Methylphenidate Effects on Task-Switching Performance in Attention-Deficit/Hyperactivity Disorder

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ABSTRACT

Objective: To examine the specificity of methylphenidate effects on the processes that support the ability to rapidly and accurately coordinate the performance of multiple tasks in children with attention-deficit/hyperactivity disorder (ADHD). **Method:** Twenty children with ADHD performed the task-switching paradigm while on and off medication. The paradigm involves switching between two different tasks, discriminating the value of a number presented on a computer screen and deciding how many numbers were present on the screen. The children also performed single-task control conditions. **Results:** Analyses of variance indicated the medication selectively enhanced the children's ability to rapidly and accurately switch between tasks and to focus attention on the currently relevant response set. **Conclusions:** This study helps to elucidate the nature of methylphenidate effects on the cognitive processes which support the ability to coordinate the performance of multiple tasks. Medication appears to selectively enhance inhibitory processes which support task-switching. *J. Am. Acad. Child Adolesc. Psychiatry*, 2001, 40(11):1277–1284. **Key Words:** attention-deficit/hyperactivity disorder, task-switching, executive control, cognition.

The main goal of this study was to examine the influence of medication on the ability of children with attention-deficit/hyperactivity disorder (ADHD) to rapidly and accurately switch between two different tasks. More specifically, we were interested in the specificity of medication effects on the component processes that support task-switching.

A number of researchers have argued that ADHD is associated with a deficit in executive control (Barkley, 1997, 2000; Bayliss and Roodenrys, 2000; Houghton et al., 1999; Klorman et al., 1999; Pennington and Ozonoff, 1996; Quay, 1996; Schachar et al., 1993). Executive control processes encompass those cognitive functions which are concerned with the selection, scheduling, and coordination of computational processes that are responsible for perception, memory, and action (Meyer and Kieras, 1997; Norman and Shallice, 1986; Shallice, 1994).

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Evidence in support of the executive control hypothesis of ADHD has been obtained in a number of recent studies. For example, Schachar et al. (1993, see also Pliszka et al., 1997; Tannock et al., 1989, 1995) reported that children with ADHD have a harder time aborting a preplanned motor response than do non-ADHD children and medications such as methylphenidate improved stopping performance. Kempton et al. (1999) observed that medication reduces planning errors on the Tower of London Task (Shallice, 1982). Other researchers have reported that children with ADHD have more difficulty ignoring irrelevant dimensions of stimuli or irrelevant stimuli in the visual field than do non-ADHD children (Houghton et al., 1999; Jonkman et al., 1999; Klorman et al., 1999). Thus data from these studies and others have suggested that a number of components of executive control are impaired in children with ADHD and some of these processes benefit from medication.

In a recent study we (Cepeda et al., 2000) examined the impact of ADHD on task-switching performance. The task-switching paradigm involves the performance of two simple tasks such as deciding whether a letter is a vowel or a consonant or deciding whether a number is odd or even. In one condition (i.e., the non-switch baseline or repetition condition), the same task is repeated a number of times. In the second condition (i.e., the switch or alterna-

tion condition), subjects switch from one task to the other. The switch and non-switch trials can be presented either in a single block of trials (Allport et al., 1994; Jersild, 1927) or in separate trial blocks (Gopher, 1996; Kramer et al., 1999; Rogers and Monsell, 1995). The time required to complete the executive control processes necessary to switch from one task to another, such as the selection from long-term memory and configuration in working memory of the appropriate processing algorithms and the inhibition of previously used processing algorithms, is inferred from the increased reaction time (RT) observed when a task switch occurs compared with the RT for the same task performed separately or in a run of trials of the same task (i.e., switch cost RT = switch trial RT – non-switch trial RT).

When we (Cepeda et al., 2000) administered the task-switching paradigm to ADHD children and non-ADHD children, we found that ADHD children exhibited a very specific deficit in the task. ADHD and non-ADHD children showed equivalent performance on the single tasks. However, the ADHD children showed substantially larger RT switch costs than did non-ADHD children. Furthermore, this large switch cost deficit was eliminated when the ADHD children were taking their medication (see also Kempton et al., 1999, for a similar effect with a different paradigm).

Although these results are quite interesting with regard to the specificity of ADHD deficits for executive (e.g., switch trials) compared with nonexecutive processes (e.g., non-switch trials) which subserve the ability to coordinate the performance of multiple tasks, they do not address the specific nature of the executive control processes which are detrimentally impacted by ADHD. Two different classes of executive control processes have been proposed to underlie task-switching performance.

A number of researchers have suggested that task-switching requires active preparation, such as the reconfiguration of internal task state and the loading of the proper algorithms into working memory for the subsequent task (DeJong, 2000; Gopher et al., 2000; Rogers and Monsell, 1995). Support for this proposal has been obtained in studies which have found that switch costs decrease as subjects are given more time to prepare for the subsequent task (Jersild, 1927; Kramer et al., 1999; Meiran et al., 2000; Rogers and Monsell, 1995). It has also been suggested that performance costs observed when individuals switch between tasks are due, in part, to interference over time from the preceding task set (Allport et al., 1994; Allport and Wylie, 1999, 2000; Mayr and Keele, 2000; Meiran, 2000). This interference, which Allport and colleagues termed *task set inertia* (TSI), decreases as the length of time increases, presumably from the decay of the previous task set from working memory. Providing additional time between a subject's response to one task and the next stimulus results in switch cost reduction, supporting the TSI proposal.

Meiran and colleagues (Meiran, 1996, 2000) have provided evidence that both preparatory processes and TSI can be observed in the same task-switching paradigm. They did this by systematically and orthogonally manipulating two different time periods between a subject's response and the subsequent stimulus. The response-to-cue interval (RCI) is the time between a subject's response and the cue which indicates which task should be performed next. The cue-to-target interval (CTI) is the amount of time between the cue indicating the task to be performed next and the stimulus for that task. Meiran (1996) reasoned that varying the RCI while holding the CTI constant would provide a measure of the decay of TSI because subjects would not know which task to prepare for next until they received the cue. On the other hand, varying the CTI while holding the time between the subject's response and the task stimulus constant would allow for an assessment of the ability of subjects to actively prepare for the next task. Meiran's (1996) results (see also Meiran, 2000) indicated that switch costs were reduced when both of these intervals were manipulated, suggesting a role for active preparation and TSI decay in switching between tasks.

We recently used this logic to explore lifespan differences (from 7 to 82 years of age) in the preparatory and TSI processes which support task-switching (Cepeda et al., in press). We found that all subjects benefited from longer CTIs, with children and older adults showing the largest benefits. These data suggest that preparatory processing can be successfully used to reduce switch costs throughout the lifespan. It is interesting that age-related differences were observed in response to the manipulation of the RCI. While adults benefited from longer RCIs, children showed the opposite pattern of results. That is, children's switch costs were smaller for the shorter than for the longer RCIs. These data suggest that older adults gradually revert to a neutral state, following a response, with regard to their expectations about the nature of the subsequent experimental trial (i.e., whether the same task or a different task will be performed next). On the other hand, the observation of larger switch costs with longer RCIs for children may suggest that children expect the same task to be

repeated. Such an expectation, coupled with longer intervals between a response and the cue for the subsequent task, may strengthen the representation of the task set, thereby increasing the switch costs with longer RCIs.

Hypotheses

The following hypotheses concerning the specificity of medication benefits for task-switching performance of children with ADHD utilize the logic and methods described above. First, we expected that children with ADHD, on and off medication, would benefit from additional time to prepare for the subsequent task on a task-switching trial just as we had previously observed for non-ADHD children (Cepeda et al., in press). Second, on the basis of previous research (Cornoldi et al., 1999) we expected that medication would have little effect on the preparatory processes indexed by the CTI manipulation. Third, we expected that switch costs would be larger, especially at the longer RCIs, when the children with ADHD were unmedicated than when they were medicated. This prediction is based on the assumption that medication aids children with ADHD in the inhibition of less relevant information, in the present case the task set for the previous trial. Fourth, we predicted that medication would help the children with ADHD to cope with response ambiguity, that is, when the currently relevant and currently irrelevant tasks called for different responses (Fig. 1).

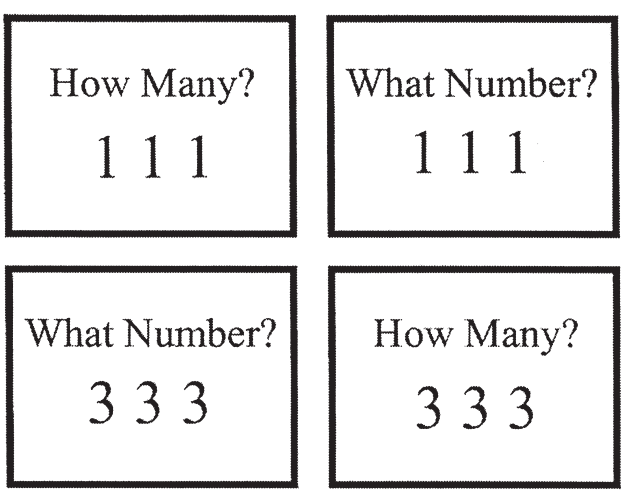

Fig. 1 Examples of stimulus displays used in the study. The top stimulus displays represent response-incompatible trials, since the 3 key is pressed when the "How Many?" task is performed and the 1 key is pressed when the "What Number?" task is performed. The bottom stimulus displays represent response-compatible trials, since the 3 key is pressed regardless of which task is performed.

METHOD

Subjects

Twenty children with ADHD (8–14 years old; average age = 8.9, SD = 1.7) participated in this experiment. Intelligence was estimated with the Kaufman Brief Intelligence Test (K-BIT). The average K-BIT composite score was 89.7 (SD = 10.6). All children had normal or corrected-to-normal vision (20/40 or better), as measured by a Snellen acuity chart. The ADHD subjects were from a clinical population of children receiving medical care from the third author (M.L.C.) through the Mobile County, Alabama, Public School System Title I School Health Program. Because of funding regulations, any child receiving services for an educational handicap such as learning disabilities or mental retardation was not eligible for Title I services and thus no ADHD subjects for this study had a suspected or known learning disability or mental retardation.

The assessment included clinical interviews with parent(s) and subject, review of classroom observations made by three school personnel (teachers or teacher/administrators), and a narrative and/or behavior log by a mainstream classroom teacher. All subjects had attention deficit disorder (based on *DSM-III-R* criteria), diagnosed with the computer-assisted version of the Diagnostic Interview Schedule for Children, Parent Version, and had ADHD diagnosed with *DSM-IV* clinical criteria. Subjects met *DSM-IV* criteria for either ADHD, combined type or hyperactive-impulsive subtype. Seventy percent of the children (14/20) were of the combined type, 30% (6/20) the hyperactive type alone. The mean Conners Teacher Rating Scale-28 (CTRS-28) Hyperkinesis Index off medication was 23 (range 20–30). The mean Hyperkinesis Index while using medication was 6 (range 1–13) for an average on-medication behavior improvement of 17 points. The dose of medication (methylphenidate) used for testing while the children were on medication was the individualized dose that had previously been shown to be clinically effective in the classroom (based on an improvement in the CTRS-28 Hyperkinesis Index). The average (both mean and mode) single dose of methylphenidate was 15 mg (range 5–30 mg). Medication was administered 30 to 90 minutes prior to experimental testing. With respect to demographics, the average family income was $ 16,255 (range $7,092–$37,492). Thirty percent of the children were white (6/20), and 70% (14/20) were African American. Seventy percent (14/20) of the children were male. Ten children with ADHD were unmedicated during the first session, and 10 were unmedicated during the second session.

The research protocols were approved by the institutional review boards of the University of Illinois and the University of South Alabama. All children were volunteers, and parental consent was obtained.

Stimuli

Stimuli for the task-switching paradigm were presented at fixation (the center of the screen, where subjects' eyes were focused). The four possible stimuli were either a single digit (1 or 3) or three digits (1 1 1 or 3 3 3). In other words, either one or three numerical ones or threes were presented. Above each target stimulus either the words "What Number?" or the words "How Many?" appeared, depending on which task was being performed on that trial (Fig. 1).

Apparatus

An IBM ThinkPad 760 laptop computer (Intel Pentium-75) with a 12.1-inch active matrix LCD screen was used in the experiment. Subjects responded by using the 1 and 3 keys on an IBM numeric keypad attached to the laptop. Subjects sat 60 to 80 cm from the laptop screen. This distance allowed easy discrimination of the stimuli.

Procedure

Subjects were tested in two experimental sessions on different days. The sessions were identical and consisted of a computerized task-switching paradigm in which accuracy and response time measures were collected. This paradigm used quasi-nonpredictable task changes, every 1, 2, or 3 trials. Two non-switch blocks (50 trials each) and four switch blocks (128 trials each) were collected during each session. The first non-switch block required the subject to identify the number present on the screen (either the number 1 or the number 3) using the 1 and 3 keys on the numeric keypad. The second non-switch block required identification of how many digits were present (either 1 or 3 digits). The words "What Number?" (for the What Number task) or "How Many?" (for the How Many task) preceded each numerical stimulus. Four different stimuli were used. Two were response-compatible (1 and 3 3 3), because both tasks required the same key press. The other two were response-incompatible (1 1 1 and 3), because different key presses were required for each task (see Fig. 1 for examples of response-compatible and response-incompatible trials). The eight switch blocks required subjects to alternate between the "What Number?" and "How Many?" tasks. In each block, half the stimuli were response-compatible and half were response-incompatible.

Subjects were cued on each trial with the words "What Number?" or "How Many?" presented above the stimulus to which the subjects responded. After each response, a variable amount of time elapsed between the response and the cue (i.e., a RCI of either 100 or 1,200 msec). This variation in the RCI was used to address TSI. The cue was present for a variable amount of time, either 100 or 1,200 msec, before the appearance of the numerical stimuli to which subjects responded. This was the preparation interval (i.e., the CTI). The RCI and CTI were varied orthogonally (i.e., all combinations possible were presented). Each combination of CTI (100 or 1,200 msec CTI) and RCI (100 or 1,200 msec RCI) was presented in a separate trial block. The order in which different types of switch blocks were presented was counterbalanced between and within subjects. A graphic illustration of the trial sequence is presented in Figure 2.

RESULTS

The data, mean RTs, and error rates obtained in the task-switching paradigm were submitted to repeated-measures analyses of variance with the following factors: medication condition (unmedicated and medicated), switch condition (non-switch trials in non-switch blocks, switch trials, non-switch trial following switch, second non-switch trial following the switch), response compatibility between tasks (compatible and incompatible), RCI (100 and 1,200 msec), and CTI (100 and 1,200 msec). The mean RT and error rate data for all of the experimental conditions are presented in Tables 1 and 2, respectively.

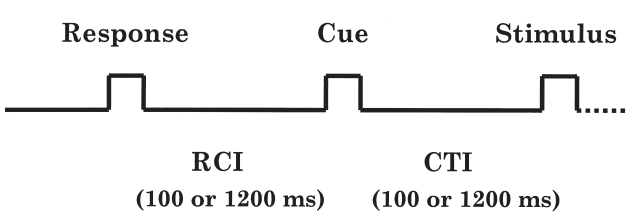

Fig. 2 A schematic illustration of the temporal sequence of the experimental trials. RCI = response-to-cue interval; CTI = cue-to-target interval.

Several main effects were obtained for the dependent measures. The children were faster ($F_{1,19} = 7.0$, $p < .02$) and more accurate ($F_{1,19} = 14.3$, $p < .001$) in their performance when medicated than when unmedicated. Performance was faster ($F_{3,57} = 47.3$, $p < .001$) and more accurate ($F_{3,57} = 31.0$, $p < .001$) on non-switch trials than on switch trials. The children were faster ($F_{1,19} = 36.1$, $p < .001$) and more accurate ($F_{1,19} = 59.1$, $p < .001$) when compatible responses were required for the currently relevant and irrelevant tasks. The children were able to benefit, in terms of speed of responding, from a longer CTI ($F_{1,19} = 27.9$, $p < .001$). Finally, the children responded more quickly with the shorter than with the longer RCI ($F_{1,19} = 30.4$, $p < .001$).

An additional set of effects enables a comparison of the switch costs obtained in this study to those in the extant literature. Consistent with the task-switching literature (Cepeda et al., in press; Gopher et al., 2000; Kramer et al., 1999; Meiran, 1996, 2000) switch costs, in terms of both RT ($F_{3,57} = 7.7$, $p < .01$) and accuracy ($F_{3,57} = 34.7$, $p < .001$), were larger for the incompatible than for the compatible trials. The effects of CTI ($F_{3,57} = 7.0$, $p < .01$) and RCI ($F_{3,57} = 45.8$, $p < .001$) were also larger for the switch than for the non-switch trials for RT. As can be seen in Table 1, switch costs were larger when subjects had less time to prepare (i.e., for the 100 msec versus the 1,200 msec CTI) and when there was a longer RCI between trials.

Of more theoretical interest, however, were the significant interactions of medication group with other experimental variables. Significant interactions between switch condition and medication group were obtained for both RT ($F_{3,57} = 4.5$, $p < .01$) and accuracy ($F_{3,57} = 4.6$, $p < .01$). The difference in RT between non-switch (863 msec for medicated and 917 msec for unmedicated children) and switch trials (1,528 for medicated and 1,765 for unmedicated children) was larger when subjects were unmedicated than when they were medicated. Error rates also increased more from the non-switch (1.3% for medicated and 1.4% for unmedicated children) to the switch trials (3.4% for medicated and 5.3% for unmedicated children) for the unmedicated children. Consistent with our prediction, this two-way interaction was qualified by a significant three-way interaction among switch condition, medication group, and RCI for RT ($F_{3,57} = 5.1$, $p < .01$; see Fig. 3). The differences in RT between switch and non-switch

TABLE 1
Reaction Times

Group	Response Compatibility	RCI	CTI	Trial Type: Non-Switch Trials in Non-Switch Blocks	Trial Type: Switch Trials	Trial Type: First Non-Switch Trial After Switch
Medicated	Compatible	100	100	968 (53)	1,599 (129)	1,570 (147)
		100	1,200	783 (47)	1,243 (128)	1,168 (109)
		1,200	100	841 (50)	1,712 (164)	1,674 (160)
		1,200	1,200	772 (39)	1,286 (122)	1,247 (123)
	Incompatible	100	100	955 (48)	1,720 (128)	1,637 (126)
		100	1,200	810 (43)	1,336 (103)	1,375 (124)
		1,200	100	947 (65)	1,840 (136)	1,813 (149)
		1,200	1,200	823 (45)	1,491 (144)	1,543 (121)
Unmedicated	Compatible	100	100	900 (44)	1,580 (153)	1,649 (211)
		100	1,200	885 (55)	1,304 (158)	1,414 (182)
		1,200	100	934 (60)	2,140 (174)	2,087 (209)
		1,200	1,200	816 (31)	1,736 (205)	1,713 (163)
	Incompatible	100	100	974 (52)	1,738 (181)	1,656 (159)
		100	1,200	901 (44)	1,471 (160)	1,480 (179)
		1,200	100	1,073 (55)	2,262 (146)	2,204 (184)
		1,200	1,200	853 (51)	1,883 (166)	1,778 (162)

Note: Reaction times are presented in milliseconds (standard errors in parentheses). RCI = response-to-cue interval; CTI = cue-to-target interval.

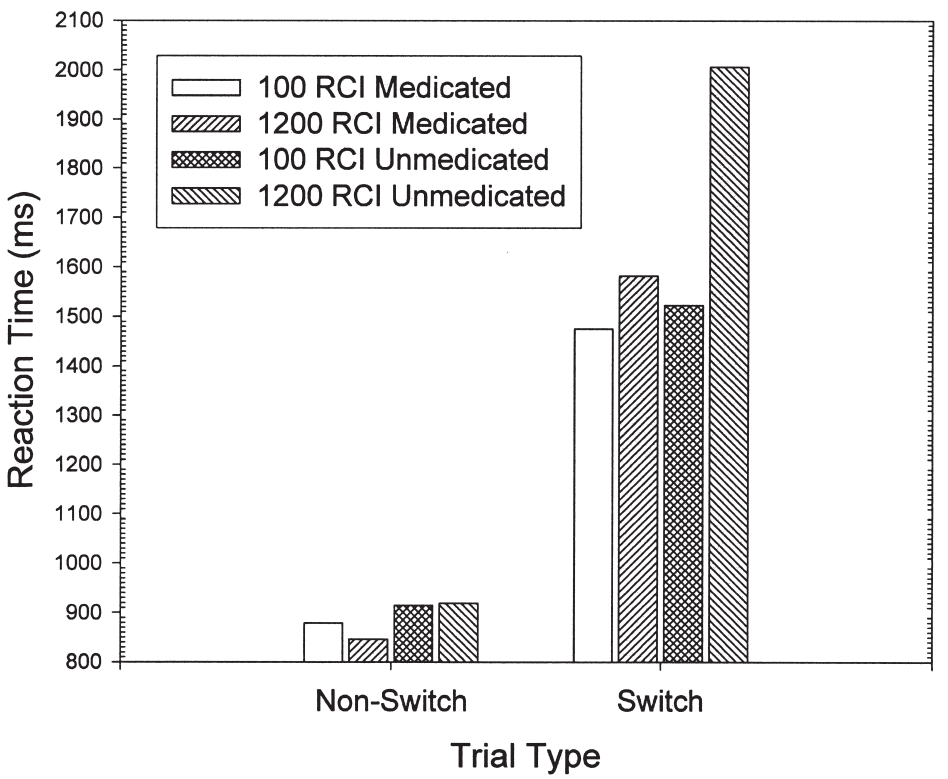

Fig. 3 Mean reaction times for the three-way interaction among the switch condition, medication, and RCI factors. RCI = response-to-cue interval.

TABLE 2
Error Rates

Group	Response Compatibility	RCI (msec)	CTI (msec)	Trial Type: Non-Switch Trials in Non-Switch Blocks	Trial Type: Switch Trials	Trial Type: First Non-Switch Trial After Switch
Medicated	Compatible	100	100	0.6 (0.4)	0.6 (0.3)	1.0 (0.4)
		100	1,200	1.2 (0.6)	0.2 (0.2)	0.2 (0.2)
		1,200	100	1.2 (0.9)	0.6 (0.4)	0.6 (0.4)
		1,200	1,200	0.0 (0.0)	0.2 (0.2)	0.6 (0.3)
	Incompatible	100	100	1.4 (1.0)	8.5 (1.6)	3.5 (1.3)
		100	1,200	2.0 (0.6)	6.9 (1.5)	4.4 (0.9)
		1,200	100	1.8 (0.7)	5.3 (1.1)	3.6 (1.0)
		1,200	1,200	2.2 (0.9)	4.8 (1.3)	3.9 (1.5)
Unmedicated	Compatible	100	100	0.8 (0.6)	1.2 (0.4)	1.6 (0.7)
		100	1,200	0.8 (0.4)	1.5 (0.5)	1.2 (0.5)
		1,200	100	0.0 (0.0)	1.2 (0.6)	0.6 (0.3)
		1,200	1,200	1.3 (0.9)	1.1 (0.4)	0.4 (0.3)
	Incompatible	100	100	3.0 (1.4)	8.8 (1.3)	6.3 (1.1)
		100	1,200	1.7 (0.8)	10.1 (1.4)	6.4 (1.2)
		1,200	100	0.6 (0.4)	7.3 (1.3)	6.8 (1.4)
		1,200	1,200	3.3 (1.1)	10.4 (1.7)	5.2 (1.3)

Note: Standard errors are shown in parentheses. RCI = response-to-cue interval; CTI = cue-to-target interval.

trials were larger for the subjects when unmedicated than when medicated when the short and long RCIs were contrasted. Finally, medication group interacted with response compatibility for the error rate measure ($F_{1,19} = 5.9$, $p < .05$). Error rates were larger for the incompatible than for the compatible trials for the subjects when they were unmedicated (5.8% for incompatible and 1.0% for compatible trials) than when they were medicated (4.0% for incompatible and 0.6% for compatible trials).

Finally, as illustrated in Tables 1 and 2, switch effects were larger and more robust when the non-switch trials from the non-switch block (i.e., Non-Switch) were compared with the switch trials (Switch) than when the switch trials were compared with the non-switch trials in the switch blocks (Non-Switch + 1 and Non-Switch + 2). However, there was also a significant main effect for error rate for the switch variable in the latter case ($F_{2,38} = 15.9$, $p < .001$). A finding of larger switch costs when comparing switch trials with non-switch trials in different trial blocks is not unusual (see Allport and Wylie, 2000; Cepeda et al., in press) and is likely the result of the carryover of TSI effects from the switch to the non-switch trials when these two trial types are included in the same block. That is, carryover of task-set activation from the switch trials to the non-switch trials reduces the difference in performance between these two trial types in the mixed blocks (i.e., blocks that include both switch and non-switch trials).

DISCUSSION

Medication had selective benefits for two components of task-switching performance. It substantially reduced the switching costs associated with the RCI manipulation. That is, as illustrated in Figure 3, medication reduced the costs observed for the longer RCI. It is important to ask why such RCI costs are observed, especially since adults show smaller switch costs with longer RCIs, consistent with Allport's TSI hypothesis. Although this question cannot be unequivocally answered by the present data, our observation of a larger RCI switch cost for the unmedicated than the medicated children is consistent with a series of studies by Sonuga-Barke and colleagues (1992, 1996), who found that children with ADHD have an aversion to long delays across a variety of tasks such that these children prefer to minimize delay even if it results in a loss in rewards. Our data suggest that it is not delay per se that causes difficulty for the children when unmedicated but long delays under uncertainty (i.e., in the switch blocks compared with non-switch blocks), especially when they are unable to prepare for the subsequent task (i.e., with a long RCI). It is interesting that error rates do not differ for the children when unmedicated than when medicated as a function of RCI. Thus the unmedicated children do not forget which task to perform as a function of their delay aversion but instead perform the next task more slowly. Whether this slowed

responding is a result of slowed preparation, when confronted by a delay, or instead more difficulty in overcoming a previous task set is a topic for future research.

We also found that medication aided the ADHD children in selectively ignoring the incorrect response on the response-incompatible trials (i.e., on those trials in which the relevant and irrelevant task called for different responses). That is, the children were able to reduce error rates when taking their prescribed medication. Such a result is consistent with the results of other studies which have found that interference effects observed for ADHD children can be reduced with medication (Cepeda et al., 2000; Kempton et al., 1999).

As hypothesized, medication did not have a significant effect on the children's use of a cue (i.e., the CTI manipulation) to prepare for a task switch. Indeed, the statistically equivalent benefits of longer preparatory intervals obtained for the children with ADHD, when on and off medication, in the present study were similar in magnitude to those obtained for non-ADHD children in a previous study in our laboratory (Cepeda et al., in press). These data suggest that children with ADHD can successfully capitalize on environmental cues to prepare to perform a task.

Limitations

Several limitations should be acknowledged. First, the sample size was relatively small, and a non-ADHD control group was not used. However, this limitation is mitigated by the fact that the basic task-switching cost obtained in this study was also obtained in a prior study which included a matched control group (Cepeda et al., 2000). Second, as discussed above, additional research will be necessary to resolve the interpretation of the RCI $\times$ switch condition $\times$ medication interaction. Finally, it would be interesting to compare, within the same population, ADHD and medication effects on task-switching and Wisconsin Card Sorting performance in an effort to delineate further the nature of processing deficit experienced in ADHD.

Clinical Implications

The present results extend our knowledge of the influence of stimulant medication on the executive control processes of children with ADHD. The results also suggest that some aspects of executive control necessary for the coordination of multiple tasks, such as preparation of a new task set, are relatively intact in children with ADHD. Future research will be needed to determine whether the ability of children with ADHD to prepare for a subsequent task is dependent on explicit environmental cues such as those used in this study or instead whether preparation can also be internally triggered (e.g., on the basis of the knowledge that the task will change every four trials). Additional research that bridges the psychological description of the components of task-switching for children with ADHD, like that discussed in this study, and the neuroanatomical circuits that implement the processes which support task-switching would also seem warranted (for example, see Bush et al., 1999). This would appear to be a particularly fruitful research direction given the given the role of frontostriatal circuits in both ADHD (Hale et al., 2000) and task-switching performance (DiGirolamo et al., 2000; Dove et al., 2000; Kimberg et al., 2000).

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