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Are Hyperactive Children Deficient in Attentional Capacity?

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A dual task was used to study attentional capcity in three groups: in 6- to 12-year-old boys with attention deficit disorder plus hyperactivity (ADDH) or with ADDH and conduct disorder, and in normal children. Subjects performed a primary-choice reaction-time task first without and then with a secondary task that also required a response. Our prediction that the reaction time of ADDH subjects to the secondary task would increase more with increasing temporal overlap of the primary and secondary stimuli, if they were deficient in capacity, was not supported. However, the performance of ADDH subjects on the primary task deteriorated more than that of control subjects with the introduction of the secondary task, indicating a greater concurrence cost or a different allocation policy. Moreover, ADDH subjects had longer reaction times to the secondary task, indicating greater refractory effects or difficulty shifting capacity from primary- to secondary-task processes.

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INTRODUCTION

Hyperactive children perform poorly on a wide range of attention-demanding laboratory tasks (see Douglas, 1983, for review). Typically, this poor performance has been attributed to specific deficits in executive or cognitive processes. For example, deficits in performance on the incidental-learning paradigm (Ceci & Tishman, 1984) or on the Matching Familiar Figures Task (Kagan, Rosman, Day, Albert, & Phillips, 1964) are attributed to deficient selective attention or poor inhibitory control, respectively (Douglas, 1983). In addition to executive processes (e.g., inhibitory control) and mechanisms of attention (e.g., selection), capacity or the amount of attention is also implicated. If a certain level of attention is required for the performance of most or all mental tasks, then the poorer performance of hyperactive children compared with that of their normally attentive peers could be a result of deficient capacity rather than, or in addition to, deficits in specific cognitive processes.

The capacity theory of attention is supported by observations that there is an apparent limit to the amount of mental work that an individual can perform in a particular amount of time. To explain the limited ability to carry out multiple activities, the capacity theory assumes that the total amount of attention that can be deployed at any time is limited (Kahneman, 1973; Pascual-Leone, 1970). Some stages of information processing require an input of attention, whereas others require little or no attention. According to this model, an activity can fail because there is insufficient capacity to meet its demands.

Although there are limits on capacity that are relatively constant within individuals, capacity may vary between individuals and within individuals because of arousal or drug-related states. Also, there are limits to the amount of capacity a given task requires: Allocating capacity increases the rate of processing until the maximum rate is reached. At that point, allocating more capacity has no effect on the rate of processing. If more capacity is available than is necessary to support the maximum rate of processing, that excess is *spare capacity* that can be used to support other tasks. The amount of spare capacity determines the rate at which any secondary task is processed during the period when both tasks are being processed simultaneously; the more spare capacity, the greater the rate of secondary-task processing. The extent of temporal overlap between two stimuli will also affect the rate of secondary-task processing. Greater temporal overlap is associated with a longer period of processing during which the secondary task is processed with spare capacity rather than at the maximum rate. After responding to the primary task, the subject can redirect the total capacity to the secondary task until its completion. Consequently, the longer the temporal overlap, the slower the response to the secondary task.

Dual-Task Paradigm

The dual-task paradigm can be used to measure capacity according to the capacity theory of attention (Kahneman, 1973). In the dual-task paradigm, subjects are presented with two stimuli in rapid succession and are required to respond to each stimulus as quickly as possible. Typically, there is substantial interference between the two tasks, with the response to the secondary task being prolonged compared with that of a single-task control condition. Assuming that the primary task demands the same maximum amount of capacity from each individual whatever his or her capacity, individuals with more capacity overall will have more spare capacity, and consequently, will have a greater rate of secondary-task processing during the period of temporal overlap. Consequently, less information about the secondary task must be gained in the interval following the primary-task response during which the secondary task receives all the capacity it demands.

The amount of information about the secondary task gained during the first overlapping interval depends on the rate of processing during that interval and the duration of the overlapping interval. In the dual task, the experimenter controls temporal overlap by manipulating the delay between the onset of the primary- and secondary-task stimuli, or as in this experiment, the delay (interval) between the onset of the secondary-task stimulus and the mean reaction time (RT) to the primary task. Varying overlap in this way controls for differences in primary-task RTs. If the overlap were not set in this way, longer secondary-task RTs would be confounded with longer primary-task RTs. Varying the extent of temporal overlap also means that it is less likely that subjects will group their responses so that they are emitted with a relatively fixed interval between the two. Variable overlap will mean that the secondary-task RT will be a purer measure of spare capacity.

If no processing of the secondary task occurred during the period of overlap, the RT to the secondary task would increase with the length of the overlap between primary- and secondary-task stimuli. This would result in a value of one for the slope of the function relating secondary-task RT to the delay between tasks. If there were no competition for capacity between tasks, secondary-task RT would be constant over the variation in temporal overlap and the slope of the function relating secondary-task RT to delay between tasks would be zero. In general, greater spare capacity and secondary-task processing will be manifest in a shallower slope of the function relating secondary-task RT to temporal overlap (see appendix for formal derivation).

In this study, we employed the dual-task paradigm to investigate the hypothesis that hyperactive children have deficient attentional capacity. We compared the performance of three groups of children: those with a diagnosis of attention deficit disorder and hyperactivity (ADDH), ADDH and a coexisting diagnosis of conduct disorder (ADD + CD), and normal controls

(NC). The ADDH + CD group was included because it is the typical presentation of hyperactive children (Szatmari, Offord, & Boyle, 1989) and because the ADDH group alone, not the ADDH + CD group, is deficient in sustained attention (Chee, Logan, Schachar, Lindsay, & Wachsmuth, 1989) and inhibitory control (Schachar & Logan, in press). If children with a diagnosis of ADDH are deficient in attentional capacity, the central prediction of this experiment is that the slopes of their function relating secondary-task RT to temporal overlap would be steeper.

METHOD

Subjects

Subjects were 30 boys, aged 6 to 12, who were referred to a child psychiatric outpatient department for behavior problems, and 12 normal male volunteers. Only boys were included because of the predominance of males among the population of children with behavior problems (Schachar, Rutter, & Smith, 1981; Szatmari *et al.*, 1989). Any subject whose full-scale IQ was less than 80, who showed evidence of a neurological disorder such as epilepsy or a history of psychosis, or who was currently on medication was excluded. For all children, a diagnosis was based on information obtained in an interview with each child's parents, from an interview with each child, from behavior ratings completed by the child's teacher, and from psychoeducational assessment.

Measures

Diagnostic Assessment of the Child

Parent Interview. Information from each child's parent or parents was obtained by one of two child psychiatrists, who followed a semistructured interview protocol that covered prenatal, birth, postnatal, developmental, medical, academic, and family history, as well as child behavior and current symptoms of psychopathology. The interview also dealt with symptoms associated with oppositional disorder (OD), CD, and ADDH, as well as affective, anxiety, and psychosomatic disorders.

The interviewer rated each symptom on the basis of the severity of the disability using the following clinical criteria: (a) the frequency of the symptom, (b) the age-appropriateness of the symptom, (c) the degree of disability resulting from the symptom, (d) the degree of provocation required to elicit the behavior, (e) the duration of symptom episode, and (f) the response to efforts to alleviate the symptom. Only symptoms rated as definitely present and severe contributed to a diagnosis, and only information from parents living in the family during the last 2 years was included.

The interrater reliability of 18 interviews was determined by a second researcher who rated audiotapes of the assessments. Raters agreed on the presence or absence of 97% of symptoms (kappa = .92). Interrater reliability was equally good for symptoms of OD, CD, ADDH, and emotional disorders. In no case did disagreement about particular symptoms result in disagreement about the diagnosis.

Child Interview. Each subject was interviewed by a clinical psychologist who used the format of Rutter & Graham (1968).

Teacher-Rating Scales. To assess the extent of behavior problems outside the home, each child's classroom teacher completed the Rutter-B rating scale (Rutter, 1967), the abbreviated Conners Teacher-Rating Scale (ACTRS) (Conners, 1973), and the SNAP questionnaire (Pelham, Atkins, & Murphy, 1981).

The Rutter-B scale comprises 26 questions about child behavior, predicts psychiatric diagnosis, and includes subscales measuring emotional disturbance, conduct disturbance, and hyperactivity (Rutter, Tizard, & Whitmore, 1970; Schachar *et al.,* 1981). The abbreviated Conners scale consists of 10 questions about restlessness, impulsiveness, and aggressive interpersonal behaviors. The SNAP questionnaire consists of questions about the 16 symptoms of inattentiveness, impulsiveness, and overactivity that constitute the DSM-III diagnostic criteria for ADDH.

Diagnostic Criteria. Children were assigned to the ADDH, ADDH + CD, or NC groups on the basis of the results of these measures. A diagnosis of ADDH was made if either the parent or teacher reported its presence.

A diagnosis of ADDH based on the parent interview was made if the parents reported three symptoms of inattentiveness, three of impulsiveness, and two of hyperactivity, in addition to a history of hyperactivity, impulsiveness, and inattentiveness before the age of 6 years.

A teacher-based diagnosis of ADDH was made if the teacher rated the child as disturbed and significantly hyperactive. A rating of 9 or more on the Rutter-B questionnaire was taken as an indication of psychiatric disturbance (Rutter *et al.,* 1970), and the presence of any two of the following three criteria was considered evidence of clinically significant hyperactivity: (1) a rating of at least 5 out of 6 on the Rutter-B hyperactivity factor, a score obtained by 3% of 10-year-old boys (Schachar *et al.,* 1981); (2) a rating of 4 inattentive, 4 impulsive, and 3 hyperactive items on the SNAP questionnaire, a score obtained by 5% of 10-year-old boys (Pelham *et al.,* 1981); and (3) an abbreviated score of 15 or more on the ACTRS, a score predictive of a clinical diagnosis of hyperactivity (Goyette, Connors, & Ulrich, 1978). The few cases of attention deficit disorder without hyperactivity were excluded from the study.

Children were assigned to the ADDH + CD group if they met the DSM-III criteria for CD as well as for ADDH. In addition, the ADDH + CD diagnosis was assigned to children diagnosed with ADDH and OD if their OD symptoms were severe and pervasive, involving relationships with both parents or a variety of adults. The practice of combining CD and OD groups is consistent with the observation that the two diagnoses have not been differentiated in school-age children and are qualitatively similar (Werry, Methven, Fitzpatrick, & Dixon, 1983; Anderson, Williams, McGee, & Silva, 1987; Reeves, Werry, Elkind, & Zametkin, 1987; Schachar & Wachsmuth, 1990).

In general, the results of individual child interviews agreed with the diagnoses based on the parent interview and the teacher questionnaire. In no case did the results of the child interview alter the diagnosis. To be included in the study, volunteers, who were assessed in the same way, had to be free of any diagnosis.

Dual Task

Apparatus and Stimuli

The dual-task paradigm involved a primary and a secondary task. The primary task was a simple forced-choice RT task consisting of the uppercase letters X or O, presented by an Apple IIE computer connected to a specialized Cognitive Testing Station (CTS; Digitry Company Inc., 1984). Response to these two stimuli (X and O) required the subject to press the corresponding response button, mapped with X or O, with the fingers of the left hand. The CTS allowed direct and precise control of the presentation of the stimulus, as well as the collection of RTs with millisecond accuracy. Each letter, presented one at a time in the center of the screen, was 2 mm wide and 5 mm high and when viewed at a distance of 40 cm subtended .29 × .72° of the visual angle.

The secondary task, which involved a 55-dB tone, 100 ms in duration, generated and presented by the computer on half of the trials, required the subject to respond by pressing a third key with a finger of the right hand. The tone was presented at one of six possible delays.

Each trial began with a fixation point illuminated for 500 ms. It was followed by the primary-task letter for that trial (X or O), displayed for

1.5 s and then extinguished. The screen then remained blank for an interval of 1 s. Consequently, there was a period of 2.5 s in which the child could respond – from the onset of the letter stimulus to the start of the next trial. Mapping the letters onto the keys was counterbalanced across subjects. A total of 336 trials were presented in 14 blocks of 24 trials. The stimulus letters occurred equally often in each block.

The tones were presented on 50% of the trials of the primary task, occurring equally often at each of the six delays with a total of 24 tones at each delay. Tones presented at each of the six delays occurred equally often with each letter. The sequence of letters, tones, and tone delays was random.

Setting Secondary-Task Tone Delay

The first block of trials was practice for the primary-task choice RT task. During this practice block, no tone was presented. The second block of practice trials included secondary-task stimuli. This block of trials was not included in the analyses. Mean RT (MRT) for the primary task was calculated at the end of the second block and was used to set the tone delays for the remaining 12 blocks of the experimental trials. On the first experimental block, six tone delays were calculated to be equal to MRTs minus (−) 500, − 400, − 300, − 200, − 100, and − 0 ms. Long delays (i.e., MRT − 500 ms) are equivalent to greater overlap of primary and secondary tasks, whereas short delays (i.e., MRT − 0 ms) indicate shorter overlap of primary and secondary tasks. Subsequently, the tone delay was dynamically adjusted from block to block. The MRT for the nontone trials from the second block was calculated and used to set delays for the third, and the MRT for the third block was used to set delays for the fourth, and so on. Dynamic adjustment of the tone delays for each individual meant that the delays for a given block depended only upon the performance in the one immediately preceding it. This method of setting secondary-task presentation is necessary to adjust for group differences in primary-task RT.

The main dependent variables were the primary-task RT before the introduction of the probes (single-taks control), the primary-task RT on trials without associated secondary-task stimuli after the introduction of secondary-task stimuli, and the secondary-task RT (the interval between the presentation of and the response to the secondary-task stimulus). The main independent variables were group (ADDH, ADDH + CD, NC) and tone delay (MR − 500, − 400, − 300, − 200, − 100, − 0 ms).

One final assumption about the dual-task paradigm was that both primary- and secondary-response processes require effort (Fisk, Derrick, & Schneider, 1986). If they do not, both tasks can be performed with little resource competition. In that case, secondary-task RT would not be a sensitive index of residual capacity. Substantial improvement in RT to primary- or secondary-task stimuli would indicate that these response processes require less capacity with time. Therefore, we assessed the effect of time on the task for each group by comparing performance during the first six experimental blocks with that during the second six blocks of trials.

Procedure

Informed consent for the experiment was obtained from the parents of each subject and assent from each subject. Subjects were tested individually while the experimenter remained in the room throughout the experiment. Subjects were seated comfortably in front of the computer screen in a quiet room and were instructed to keep two fingers of the left hand on each of the two response buttons for the X's and O's throughout the experiment. Instructions for the choice-reaction-time task were given before the first block of practice trials was started. Subjects were instructed to respond as quickly and as accurately as possible to the primary task. Following the block of practice trials, they were instructed to keep one finger from the right hand on a third response button in case they heard the tone which required that they respond to the tone as well as to the X or O. Response to the primary-task stimuli was given priority: The children were told to respond to the primary-task stimuli before responding to the secondary task. The task was approximately 30 min in length and allowed for short breaks following the fourth and the eighth blocks.

RESULTS

Subject Characteristics

Of the 19 ADDH subjects, 4 were diagnosed with ADDH according to both the parental interview and the teacher ratings, 6 according to the parental interview only, and the remaining 9 according to teacher ratings only. Of the 11 ADDH + CD subjects, 9 were diagnosed with ADDH according to both the parental interview and the teacher ratings, 1 according to the parental interview only, and 1 according to the teacher ratings only.

The three subject groups did not differ in mean age [F (2, 39) = .8, n.s.], but the mean IQ of the normal control group was significantly greater than that of the ADDH and ADDH + CD groups [$F(2, 39) = 11.2, p < .001$] (Table I).

Table I. Mean Age, IQ, Primary-Task Reaction Times, and Percent Errors by Group[a]

	Controls (n = 12)		ADDH + CD (n = 11)		ADDH (n = 19)	
	Mean	*(SD)*	*Mean*	*(SD)*	*Mean*	*(SD)*
Mean age (months)	109		103		109	
Mean IQ	126		108		107	
MRT during practice	719	(142)	729	(159)	700	(188)
MRT primary task	812	(155)	887	(182)	917	(210)
Mean % errors	2.9		7.2		6.6	
Slope	.42		.35		.36	

[a] ADDH + CD = coexistent diagnoses of attention deficit disorder with hyperactivity and conduct disorder; ADDH = attention deficit disorder with hyperactivity; MRT = mean response time; Slope = slope of function relating secondary-task reaction time to delay.

Effect of Time on the Task

A series of analyses of variance that compared the latency and accuracy of the RTs during the first six experimental blocks with those of the second six experimental blocks revealed that the demand of the primary task did not change substantially during the experiment. For nonsignal trials, there was virtually no change in the latency of primary-task responses during the course of the task [$F(1, 39) = .01$, n.s.]. The response to the primary task on signal trials increased in latency by approximately 30 ms, but the effect was nevertheless nonsignificant [$F(1, 39) = 3.5$, n.s.]. Similarly, primary-task error rates did not vary throughout the task on either signal [$F(1, 39) = .4$, n.s.] or nonsignal trials [$F(1, 39) = 2.3$, n.s.].

However, secondary-task RTs had shorter latencies (by approximately 25 ms) during the second half of the task than during the first half, indicating that the secondary task required somewhat less effort as the task proceeded [$F(1, 39) = 6.95, p < .01$]. This decrease in latency of secondary-task RTs was not associated with any significant change in accuracy over the task (i.e., failures to respond to secondary-task stimuli) [$F(1, 39) = 2.2$, n.s.]. Together, this decrease in RT with stable error rates indicates only a marginal change in the effort required to perform the secondary task.

Effect of Introduction of the Secondary Task

There was evidence that the introduction of the secondary task affects the performance of all groups (Table I). Primary-task RT increased significantly (by approximately 150 ms) after the introduction of the secondary-

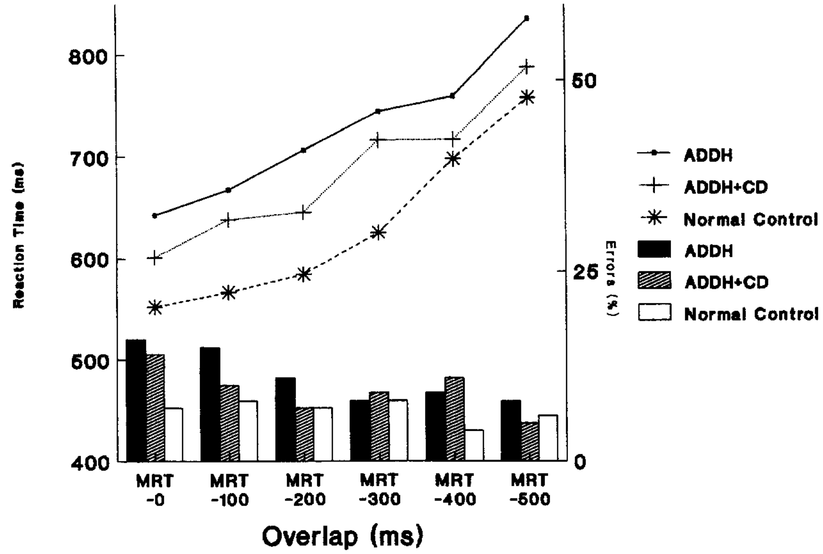

Fig. 1. Reaction times (in ms) and error rates (in % of trials) to secondary-task tones as a function of delay (overlap) and group.

task stimuli (the concurrence cost). An analysis of variance (ANOVA) comparing primary-task RTs for practice trials with primary-task RTs on experimental trials indicated that this increase in RTs was highly significant [$F(1, 39) = 49.2, p < .00$].

Effect of Delay

Mean secondary-task RTs and corresponding error rates for each group are presented as a function of the delay between primary-task MRT and secondary-task presentation in Fig. 1. As predicted, the mean secondary-task RT varied with delay: that is, with the extent of temporal overlap between the primary and secondary stimuli. Secondary-task RTs were approximately 200 ms longer when the secondary-task stimulus occurred 500 ms before the subject's mean primary-task RT (MRT − 500) than when it occurred at the subject's mean primary-task RT (MRT − 0). This effect was confirmed by an ANOVA that compared the RTs at each delay for each experimental group. Over all groups, the effect of delay was highly significant [$F(5, 195) = 45.4, p < .00$]. Error rates also increased significantly with decreasing temporal overlap between primary and secondary stimuli [$F(5, 195) = 5.4, p < .00$].

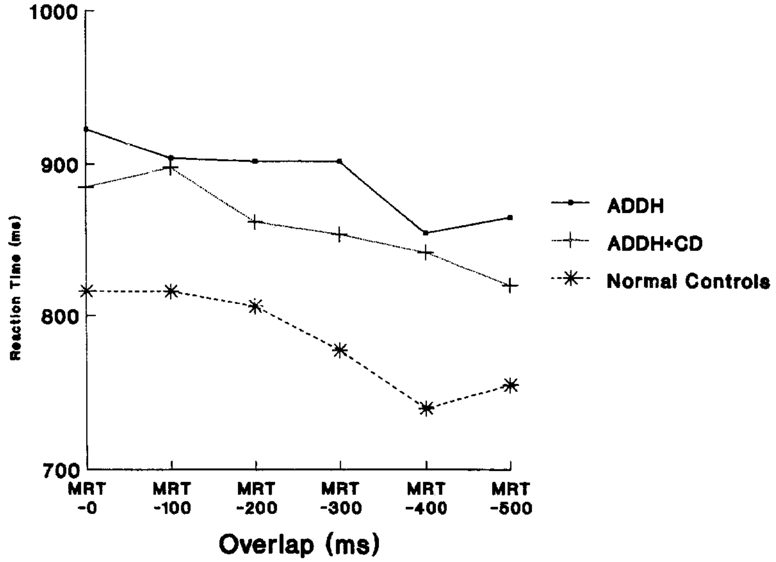

Fig. 2. Reaction times (in ms) to primary-task letters as a function of delay and group.

The mean primary-task RTs on the signal trials for each group are presented as a function of the delay between the primary-task MRT and the secondary-task presentation in Fig. 2. The main effect of delay was significant [$F(5, 195) = 8.8$, $p < .00$], indicating that the primary-task MRT decreased with the increasing temporal overlap of primary- and secondary-task stimuli (i.e., at longer compared to shorter delays). Greater emphasis seemed to be placed on primary-task responses in the presence of secondary-task stimuli and this emphasis increased with the increasing temporal overlap of the two stimuli.

Secondary-Task RT and Delay

Figure 1 indicates that the relationship between secondary-task RT and delay is linear with a nonzero slope of .38. When the shape of this function was examined by trend analysis (Keppel, 1982), only the linear trend was evident ($F = 21.7, p < .001$). The slope of the function relating secondary-task RT to delay did not differ by group ($F = .12$, n.s.), indicating that the best-fitting linear function for each group was similar. The slopes of the linear trend did not differ among diagnostic groups (Table I). Omega-squared values (Keppel, 1982) were calculated to estimate the percentage of the variance that was attributable to the linear effect. The linear trend accounted for a substantial amount of the variance (43%) in the function relating secondary-task RT to delay.

Group Differences in Dual-Task Performance

The rate of primary-task processing during practice sessions was similar for all experimental groups [$F(2, 39) = .11$, n.s.] (Table I). However, groups differed in the extent of concurrence cost: The increase in the RT following the introduction of the secondary-task was greater in the ADDH (217 ms) and ADDH + CD (158 ms) groups than in the NC group (93 ms). We compared the concurrence cost among groups in an ANOVA of the RTs with the factors of the experimental condition (primary-task practice trials vs. experimental trials) and the group. The interaction between the group and the experimental condition was not significant [$F(2, 39) = 2.9$, $p = .06$], but planned comparison indicated that the difference in concurrence cost between the ADDH and NC groups was significant [$F(1, 39) = 5.8$, $p < .05$] (Kirk, 1982).

Groups also differed in their mean RTs to the secondary-task stimuli. Secondary-task RT is presented as a function of delay and group in Fig. 1. The RT to the secondary task was approximately 100 ms longer in the ADDH group than in the NC group. The effect of delay and group on secondary-task RT was analyzed in an ANOVA with factors for group and delay. The significant main effect of group confirmed that mean secondary-task RT varied across groups [$F(2, 39) = 4.6$, $p < .05$]: The ADDH group had a slower secondary-task RT than the NC group [$F(1, 39) = 9.1$, $p < .01$], but not significantly slower than that of the ADDH + CD group [$F(1, 39) = 1.7$, n.s.]. Contrary to our prediction of deficient capacity among ADDH subjects, the interaction between each group and the secondary-task delay was nonsignificant [$F(10, 195) = .66$, n.s.], indicating that the extent of interference between primary and secondary tasks among diagnostic groups did not differ over the range of temporal overlap. Although error rates varied with delay, there were no differences in the overall number of errors [$F(2, 39) = 0.8$, n.s.] or in the effect of delay [$F(10, 195) = 1.7$, n.s.] among groups.

Capacity, Age, and IQ

The relationship among capacity, age, and IQ was examined in two analyses. First, concurrence cost, defined as the difference between the primary-task RT during practice and the primary-task RT following the introduction of the secondary-task stimuli, was not significantly correlated with either age (– .02) or IQ (– .003). Second, interference, defined as the difference between secondary-task RT with maximal overlap (MRT – 500 ms) and minimal overlap (MRT – 0 ms), was not significantly associated with age (– .19) and IQ (– .19).

DISCUSSION

In this experiment, the dual-task paradigm was employed to determine if ADDH and control subjects differ in attentional capacity. Results indicated that the dual task provides a sensitive and feasible index of capacity. However, the hypothesis that ADDH subjects have less capacity was not unequivocally supported.

As predicted by capacity theory, secondary-task RT varied with the extent of the temporal overlap between the secondary- and primary-task stimuli. Secondary-task RTs were significantly greater as the overlap between the primary and secondary tasks increased. The effect of temporal overlap indicates that the secondary task is drawing on the same pool of resources as the primary task. No variation of secondary-task RT with temporal overlap would have suggested that the secondary-task processes demand minimal effort or were drawing on a different pool of resources (Wickens, 1984).

To provide a sensitive index of capacity demand, processing both primary and secondary tasks must require effort throughout the experiment. The effect of time on performance was assessed to determine the extent to which the performance of a task became automatic during the experiment. RT for the primary task remained constant throughout the experiment. By comparison, secondary-task RT decreased significantly but moderately, and secondary-task accuracy decreased with the time spent on the task. A decrease in secondary-task RT implies that secondary-task processes were less demanding as the experiment progressed. However, the decrease in secondary-task RT was similar for all groups. Moreover, this decrease in RT was associated with a minimal decrease in accuracy, indicating a shift in the speed-accuracy tradeoff rather than a decrease in capacity demand.

The results of this experiment support the capacity theory of dual-task performance rather than the single-channel theory. According to single-channel theory, the primary task occupies all capacity until its response is complete: Secondary-task response must wait until the primary task is complete. Consequently, single-channel theory predicts that secondary-task RT will not vary with delay, but will decrease as temporal overlap decreases, resulting in a function with a slope of one (Welford, 1967; Broadbent, 1958).

Conversely, perfect time-sharing of the two tasks implies no competition for capacity between tasks and predicts that the secondary-task RT would be constant over variation in temporal overlap. The observed values were less than 1, indicating that some time-sharing is possible. Therefore, we can conclude that some secondary-task processing is occurring during the temporal-overlap period.

The central hypothesis of this study was that children with a diagnosis of ADDH would have less capacity than control children. We predicted that the performance of the ADDH group would be more adversely affected by the temporal overlap of the primary and secondary tasks. This was not the case. The latency of the secondary-task process was equally affected by the increase in the temporal overlap in the ADDH, NC, and ADDH + CD groups. This finding supports the conclusion based on single-task experiments (Sergeant and Scholten, 1985) that these groups do not differ in capacity.

There were, however, a number of observations which raise doubt about the certainty of this conclusion or which indicate that ADDH is associated with deficits other than capacity deficits on the dual-task paradigm. The first of these observations concerns concurrence cost. The performance of all subjects, but of ADDH subjects in particular, on the primary task was not held constant once the secondary-task stimuli were introduced: There was an increase in the primary-task RT when both primary and secondary tasks were performed concurrently. On the one hand, this indicates that both tasks draw on the same pool of resources—a necessary requirement of the dual-task paradigm. On the other hand, it also indicates that the subjects trade off speed on the primary task for speed on the secondary task. The possibility of a tradeoff between the two tasks has been demonstrated in adults (Gopher, Brickner, & Navon, 1982). This complicates the interpretation of the secondary-task RT (Fisk *et al.,* 1986). One interpretation of concurrence cost is that the subjects take some capacity from processing the primary task and allocate it to the secondary task. This would mean that the primary task is processed more slowly and the secondary task more quickly during the period of temporal overlap. The capacity given to the secondary task would increase the speed of its processing during the period of temporal overlap, thus reducing the slope of the function relating secondary-task reaction time to temporal overlap. Differences among groups would be obscured if a group with less capacity were trading capacity between tasks more than the other groups. Thus, the equivalent slopes across groups, despite their differences in capacity, could occur if the extra capacity the ADDH group gave to their secondary task balanced the deficit they would have experienced given their lesser capacity. We have no way of excluding this possibility. However, it seems implausible that the tradeoff would work out so exactly as to produce slopes identical to those of normal subjects.

Alternatively, concurrence cost may reflect the added cost of performing the two tasks together over that of doing them separately (Duncan, 1980). Two tasks performed together produce emergent problems that require resources to solve. For example, the subject must keep closer track of response mapping, of the order of response to the two tasks, and of which stimuli are relevant to which task. If children with a diagnosis of ADDH have less spare capacity to devote to the secondary task than normal children, then, again, it is implausible that ADDH subjects could allocate capacity exclusively from primary-task processes in order to maintain an equal amount of spare capacity for the secondary task. This is particularly true given that primary- and secondary-task responses were stressed equally in the instructions to the task.

The effect of temporal overlap on the primary-task RT in children differed from that observed among adults. Adults usually protect their response to the primary task (Logan & Burkell, 1986; Herman & Kantowitz, 1970; Posner & Boies, 1971), concentrating the interference on the response to the tone. Not only did the children in this study sacrifice the primary-task response process, but their primary-task response latencies varied with the temporal overlap of the two tasks. This observation indicates that children rush through the primary-task response in the presence of a secondary task and that they rush more when there is a greater temporal overlap.

ADDH and control groups also differed in their mean RT to the secondary task. Although there was no single-task control condition to exclude the possibility that ADDH subjects have longer latencies to an auditory signal, this possibility seems remote given that similar single-task latencies to visual signals were observed in this experiment. Instead, longer secondary-response latencies among ADDH subjects indicate one of several possibilities. First, it might be possible that ADDH subjects are less prepared for the secondary-task stimuli, which occurred unexpectedly because they were not presented on every trial. This explanation seems untenable given that, in a previous experiment, we found no difference between ADDH and control groups in their ability to attain and maintain preparation for an unexpected stimulus (Schachar, Logan, Wachsmuth, & Chajczyk, 1988).

By contrast, there is evidence that hyperactivity may be associated with greater or longer refractory effects. In a previous study, we found that the performance of ADDH subjects deteriorated more than that of control subjects during short interstimulus intervals (Chee *et al.*, 1989). This deficit diminished with practice, suggesting that the deficit was not associated with a relative deficit in capacity. The greater refractory effect associated with ADDH might be the result of the greater difficulty ADDH children experience in switching capacity from primary-task processes to secondary-task processes after the execution of the primary-task response, or it could be associated with their greater difficulty in processing feedback from the primary-task response (Welford, 1952, 1968).

For this study, it was theoretically and methodologically important to determine if capacity is related to IQ or age, especially because the clinical and normal groups differed in IQ. However, no association of age or IQ with capacity was observed in these data. This observation accords with studies of general mental capacity as it is measured in tasks which present new units of information and minimize the influence of prior experience (Globerson, 1983a, 1983b; Pascual-Leone, 1970). Performance on these tasks does not vary with IQ, but does improve with age. The fact that the capacity measured in the dual-task paradigm did not vary with age or IQ suggests that mental capacity and attentional capacity are not equivalent concepts.

A conservative interpretation of the results of this study would suggest that ADDH is not associated with deficient capacity. However, these results encourage speculation about other difficulties which ADDH subjects have in performing two tasks concurrently. The most likely explanations for these deficits lie with their time-sharing or response-related processes. However, these observations do not support the argument that ADDH subjects differ in any innate, constitutional, or biological way from normal children or from those with other pediatric psychiatric conditions. It does offer a potential explanation for the poor performance of hyperactive children on a variety of attention-demanding tasks, including our observations that ADDH is associated with deficient inhibitory control (Schachar & Logan, in press). In our study of inhibitory control, we found that hyperactive subjects were less able to inhibit a response. We interpreted this observation as evidence that hyperactive subjects were slower to respond to the signal to disengage an ongoing response. However, this deficit might have reflected a relative inability to detect the stop signal because of deficient resources. The results of our present study do not support this alternative, but instead raise the possibility that ADDH subjects have difficulty reallocating their capacity from response processes to inhibitory processes.

Finally, these results corroborate previous studies about ADDH and ADDH + CD groups. Although there was no evidence that the ADDH group differed significantly from the ADDH + CD group in capacity, concurrence cost, or secondary-task response latency, the ADDH group demonstrated greater deficits in these parameters than did the ADDH + CD group. We have consistently found that greater attention deficit is associated with pure hyperactivity (ADDH) than with hyperactive conduct disorder (ADDH + CD) or other pediatric psychiatric conditions (Chee *et al.*, 1989; Schachar and Logan, in press). The less prominent performance deficit among the ADDH + CD subjects supports the conclusion that attention deficit as measured in these laboratory tasks is specifically associated with ADDH rather than with disturbance in general. If deficient attention on laboratory tasks were a nonspecific correlate of psychopathology, a greater deficit in the mixed ADDH + CD group could be expected. Moreover, this raises the possibility that the mixed clinical presentation of ADDH + CD may be something other than hyperactivity which develops into conduct disorder because of an interaction between the cognitive deficit associated with ADDH and the environmental adversity associated with CD. It seems, rather, to argue that the hyperactivity of children with a diagnosis of conduct disorder may be a nonspecific epiphenomenon of their conduct disorder or at least a behavior which is not associated with cognitive deficit.

APPENDIX: CAPACITY THEORY OF OVERLAPPING–TASK PARADIGM

We assume that reaction time (RT) depends on the rate of processing (r) and the amount of information (i) to be processed. The rate of processing depends on the amount of available capacity, ranging from 0.0 when no capacity is available to some maximum value, r_{max}. RT to the secondary task (RT_{S}) reflects the time required to process the information conveyed by the secondary-task stimulus, i_{S}. Single-task conditions (i.e., when only one stimulus is presented) can be described by a simple equation:

$$\text{RT}_{\text{s.single}} = i_{\text{s}}/r_{\text{max}} \tag{1}$$

All of the capacity required is devoted to processing the task throughout the RT interval, so the RT is as fast as possible.

Dual-task conditions could also be described by a simple equation in which the rate of processing the secondary task, r_{dual}, is slower than the maximum (r_{max}) because less capacity is available than the processing requires. Thus,

$$\text{RT}_{\text{s.dual}} = i/\text{r}_{\text{dual}}$$

However, this simple equation applies only if the amount of available capacity stays constant throughout the interval in which the secondary task is performed. This is not the case in the dual- or overlapping-tasks paradigm. In that paradigm, the secondary-task stimulus is presented before the primary-task response is completed, so there is a period in which the secondary task must share capacity with the primary task. But there is also a period, after the primary-task response, during which the secondary task can receive all the capacity it demands. Thus, information about the secondary-task stimulus is accumulated at two different rates: r_{dual} during the first interval in which the two tasks overlap and $r_{\max}$ during the second interval in which only the secondary task is performed. The total time to perform the secondary task can be divided into two intervals, t_1 and t_2, reflecting the duration of the first and second phases. Thus,

$$\mathrm{RT}_s = t_1 + t_2 \tag{2}$$

Similarly, the total information acquired about the stimulus, i_s, can be divided into two parts, i_1 which is acquired during the first phase, and i_2 which is acquired during the second phase. Thus,

$$i_s = i_1 + i_2$$

This equation can be rearranged to express the amount of information to be gained during the second phase:

$$i_2 = i_s - i_1 \tag{3}$$

This equation illustrates the point that the more information gained during the first (overlapping-task) interval, the less there is that remains to be gained during the second (single-task) interval. The amount of information gained during the first interval depends on the rate of processing during that interval (r_{dual}) and on the duration of the interval t_1. Specifically,

$$i_1 = (r_{\text{dual}})(t_1) \tag{4}$$

The duration of the first interval is set by the experimenter, who manipulates the delay between the onset of the primary- and secondary-task stimuli or, as in this experiment, the delay between the mean RT to the primary task and the onset of the secondary-task stimulus. Varying the overlap in this way controls for differences in primary-task RTs. If overlap were not set in this way, longer secondary-task RTs would be confounded with longer primary-task RTs. Our manipulation varies the amount of overlap directly and uses the same values for different groups. Substituting Equation (4) into Equation (3) yields

$$i_2 = i_s - (r_{\text{dual}})(t_1) \tag{5}$$

The duration of the second interval (t_2) is determined by the maximum rate of processing ($r_{\max}$) and the amount of information still to be gained (i_2). Thus,

$$\begin{aligned} t_2 &= i_2/r_{\max} = [i_s - (r_{\text{dual}})(t_1)]/r_{\max} \\ &= i_s/r_{\max} - [(r_{\text{dual}})(t_1)]/r_{\max} \\ &= i_s/r_{\max} - (r_{\text{dual}}/r_{\max})(t_1) \end{aligned} \tag{6}$$

The meaning of Equation (6) is clearer if it is substituted into Equation (2) to represent the entire RT to the secondary task:

$$\begin{aligned} \text{RT}_s &= t_1 + i_s/r_{\max} - (r_{\text{dual}}/r_{\max})(t_1) \\ &= i_s/r_{\max} + t_1 - (r_{\text{dual}}/r_{\max})(t_1) \\ &= i_s/r_{\max} + t_1[1 - (r_{\text{dual}}/r_{\max})] \end{aligned} \tag{7}$$

The first term in Equation (7) is the expression for single-task RT for the secondary task, given in Equation (1). Substituting Equation (1) into Equation (7) yields

$$\text{RT}_s = \text{RT}_{s.\text{single}} + t_1[1 - (r_{\text{dual}}/r_{\max})] \tag{8}$$

According to Equation (8), the secondary-task RT will equal the single-task RT ($\text{RT}_{s.\text{single}}$) plus the overlap of the tasks (t_1) multiplied by a factor ($1 - r_{\text{dual}}/r_{\max}$) that reflects the ability to share capacity between tasks. This factor represents the slope of the function relating secondary-task RT to the delay between tasks. It must range between 0 and 1.

A value of 1 would occur if capacity could not be shared between tasks: Under those conditions, there would be no processing of the secondary task during t_1. The rate of processing (i.e., r_{dual}) would equal 0, so the ratio of r_{dual} to $r_{\max}$ would be 0. The factor would thus equal 1, producing the classic prediction of single-channel theory: Secondary-task RTs decrease as temporal overlap decreases, producing a slope of 1.

A value of 0 would occur if there were no competition for capacity between tasks. In that case r_{dual} would equal $r_{\max}$ and the multiplication factor would equal 0; secondary-task RT would be constant over variation in temporal overlap and equal to single-task controls.

The key factor operating here is r_{dual}. At one extreme, it predicts complete single-channel refractoriness; at the other, perfect time-sharing. At intermediate values, it predicts a slope less than 1. Observed values are typically less than 1, which indicates that some time-sharing is possible ($r_{\text{dual}} > 0.0$). Thus, we can conclude in our data that some secondary-task processing is going on during the temporal-overlap period.

Differences in the observed slope can be interpreted as evidence of the differences in the amount of underlying capacity: The basic idea is that the more capacity there is avaiable, the greater the rate of processing during the temporal-overlap period (i.e., the greater the r_{dual}) and, hence, the shallower the slope. The group with the shallower slope has more capacity.

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