group and 95% for the controls. The young adults consisted of 10 master-level speech-language pathology students. They were all female and had a mean age of 26.2 years (*SD* = 6.2).

Instrumentation

The instrumentation used to measure VRT was developed in the Department of Rehabilitation Sciences, Division of Speech and Hearing Sciences, at the University of Alabama at Birmingham. The VRT device consisted of an external unit for digitizing speaker responses and an internal timer board (CIO-CTR, Computer Boards, Inc.). The external unit also had a signal processing circuit that acted as a high-pass filter. The filter had a cut-off of 2 kHz, with a 12 dB per octave roll-off. This circuit allowed for amplification of high frequencies so that the system responded relatively evenly to all speech sounds.

Driven by a personal computer (a 386 25-MHz personal computer with VGA color monitor), the instrumentation recorded two time measures: the amount of time from the presentation of a stimulus item on the monitor until the speaker vocalized and the duration of the vocalization. Specifically, when the program presented the stimulus, it also started a counter on the timer board. The speaker responded to the visual presentation by speaking into a microphone, which delivered an analog signal to the external device. When the intensity of the signal from the speaker exceeded the threshold (adjustable by a knob on the front of the unit), a 1-bit analog-to-digital (A/D) converter was activated; and this was detected by the timer board. The board recorded the time of this activation as the VRT. The VRT value was sent to the computer, and all values were stored in a file at the end of the session.

For each condition, speakers had 3 s in which to respond. If a response was not made within this time or the speakers vocalized before the presentation of the stimulus, the computer beeped, initiated a 5-s time-out, and then re-presented the stimulus. The delay between each stimulus presentation was randomized within the limits of 1 to 3 s.

The system was designed to run in three modes. The first mode presented the word to be spoken without any warning or delay condition. This was referred to as the *immediate-response condition*. The second mode was referred to as the *short-delay condition*. For this condition, the stimulus was presented—then removed from the screen. The speaker then spoke the word when a green light appeared on the screen. The delay before the green light was randomly determined and was within the range of 0.75 to 1.5 s. The final condition was the *long-delay condition*. For this, the stimulus was presented, followed by a series of lights (red, yellow, then green) after which the word was to be spoken. The delays between the sequential lights were randomized such that the ultimate range of the delays (across the three-light sequence) was from 2.5 to 4.0 s.

Stimuli

Ten one-syllable and 10 two-syllable words were used as stimuli. These words, listed in Table 1, were of the highest relative ranking for frequency of occurrence in third-grade texts (Carroll, Davies, & Richman, 1971). Each word has a voiced phoneme in the initial position. For each condition, each stimulus was repeated three times for a total of 30 items (3 repetitions × 10 stimuli).

Procedures

The seven conditions were presented in the same order to all speakers and are listed in Table 2. A fixed order of presentation was used in order to present the presumably easier-to-produce one-syllable words before the two-syllable words. In addition, although the

Table 1. Stimulus words used in VRT study.

One-syllable	F	U	Two-syllable	F	U
One	3687	3907.7	Baby	258	132.9
Man	5486	971.4	Winter	242	182.5
Day	1207	937.1	Better	375	361.6
Name	259	629.9	Mother	758	417.7
Land	525	461.8	Answer	353	329.6
Boy	528	454.9	Body	297	295.7
Room	375	324.8	River	239	202.8
Door	445	290.2	Money	367	307.6
Wind	259	240.8	Window	259	150.7
Box	366	207.1	Letter	411	238.2

Note. F indicates frequency of occurrence in corpus of 5,088,721 words (third-grade material only), and U indicates frequency per million words (Carroll, Davies, & Richman, 1971).

Table 2. Description of tasks.

Order	Condition	Description
1	"uh"	Speakers produced "uh" after presentation of a green light.
2	Short delay (0.75–1.5 s), one-syllable word	Speakers were shown the word, but waited for a green light before speaking.
3	Immediate naming, one-syllable word	Speakers produced the word immediately following its presentation.
4	Long delay (2.5–4.0 s), one-syllable word	Speakers were shown the word but waited for a sequence of lights (red, yellow, then green) before speaking.
5	Short delay (0.75–1.5 s), two-syllable word	Speakers were shown the word, but waited for a green light before speaking.
6	Immediate naming, two-syllable word	Speakers produced the word immediately following its presentation.
7	Long delay (2.5–4.0 s), two-syllable word	Speakers were shown the word but waited for a sequence of lights (red, yellow, then green) before speaking.

procedures were not considered tiring, the fixed order would have all speakers experiencing the same fatiguing or learning effects.

Speakers received written and then verbal instructions for the tasks. Before each test condition, they were asked to paraphrase the instructions given for that specific condition. In addition, to verify speakers' knowledge of each stimulus item, they were required to read each stimulus word aloud and use it in the formulation of two different sentences with 100% accuracy. Speakers were tested individually in a sound-treated booth. They were seated in front of the computer monitor and spoke into a microphone placed approximately 2 inches from the mouth. They were told that the printed words would appear on the monitor one at a time. Their task was to say the word quickly and accurately when they saw it (the immediate-response conditions) or after the lights appeared (see Table 2). Practice sessions were completed before all conditions using one-syllable words not included in the corpus.

During testing, speakers' utterances were simultaneously tape-recorded and checked by the examiner for correct and incorrect responses. VRT scores were recorded by the computer. After testing was completed, the examiner again scored all of the tape recordings to establish intrajudge reliability. To ensure interjudge reliability, a second listener scored each tape recording, checking for correct/incorrect responses. Interjudge and intrajudge reliabilities were 100%.

Data Analysis

Data recorded by the computer were stored in individual files for each test condition for each speaker. The program generated means and standard deviations for each stimulus and grand means and standard deviations across stimuli for each testing condition. These grand means were used to determine means and standard deviations for each group for each of the seven conditions. Each data set for each group and condition was examined for possible outliers. Box plot analysis (Norman & Streiner, 1994) was completed to identify data points beyond 2 standard deviations from the mean. After removing any outliers, statistical analyses included two-way and one-way analyses of variance (ANOVA). Post hoc testing used the Bonferoni method, which includes control for any Type I errors when multiple pairwise comparisons are made (Norman & Streiner, 1994).

Results

Results are presented for the speakers' performances on seven experimental conditions. For each speaker under each condition, testing yielded two dependent variables: VRT and the number of total errors (consisting of the number of nonvocalizations plus the number of word substitutions).

Vocal Reaction Times

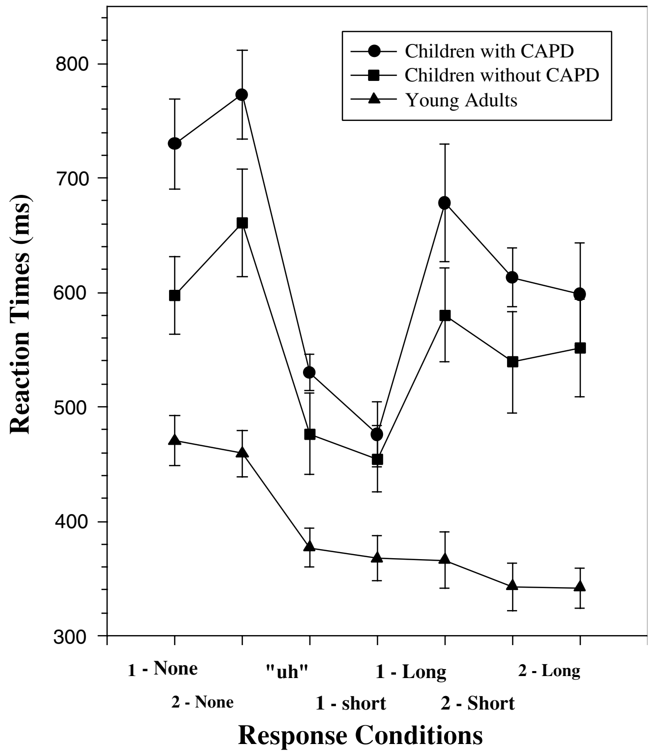
Initial examination of the VRT data indicated several broad standard deviations that suggested the presence of outlier data. Four outliers were found in the data set of the children with CAPD only. Two outliers, one exceeding 2 standard deviations (699 ms) and one below 2 standard deviations (367 ms), were found for the "uh" condition. One outlier (837 ms) was above 2 standard deviations for the one-syllable short-delay condition, and one (332 ms) was below 2 standard deviations for the two-syllable short-delay condition. These outliers were removed from the data sets, and the remaining VRT data were used for the analysis. Means and standard errors are presented in Figure 1. The performances of the two child groups were broadly similar in that immediate naming tasks resulted in longer VRTs than the delayed tasks. The adults had shorter VRTs than both child groups in all conditions.

A two-way analysis of variance (ANOVA; 3 Groups x 7 Conditions) was completed. Results showed significant differences for Group [$F(2, 27) = 20.4$, $p < .01$] and Condition [$F(6, 162) = 34.8$, $p <. 01$], with a significant interaction, $F(12, 162) = 4.0$, $p < .01$. Because of the interaction, subsequent analyses looked at differences within groups and across each condition.

As Figure 1 illustrates, VRTs for the adults were in two different categories: (a) the immediate responses for the one- and two-syllable words, and (b) the delayed responses for both syllable types and the "uh" syllable. A one-way ANOVA showed significant differences across conditions for the adults, $F(6, 54) = 15.1$, $p < .01$. Post hoc testing revealed that the VRTs for the immediate tasks were significantly longer than the other five conditions ($p < .05$). The immediate-task means did not differ from one another. Means for the "uh" condition and the four delayed conditions also did not differ from one another.

As also shown in Figure 1, the mean scores for both groups of children followed similar configurations. For the immediate naming tasks, the two-syllable words had longer VRTs than the one-syllable. Within each group, these tasks had longer VRTs than the "uh" and all the delayed conditions. Of note, there were differences in the response times for the delayed conditions between the two types of words used as stimuli. Specifically, responses for the two-syllable words for both delayed conditions were similar, whereas the responses for the one-syllable words differed depending upon the amount of the delay. The short-delay condition for the one-syllable words had a mean response time that was shorter than both the two-syllable word conditions. For the long-delay condition, the one-syllable words had longer response times than those recorded for both two-syllable word conditions. A one-way ANOVA across conditions for the children with CAPD showed significant differences, $F(6, 54) = 16.8$, $p < .01$. Post hoc testing showed the conditions divided into three significantly different groups ($p < .05$). The means for the one- and two-syllable words in the immediate naming tasks did not differ from one another and were significantly longer than the other conditions. The means for the one-syllable long-delay and

Figure 1. Mean vocal reaction times (VRT) in ms and standard error for the children with CAPD, children without CAPD, and young adults for the test conditions: one-syllable words with no delay (1-None), two-syllable words with no delay (2-None), the "uh" syllable, one-syllable words with a short delay (1-Short), one-syllable words with a long delay (1-Long), two-syllable words with a short delay (2-Short), and two-syllable words with a long delay (2-Long).



both two-syllable delayed conditions were significantly shorter than the immediate-response conditions, did not differ from one another, and were significantly longer than the one-syllable short-delay condition and the "uh" condition. These two final means did not differ from one another.

The child peers also showed significant differences across conditions, $F(6, 54) = 10.5$, $p < .01$. Post hoc testing revealed that the conditions were divided into two groups that were significantly different from one another ($p < .05$). The means for the one- and two-syllable immediate-response conditions and the one-syllable long-delay did not differ from one another and were significantly longer than all other conditions. The means for the four remaining response conditions (one-syllable short-delay, two-syllable short- delay, two-syllable long-delay, and the 'uh' condition) did not differ from one another.

Further analysis involved comparisons across the three groups for each condition. A one-way ANOVA for the one-syllable words in the immediate-response condition showed significant differences between groups, $F(2, 27) = 16.0$, $p < .01$. Post hoc testing showed significant differences between each group ($p < .05$), with the adults having the shortest VRTs, followed by the child peer group, then the children with CAPD who had the longest VRTs. For the two-syllable words in the immediate-response condition, the ANOVA again showed significant differences, $F(2, 27) = 18.0$, $p < .01$, but the post hoc testing revealed that the adults had significantly shorter VRTs ($p < .05$) than both child groups, who did not differ from one another.

Between-group comparisons for the "uh", the one-syllable long-delay, the two-syllable short-delay, and the two-syllable long-delay conditions were similar, with significant differences between groups, $F(2, 27) =$ 9.9 ("uh"), 15.4 (one-syllable long-delay), 19.1 (two-syllable short-delay), and 13.5 (two-syllable long-delay), $p < .01$. For these conditions the adults had significantly shorter VRTs ($p < .05$) than the child groups who did not differ from one another. For the one-syllable word short-delay condition, there was a significant difference between groups, $F(2, 27) = 4.9$, $p < .01$, with the post hoc testing revealing that the adults had significantly shorter VRTs ($p < .05$) than the children with CAPD. The VRTs for the child peer group did not differ from the other two groups.

Production Errors

The adults in the study did not produce any sound production errors. As a result, only differences between the two child groups are described. The total number of production errors consisted of two types of errors, nonvocalizations and word substitutions, which were summed for statistical analysis. Means and standard deviations of errors are presented in Table 3. The children with CAPD produced more production errors than their peers for both long-delay conditions (4 and 7). Speaker-to-speaker results for conditions 4 and 7 were examined. For condition 4, the range of errors across the children with CAPD was from 0 to 5, with the mode value being 2 errors, suggesting a relatively even spread of error across the 10 speakers. For condition 7, the distribution was not as even. Four speakers had 0 errors, whereas for the rest the number of errors spanned 2 through 6, and one speaker had 13 errors. With respect to word substitutions, for conditions 3, 4, and 7, the children with CAPD produced more word substitutions than the peer group.

Table 3. Means (and standard deviations) for number of total errors (nonvocalizations plus substitutions) for the children with CAPD ($N = 10$) and without CAPD ($N = 10$).

Condition	Children with CAPD	Children without CAPD
The "uh" syllable	0.1 (0.32)	—
One-syllable, short delay	—	—
One-syllable, no delay	0.1 (0.32)	—
One-syllable, long delay	2.5 (1.84)	0.3 (0.50)
Two-syllable, short delay	—	0.3 (0.95)
Two-syllable, no delay	—	0.2 (0.63)
Two-syllable, long delay	3.7 (4.37)	0.3 (0.95)

Note. Dashes indicates that no errors were noted for the specific condition.

A two-way ANOVA for total errors indicated significant differences for Group [$F(1, 18) = 6.7$, $p < .05$] and Condition [$F(6, 108) = 8.3$, $p < .05$], with a significant interaction effect [$F(6, 108) = 6.5$, $p < .05$]. Subsequent analysis with two one-way ANOVAs resulted in significant differences between conditions for the children with CAPD [$F(6, 54) = 8.2$, $p < .05$] but not for the peer group [$F(6, 54) = 0.7$, $p >$ 05]. Post hoc testing for the children with CAPD revealed significantly more errors ($p < .05$) for both long-delay conditions (4 and 7) as compared to the other five conditions.

Discussion

There were two primary objectives of this study. The first was to determine if children diagnosed with CAPD demonstrated more evidence of processing difficulties while attending to visual stimuli than normally developing peers. The second purpose was to compare the abilities of both child groups to an adult group. A trend was observed across the conditions, with the mean VRT scores for the CAPD children always being longer than the peer child group and the VRT scores for the peer child group being longer than those for the adults. However, with respect to the children with CAPD, they differed significantly from the other groups only for the one-syllable word immediate-response task. For this condition, the three groups performed with mutually significant differences, with the children with CAPD performing with the longest VRT scores, the peer child group having shorter VRT scores, and the adults having the shortest scores. For the other six conditions, the CAPD children did not differ statistically from their age-matched peers. Both groups of children had significantly longer VRTs than the adults for all these conditions except the one-syllable long-delay condition. For this condition, the peer group did not perform differently from the adults, although the children with CAPD had significantly longer VRTs than the adults.

With respect to total errors (omissions and substitutions), the children with CAPD had significantly more errors than their peers for the two long-delay conditions.

Errors were more evenly spread across the entire CAPD group for the one-syllable long-delay condition than for the two-syllable long-delay condition.

The results from the immediate naming tasks suggest that the children with CAPD required more time in processing the stimuli from visual recognition to verbal utterance than their peers and the adults. Inasmuch as there were no delays involved in these protocols, short-term memory deficits can be discounted with these tasks. Also, because there were no between-group differences with respect to production errors, there appeared to be no problems or confusions with recognition, per se. The children with CAPD completed the tasks appropriately; they merely took longer to complete them. Although the specific cause for the noted discrepancy cannot be isolated, it can be stated that in this nonauditory task the children with CAPD did not function at the same level as their peers. It is possible that the reason for the discrepancy is associated with Katz's (1992) Decoding Category deficit. Katz stated that children with CAPD often have difficulty remembering and manipulating phonemes; this results in reading problems, especially when reading aloud.

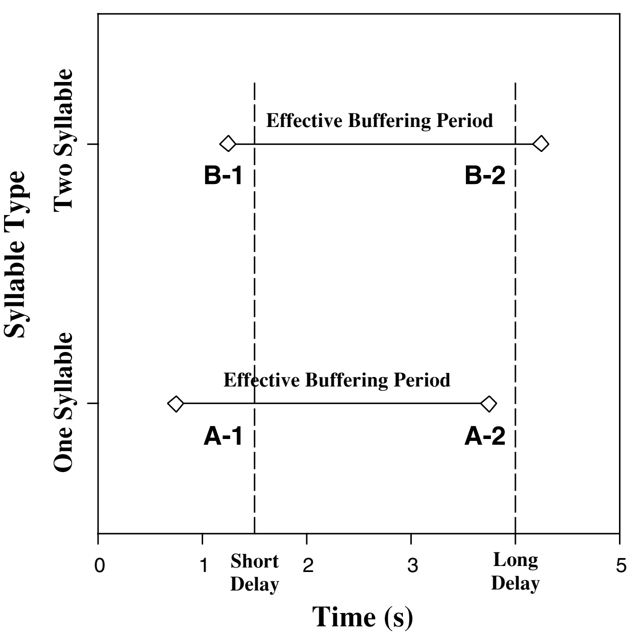
The results for the delayed conditions showed that the two child groups did not have different response times. This suggested that their abilities to execute the motor aspect of the tasks were similar, when given time to process the words presented. In conjunction with the results from the immediate-response tasks, this suggests that an internal processing deficit may distinguish the two child groups, not a motor response deficit. Overall, the faster response times for the delayed conditions are consistent with the Grandori et al. (1994) findings. They found that reaction times were reduced when warning signals were presented before speakers were to respond. For the delayed tasks, the children with CAPD were consistently slower than their peers but not significantly so. However, the CAPD children did make more production errors, especially for the long delays. This suggested that there is some short-term memory deficit involved in the children with CAPD, a finding in agreement with statements by Oberklaid et al. (1989). The possible existence of such a short-term memory deficiency could lessen the distinction among children with CAPD, children with learning disabilities (Johnson, 1981), and language-disordered children (Tallal, 1980). Also, this result supported Young's (1985) suggestion that a visual short-term memory test be added to CAP test batteries.

It was noted that for the immediate naming tasks, both child groups required longer times to produce two-syllable words than one-syllable words. The adults produced both word types at the same rate. This suggested that not only did the children take longer to process the stimuli than the adults, they also appeared less automated than the adults. That is, the adults appeared to recognize and produce all words similarly (possibly as gestalts), whereas the children with less automated abilities took longer to recognize and produce the two-syllable words. The fact that the children took longer for the two-syllable words also suggested that production does not occur until entire words have been processed. This could support the notion that a morphophonemic aspect is involved in the speech production process. The longer VRTs for the children suggest that they responded more in keeping with findings by Sternberg et al. (1978), who reported that their speakers' response times were dependent upon the syllable length of the words they produced. Sternberg et al. proposed that the syllable effect was due to "unpacking" of the response, a lower-level function of the response hierarchy. More specifically, although the time of activation of an entire motor sequence is determined by the number of units in the sequence or the retrieval of the first unit (upper-level controls), the syllable size of the initial unit also affects the reaction time.

When examining the delayed-response conditions, it was noted that the length of the delay had differing effects for the one- and two-syllable words for both child groups. The VRTs for the one-syllable words were the fastest for the short-delay condition and slowest for the long-delay condition. The VRTs for the two conditions for the two-syllable words were very similar, and were located between the VRTs for the two conditions for the one-syllable words (see Figure 1). This result could be explained in terms of a limited temporal motor buffer. Sternberg et al. (1978) and Grandori et al. (1994) discussed motor buffers as part of the speech production process. A temporal motor buffer could be thought of as the limited amount of time that speech motor commands can be held in memory before they are executed. Sternberg et al. (1978) have proposed that motor buffers might experience rapid decays.

The possible effects of a limited temporal motor buffer are shown in Figure 2. In the figure, the word is presented to the speaker at time 0 s and is to be spoken after either the short delay (1.5 s) or the long delay (4.5 s), which are represented by the vertical dashes. The time intervals before the left diamond represent the interval necessary for formulation of the motor commands for the one- or two-syllable words. After the motor commands are formulated, they are placed in the buffers. The time intervals when the temporal motor buffers are effective are represented by the horizontal lines with diamond symbols at either end. Because motor commands for the one-syllable words are formulated faster than commands for the two-syllable words, the buffered period starts sooner for the one-syllable words than for the two-syllable words. The faster VRTs for one-syllable

Figure 2. Proposed motor buffer model demonstrating differing responses to one- and two-syllable words by both child groups. See text for explanation.



words under the short-delay condition could have two explanations: (a) the motor commands are still held in the motor buffer when they are to be executed, and (b) the one-syllable, being a short sequence, is quickly executed once signaled. The execution of the one-syllable word would occur at site A-1 in Figure 2, which represents the intersection of the signal to speak with the buffered motor command. The VRTs for the two-syllable words are similar in both delayed conditions possibly because (a) their motor commands are still held in the motor buffer when they are executed, and (b) they consist of longer sequences than one-syllable words or require more time to execute. Their executions would occur at intersection sites B-1 (short delay) and B-2 (long delay). Finally, a possible explanation for the slower VRTs for the one-syllable words in the long-delay condition is that the delay is too long for the initially generated motor commands to be maintained in the buffer. That is, the motor commands, which were created sooner because of shorter word length, also are dissipated sooner. Thus when the signal to respond is given for the long delay, there is no intersection at site A-2 with the buffered motor command, and the motor command must be regenerated, resulting in the slowest VRT.

Because the adults had similar VRTs for all delayed conditions, they must have buffers that greatly exceed the temporal limitations proposed for the children. As suggested by their immediate naming abilities, the adults probably initiate productions of all words at the same time, formulating commands for the latter parts of the word while the former parts are being executed. This possibility does not correspond with proposals by Sternberg et al. (1978). Differences in test results and subsequent interpretation between the current study and that of Sternberg et al. (1978) may be due to different test protocols. In the current study speakers were tested once, whereas they were tested repeatedly by Sternberg et al.

Finally, definitive diagnostic procedures for determining CAPD have not been standardized. As such, it is possible that the speakers identified as having CAPD in this study might not correspond with speakers so identified at other centers. A consensus on diagnostic procedures would help to alleviate this problem. With this caveat in mind, the following summary is offered.

Slower VRTs and a significantly greater number of total errors for speakers with CAPD appeared to support the premise that CAPD may be only a symptom of a larger processing disorder. This suggests that children with CAPD may demonstrate general short-term memory difficulties or general attention problems. Further it supports findings of other researchers that the symptomatology of CAPD overlaps the symptomatology of such other disorders as Attention Deficit Hyperactivity Disorder (ADHD), language disorders, and learning disorders (Cook et al., 1993; Oberklaid et al., 1989). Moreover, the findings from the present study raise the question of why CAPD diagnostic test batteries employ tests with primarily auditory input as stimuli. These findings suggest that adding a visual component to the CAPD diagnostic test battery could provide a better understanding of the problems experienced by individuals with CAPD.

Acknowledgments

Portions of this paper were presented at the November 1994 annual meeting of the International Clinical Linguistics and Phonetics Association, New Orleans, LA.

References

American National Standards Institute. (1989). *Specifications for audiometers*. New York: ANSI.

Bloom, L., & Lahey, M. (1978). *Language development and language disorders*. New York: John Wiley and Sons.

Carroll, J. B., Davies, P., & Richman, B. (1971). *The American Heritage word frequency book*. New York: American Heritage Publishing Co.

Connor, N. P., & Abbs, J. H. (1991). Task dependent variations in Parkinsonian motor impairments. *Brain, 114*, 321–332.

Cook, J. R., Mausbach, T., Burd, L., Gascon, G. G., Slotnick, H. B., Patterson, B., Johnson, R. D.,

Hankey, B., & Reynolds, B. W. (1993). A preliminary study of the relationship between central auditory processing disorder and attention deficit disorder. *Journal of Psychiatry and Neuroscience, 18*(3), 130–137.

Dagenais, P. A., Southwood, M. H., & Watts, C. R. (1995, December). **Dual task testing for speech production to assess attentional capacities** [abstract]. Poster session presented to the annual meeting of the American Speech-Language-Hearing Association, Orlando, FL.

Edwards, J., & Lahey, M. (1993). Auditory lexical decisions in children and adults: An examination of response factors. *Journal of Speech and Hearing Research, 36*, 996–1003.

Fletcher, S. G., Smith, S. C., & Hasegawa, A. (1985). Vocal/verbal response times of normal-hearing and hearing-impaired children. *Journal of Speech and Hearing Research, 28*, 548–555.

Grandori, F., Pinelli, P., Ravazzani, P., Ceriani, F., Miscio, G., Pisano, F., Colombo, R., Insalaco, S., & Tognola, G. (1994). Multiparametric analysis of speech production mechanisms. *Engineering in Medicine and Biology*, April/May, 203–209.

Howard, M. H., & Hulit, L. M. (1992). Response patterns to central auditory tests and the clinical evaluation of language fundamentals–revised: A pilot study. *Perceptual and Motor Skills, 74*, 120–122.

Johnson, D. J. (1981). Considerations in the assessment of central auditory disorders in learning disabled children. In R. W. Keith (Ed.), *Central auditory and language disorders in children* (pp. 77–84). San Diego: College-Hill Press.

Katz, J. (1977). The staggered spondaic word test. In R. W. Keith (Ed.), *Central auditory dysfunction* (pp. 103–127). New York: Grune & Stratton.

Katz, J. (1983). Phonemic synthesis. In E. Lasky & J. Katz (Eds), *Central auditory processing disorders: Problems of speech, language and learning* (pp. 269–295). Baltimore: University Park Press.

Katz, J. (1992). Classification of auditory processing disorders. In J. Katz, N. A. Stecker, & D. Henderson (Eds.), *Central auditory processing: A transdisciplinary view* (pp. 81–92). St. Louis: Mosby Year Book.

Katz, J., Stecker, N. A., & Henderson, D. (1992). Introduction to central auditory processing. In J. Katz, N. A. Stecker, & D. Henderson (Eds.), *Central auditory processing: A transdisciplinary view* (pp. 3–8). St. Louis: Mosby Year Book.

Keith, R. (1986). *SCAN: A screening test for auditory processing disorders*. San Diego: The Psychological Corp.

Keller, W. D. (1992). Auditory processing disorder or attention-deficit disorder? In J. Katz, N. A. Stecker, & D. Henderson (Eds.), *Central auditory processing: A transdisciplinary view* (pp. 107–114). St. Louis: Mosby Year Book.

Martin, F. N. (1994). *Introduction to audiology* (5th ed.). Englewood Cliffs, NJ: Prentice Hall.

Norman, G. R., & Streiner, D. L. (1994). *Biostatistics: The bare essentials*. St. Louis: Mosby.

Oberklaid, F., Harris, C., & Keir, E. (1989). Auditory dysfunction in children with school problems. *Clinical Pediatrics, 28*, 397–403.

Rees, N. S. (1981). Saying more than we know: Is auditory processing disorder a meaningful concept? In R. W. Keith (Ed.), *Central auditory and language disorders in children* (pp. 94–120). San Diego: College-Hill Press.

Stecker, N. A. (1992). Central auditory processing: Implications in audiology. In J. Katz, N. A. Stecker, & D. Henderson (Eds.), *Central auditory processing: A transdisciplinary view* (pp. 117–128). St. Louis: Mosby Year Book.

Sternberg, S., Monsell, S., Knoll, R. L., & Wright, C. E. (1978). The latency and duration of rapid movement sequences: Comparisons of speech and typewriting. In G. E. Stelmach (Ed.), *Information processing in motor control and learning* (pp. 117–152). New York: Academic Press.

Tallal, P. (1980). Auditory processing disorders in children. In P. J. Levinson & C. Sloan (Eds.), *Auditory processing and language: Clinical and research perspectives* (pp. 81–100). New York: Grune & Stratton.

Task Force on Central Auditory Processing Consensus Development. (1996). Central auditory processing: Current status of research and implications for clinical practice. *American Journal of Audiology, 5*(2), 41–54.

Webster, W. G., & Ryan, C. R. L. (1991). Task complexity and manual reaction times in people who stutter. *Journal of Speech and Hearing Research, 34*, 708–714.

Willeford, J. (1977). Assessing central auditory behavior in children: A test battery. In R. Keith (Ed), *Central auditory dysfunction* (pp. 43–72). New York: Grune & Stratton.

Wulfeck, B. B. (1993). A reaction time study of grammaticality judgment in children. *Journal of Speech and Hearing Research, 36*, 1208–1215.

Young, M. L. (1985). Central auditory processing through the looking glass: A critical look at diagnosis and management. *Journal of Childhood Communication Disorders, 9*(1), 31–42.

Received June 7, 1996

Accepted January 16, 1997

Contact author: Paul A. Dagenais, PhD, Department of Speech Pathology and Audiology, University of South Alabama, 2000 University Commons, Mobile, AL 36688-0002