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Memory Capacity, Selective Control, and Value-Directed Remembering in Children With and Without Attention-Deficit/Hyperactivity Disorder (ADHD)

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Objective: The ability to select what is important to remember, to attend to this information, and to recall high-value items leads to the efficient use of memory. The present study examined how children with and without attention-deficit/hyperactivity disorder (ADHD) performed on an incentive-based selectivity task in which to-be-remembered items were worth different point values. ***Method:*** Participants were 6–9 year old children with ADHD ($n = 57$) and without ADHD ($n = 59$). Using a selectivity task, participants studied words paired with point values and were asked to maximize their score, which was the overall value of the items they recalled. This task allows for measures of memory capacity and the ability to selectively remember high-value items. ***Results:*** Although there were no significant between-groups differences in the number of words recalled (memory capacity), children with ADHD were less selective than children in the control group in terms of the value of the items they recalled (control of memory). All children recalled more high-value items than low-value items and showed some learning with task experience, but children with ADHD Combined type did not efficiently maximize memory performance (as measured by a selectivity index) relative to children with ADHD Inattentive type and healthy controls, who did not differ significantly from one another. ***Conclusions:*** Children with ADHD Combined type exhibit impairments in the strategic and efficient encoding and recall of high-value items. The findings have implications for theories of memory dysfunction in childhood ADHD and the key role of metacognition, cognitive control, and value-directed remembering when considering the strategic use of memory.

Keywords: ADHD, memory, cognitive control, metamemory, encoding strategies

Attention-deficit/hyperactivity disorder (ADHD) is characterized by an early onset of developmentally aberrant and impairing levels of inattention and/or hyperactivity-impulsivity (American Psychiatric Association [APA], 2000). In addition to its concurrent and prospective association with disrupted social/family relationships, substandard academic achievement, and elevated comorbidity (Barkley, Fischer, Edelbrock, & Smallish, 1990; Barkley, Fischer, Smallish, & Fletcher, 2002; Lee, Lahey, Owens, & Hinshaw, 2008; Owens, Hinshaw, Lee, & Lahey, 2009), ADHD is also associated with neuropsychological deficits across domains such as cognitive flexibility, problem solving, and working memory (Willcutt, Doyle, Nigg, Faraone, & Pennington, 2005). Working memory (WM) involves the active maintenance and manipulation of information, and is governed by executive control processes (Baddeley, 1992, 2007). A recent meta-analysis showed that children with ADHD have specific, robust deficits in WM, which are more pronounced in spatial WM tasks than in verbal WM tasks (Martinussen, Hayden, Hogg-Johnson, & Tannock, 2005). Furthermore, there is evidence that neuropsychological deficits, including problems with WM, partially mediate the persistence of ADHD over time, as well as the degree of functional impairment associated with ADHD (Halperin, Trampush, Miller, Mark, & Newcorn, 2008).

Douglas (1988) suggested that poor executive or self-regulatory processes may be implicated in the memory performance of children with ADHD, and subsequent hypotheses that prioritize the role of self-regulation and memory dysfunction in ADHD have emerged. For example, ADHD is associated with ineffective use of memory strategies and/or a failure to sustain effortful processing over time (O'Neill & Douglas, 1996). This may also be related to impairments in goal maintenance (Kane & Engle, 2003). A great deal of research shows that inhibitory control changes dramatically across the life span (Bedard, Nichols, Barbosa, Schachar, Logan, & Tannock, 2002; Zelazo, Craik, & Booth, 2004), and that children with ADHD have specific deficits in inhibitory control (Barkley, 1997). However, most research on WM, inhibition, and executive control has used tasks that do not provide strong incentives to selectively focus on and remember important or high-value information, at the cost of lower-value information. Typically,

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WM tasks do not discriminate items by their relative importance and WM performance is operationalized by how many items are retained. The present study expands on the literature on WM by examining how children with and without ADHD strategically focus on and retain high-value information in WM and how this ability changes with task experience.

The "selectivity task," a relatively novel method for examining how people can selectively encode and maintain high-value information, differs from traditional measures of WM in that it investigates how one selectively encodes information using strategic control, and has now been used in several studies with various populations (see Castel, Benjamin, Craik, & Watkins, 2002; Castel, Farb, & Craik, 2007; Hanten, Li, Chapman, Swank, Gamino, Roberson, & Levin, 2007; Watkins & Bloom, 1999). In the present study, we used a modified form of this paradigm, in which words with different values (e.g., points) were to be remembered by the participant. This procedure allows one to examine the extent to which people use value-based information to guide the efficient use of memory (e.g., by intentionally recalling higher valued items). The point value assigned to each item during encoding indicates how important each item is to remember. This task differs from traditional measures of episodic memory or common tests of WM span as it examines the strategic control of encoding high-value information. Whereas this value-directed remembering approach may share some resources with WM function, the selectivity task specifically allows for an examination of the strategic deployment of memory capacity, and the awareness of limited memory capacity (which can be conceptualized as a form of metamemory).

In the selectivity paradigm, participants are presented with lists of words, with each word in the list having a distinct value ranging from 1 to 12 points. Participants are instructed to remember as many words as possible, with the goal of maximizing their score, which is the sum of the point values of each recalled word. After recall, participants are told their score, and then are given a new list, with instructions to maximize their score. Using a selectivity index (SI) developed by Watkins and Bloom (1999; see also Hanten et al., 2007), we examined how selectivity changed with task experience. This SI is based on the participant's score (the sum of the points that were paired with the recalled items, or the "value" of the recalled items), relative to chance and ideal performance. The equation accounts for the participant's score relative to an ideal score that represents recall of only the most highly valued words at that level of recall. For example, if a given participant remembered four words, and the points associated with the words were 12, 10, 9, and 8, that participants' SI would be considered quite high. The ideal score for four words is $12 + 11 + 10 + 9 = 42$, whereas the score of the participant in question is 39. A chance score is based on calculating the average value of the points (using a 12-word list, with numbers ranging from 1 to 12, the average would be 6.5) and multiplying that value by the number of words recalled (in this case, 4). Thus, the SI in this case is $(39–26)/(42–26) = .81$. It is important to note that the index can range from 1 to -1. Perfect selectivity would result in an SI of 1.0, whereas selection of words with the lowest values (e.g., recalling the 1-, 2-, and 3-point words) would result in an SI of -1.0. A set of words recalled with no regard to their point values (i.e., showing no selectivity) would result in a selectivity index close to 0. Thus, the SI provides a selectivity, or efficiency, index based on one's actual score, relative to an ideal score, taking into account the number of words recalled.

Previous work using the selectivity task has shown that although healthy older adults recalled fewer words than younger adults, older adults enhanced their selectivity score (to levels similar to younger adults) by recalling high-value items (Castel et al., 2002). In addition, Castel and colleagues (2009) have shown that, despite recalling fewer items relative to younger adults, healthy older adults begin to develop a strategy (after several lists) of focusing on the higher value items to maximize their score. This ability to be selective was found to be somewhat impaired in older adults with early signs of Alzheimer's disease (Castel, Balota, & McCabe, 2009). In addition, Hanten and colleagues found deficits among children with brain injury and autism (Hanten et al., 2002, 2004). Of significance to the current study, Hanten and colleagues (2007) observed that the number of words recalled and selectivity were independent in a diverse sample of children, suggesting that perhaps different neural systems may contribute to memory capacity and the selective control of attention to high-value items. Thus, the SI provides a useful measure of memory efficiency that goes beyond simply measuring the overall quantity of recalled items (cf. Koriat & Goldsmith, 1996). These findings suggest an important distinction between memory quantity and efficiency across the life span.

The selectivity task can also provide a measure of how people learn which items to attend to across lists (i.e., with task experience). In this task, participants are presented with several lists or trials, and after each list are given feedback about their score, which is the sum of the point values of the words that they recalled. To achieve an optimal score (via efficient use of memory), participants need to focus on or attend to the high-value items and recall them on the immediate memory test. The number of items presented in each list (i.e., 12) is greater than the typical memory span of an individual, so many participants learn that they cannot remember all of the items, and, consequently, attempt to maximize their score by focusing on remembering only the most valuable items in each list. Participants typically learn to attend to high-value items, as reflected by the finding that the SI increases across successive lists and with task experience (Castel, 2008). The ability to selectively recall high-value items has been examined in children as young as 6 years old and has been shown to be impaired in children with traumatic brain injury (Hanten et al., 2004, 2007).

Given the need to selectively allocate attention to high-value words and to inhibit the allocation of attention to low-value words in the selectivity task, we were especially interested in how children with ADHD would perform on this task. To more rigorously ascertain the nature of WM deficits in ADHD, we administered the selectivity task to examine how value influences strategic encoding processes and attentional control. Specifically, we hypothesized that children with ADHD would show similar levels of overall recall relative to age-matched control children in the selectivity task, but that children with ADHD would have a specific deficit in directing attention to, and recalling, high-value items (and might possibly recall more low-value items) resulting in a lower SI. This would suggest that ADHD is associated with a specific deficit in value-directed remembering. In addition, the selectivity task measures how value-directed remembering emerges and/or changes with task experience via the use of multiple study-test lists, with different words and point values. We were also interested in whether children with ADHD can learn to focus on high-value items with task experience.

We were particularly interested in examining whether deficits in selectivity varied depending on ADHD subtypes (APA, 2000). ADHD Combined type (ADHD-C) is the most common subtype of ADHD and it is characterized by clinically significant inattention-disorganization and hyperactivity-impulsivity whereas ADHD Inattentive type (ADHD-I) is specific to inattention-disorganization only. The validity of ADHD subtypes is subject to debate (Geurts et al., 2002; Milich et al., 2001), and cognitive deficits have the potential to clarify the etiology of ADHD (Nigg et al., 2002). Specifically, executive function (EF) constructs, including planning, WM, and inhibition, have been proposed as potentially useful domains to discriminate children with different subtypes of ADHD. For example, there is some evidence that children with ADHD-C may exhibit greater deficits in planning relative to children with ADHD-I (Klorman et al., 1999), and relative to healthy controls (Nigg et al., 2002). However, other studies found no differences in EF between ADHD subtypes (Geurts et al., 2002; Houghton et al., 1999). Given that the encoding of high-value information in the selectivity task requires the allocation of attention to high-value items while concurrently inhibiting attention to low-value items, we predict that children with ADHD would display some impairments in terms of the SI. Although we do not predict large group differences in the total number of words recalled during the task, we hypothesize that control children will be more selective in the value of words recalled relative to the ADHD-C group. This type of finding would help clarify important differences between these two subtypes of ADHD and further specify the nature of cognitive and memory deficits associated with ADHD.

Method

Participants

Participants were 116 ethnically diverse 6–9 year old children ($M = 8.11$, $SD = 1.1$) with ADHD ($n = 57$) and without ADHD ($n = 59$) (see Table 1 for more details regarding the sample). Approximately 40% of the sample was White. Participants were recruited through presentations to families attending self-help groups, educators, and advertisements mailed to local elementary schools, pediatric offices, and clinical service providers. Participants were excluded from the study if they had a Full Scale IQ (FSIQ) <70, or if they had ever been diagnosed with a pervasive developmental disorder, seizure disorder, or any neurological disorder that prevented full participation in the study. Participants were required to live with at least one biological parent no less than half time and both parent and child were required to be fluent in English. Control children were recruited, screened, and assessed using the same methods as the probands.

Probands were further divided into subtypes based on the diagnostic criteria specified in the Diagnostic and Statistical Manual of Mental Disorders, 4th edition, Text Revision (*DSM–IV–TR*; APA, 2000) for ADHD-I ($n = 25$), ADHD Hyperactive/Impulsive Type (ADHD-H/I, $n = 6$), and ADHD-C ($n = 26$). Based on evidence that ADHD-H/I is a developmental precursor to ADHD-C (Lahey et al., 2004) and consistent with past research in this area (e.g., Mahone, Mostofsky, Lasker, Zee, & Denckla, 2009), we collapsed the six ADHD-H/I children into the ADHD-C group. To improve the external validity of the ADHD probands, participants with comorbid disorders (e.g., oppositional defiant disorder [ODD], anxiety, depression) were not excluded from participating. To avoid recruiting an unrealistic 'high-achieving' control group, which could exaggerate group differences, control children who met criteria for any disorder other than ADHD were not excluded from participating (the most common condition in controls was anxiety).

Background Measures

Wechsler Intelligence Scale for Children. *Fourth Edition* (WISC-IV; Wechsler, 2003). We administered three subtests from the WISC-IV to each child: Vocabulary, Symbol Search, and Arithmetic. The scaled scores were summed to estimate Full Scale IQ (FSIQ). This composite estimate of participant's FSIQ scores has been found to be highly correlated with the FSIQ based on the full 10 subtest battery administered to a normative sample ($r = .91$; Sattler & Dumont, 2004).

The Wechsler Individual Achievement Test. *Second Edition* (WIAT-II; Wechsler, 2002). To obtain an objective measure of reading ability, we administered the Word Reading subtest to all participants. The Word Reading subtest assesses phonemic awareness, rhyming, word sounds, and the ability to fluently read familiar words of increasing difficulty. Rather than using age norms, as the standard scores provide a metric based on age-expected ability, we used the raw score to ensure that all participants exhibited a minimum threshold for reading ability. Prior research indicates that the Word Reading subtest demonstrates discriminant validity in learning disabled children (Geary, Hoard, Byrd-Craven, Nugent, & Numtee, 2007), and is correlated with intelligence and working memory (Englehardt, Nigg, Carr, & Ferreira, 2008). See Wechsler (2003) for additional psychometric and demographic information from the normative sample.

Table 1
The Mean (and SD) Age, IQ and Percent Male for Each Group, and a Summary of the ANOVA That Examines Group Differences

Variable	Control ($n = 57$)	ADHD-I ($n = 25$)	ADHD-C ($n = 32$)	ANOVA F or χ^2	Group diff.
Age	8.11 (1.04)	8.40 (0.99)	7.87 (1.14)	1.73	—*
IQ	110.03 (15.80)	104.80 (13.42)	106.81 (12.59)	1.30	—
Male (%)	61	80	78	4.47	—♀

* For age, there was a trend for ADHD-I > ADHD-C, $p = .07$. ♀ For % male, there was a trend for ADHD-I > Control, $p = .09$, and ADHD-C > Control, $p = .1$.

Diagnostic Interview Schedule for Children. *Fourth Edition* (DISC-IV; Shaffer et al., 2000). To ascertain whether children met *DSM–IV* diagnostic criteria for ADHD and its subtypes, we administered the computerized DISC-IV to each participant's parent. This highly structured interview probes required ADHD symptom levels, duration/persistence, age of onset, and functional impairment. Test–retest reliability for ADHD diagnosis as determined by the DISC was between .51 and .64 in the *DSM–IV* Field Trials (Lahey et al., 1994). In addition, diagnostic designations from the DISC have shown predictive validity in other studies of ADHD (Lee et al., 2008; Owens et al., 2009).

Procedures

Participants' eligibility for the study was determined through an initial telephone screening. After eligibility was established, parents completed behavior rating scales and were invited to our research laboratory for in-person assessments of child behavior and family functioning. Parallel rating scales of child behavior were also completed by each child's primary teacher. Whenever possible, children were assessed in our laboratory without psychotropic medication (including stimulants). If a child normally received medication, his or her parents and teachers were instructed to provide ratings based on the child's unmedicated behavior. Similar procedures have been used in other ADHD studies, including the Multimodal Treatment Study of ADHD (Hinshaw et al., 1997; Lee et al., 2008). All interviewers were blind to the child's diagnostic status. Children assented to all procedures. The UCLA Institutional Review Board approved all study procedures.

Parents were interviewed using the DISC-IV (Shaffer et al., 2000). Children were diagnosed with ADHD if they met full diagnostic criteria according to the DISC (based on *DSM–IV–TR* criteria).

Selectivity Task

In the present study, we used a modified version of the paradigm, in which words with different values (i.e., points) were to be remembered by the participant. Before participants began the selectivity task, they were told that they would be presented with lists of 12 words, and that each word would be paired with a number, (i.e., a point value) ranging from 1 to 12, which indicates how important it is to remember the word (e.g., much like a game in which the words are worth different amounts of money). Children were told that each word and number would appear on the screen for 2 s, followed by another word and number. Participants were told that after they see each list of words, they will see the word "REMEMBER" on the screen, and that their job would be to recall (say out loud) as many of the words from that list as possible within 30 s with the goal of maximizing their score, which is the sum of the point values of each recalled word. They were told that they should pay as much attention to the words and the numbers, even though it would be difficult to remember all of the words. Participants were told they just needed to say the word itself, and not the value of the word, and that the experimenter would record their response. To further emphasize the procedure, participants were told that this was like a "game" with words and points. They were told that the more points that they earned, the more prizes they could choose at the end of the session. The experimenter provided each participant with examples of the scoring procedure, such that participants were made aware that their score would equal the sum of the point values of the words they recalled (e.g., if you recall three words [table, donkey, and apple] and these words were paired with the 8-, 10-, and 12- point values, then your score would be 8 + 10 + 12, which is 30). After being invited to ask any questions they had about the procedure, participants were presented with the first list and recall session, after which they were once again prompted to ask any questions about the procedure. After the child finished recalling items from each list, the experimenter informed the child of the point total he or she earned for that list and provided him or her feedback about his or her score. The participant then began the next list, and eight lists were presented during the session.

Materials and Design

The words were presented visually, one at a time in 2-s intervals on the center of a computer screen in white Times New Roman 48-point font on a black background. The words in each list were concrete nouns that contained between four and five letters, and were selected such that children would be highly familiar each word. The mean hyperspace analog to language (or HAL, a model of semantics which derives representations for words from analysis of text, Burgess & Lund, 1997) frequency of the words was 33,374 (Log HAL = 9.03), as obtained from the elexicon.wustl.edu Web site (see Balota et al., 2007). The words were randomly sorted into eight lists of 12 words. Each participant was shown eight lists, and engaged in recall after each list. In each list, each word was randomly assigned a unique number between 1 and 12, and arranged such that a different value was present in each serial position for each list (to ensure that the higher and lower value words were well distributed across serial positions). To ensure that this was the case, the mean value of each word for each serial position ranged from 6.2 to 6.8.

Results

The mean age, FSIQ, and gender distribution of each group is listed in Table 1. The selectivity task provides several measures of memory performance, including capacity (mean number of words recalled), sensitivity to value (how well one successfully recalls words based on the point value of the words), and efficiency (the SI, which provides a more concise measure of selectivity that takes into account the ideal performance based on number of words recalled). The results are presented below in terms of (1) overall recall performance and measures from the selectivity task as a function of diagnostic status (i.e., ADHD-C vs. ADHD-I vs. controls), (2) the degree to which each group was sensitive to point value, (3) performance as a function of the first and second half of the task, (4) the relationship between selectivity, recall and measures of WM, age, and IQ; and (5) and exploratory factor analyses to examine the possibility that low- and high-value items would comprise distinct factors in the present study (cf. Castel, Balota, & McCabe, 2009).

Recall and SI. The results for overall recall performance for total correct words recalled, total score, mean selectivity index, and number of intrusions for each group are displayed in Table 2. No significant differences were found among the three groups for

Table 2
The Mean (and SD) Number of Words Recalled, Total Score, the SI and Number of Intrusions for Each Group in the Present Study, and a Summary of the ANOVA That Examines Group Differences in the Selectivity Task Measures

Variable	Control (n = 57)	ADHD-I (n = 25)	ADHD-C (n = 32)	ANOVA F	Group diff.
Words	3.36 (0.85)	3.23 (1.37)	3.18 (1.07)	0.38	—
Score	25.59 (7.30)	24.97 (10.58)	22.59 (8.37)	1.36	—
Selectivity	.27 (.29)	.30 (.30)	.14 (.18)	3.70	C < N, I
Intrusions	0.42 (0.48)	0.48 (0.42)	0.30 (0.42)	1.32	—

Note. Words = total correct words recalled; Score = total score; and Intrusions = number of intrusions.

number of words recalled, total score, and number of intrusions. However, analysis of variance (ANOVA) revealed a significant group effect on the SI, $F(2, 113) = 3.70$, $MSE = .07$, $\eta_p^2 = .06$, $p = .028$. Post hoc comparisons (Least Significant Difference [LSD]) revealed that the ADHD-C group exhibited significantly lower SI than both the control and ADHD-I groups (Cohen's d = .57, $p = .021$ and $d = .69$, $p = .017$, respectively), which did not differ from each other ($p = .59$). To test if value-directed remembering was independent from overall recall performance, we compared the SI as a function of group (Controls, ADHD-I, ADHD-C) while controlling for word recall performance using analysis of covariance (ANCOVA). The results of the ANCOVA were essentially identical to the original ANOVA, strengthening the inference that the deficit in value-directed remembering found in children with ADHD-C was not spuriously related to group differences in recall performance. Namely, there was still a group difference in the SI, $F(3, 112) = 3.59$, $MSE = .07$, $\eta_p^2 = .06$, $p = .031$, with post hoc analyses revealing the same pattern of significant group differences. Overall, individuals with ADHD-C demonstrated a specific deficit in SI that was not simply an artifact of a deficit in overall recall.

To further examine whether the observed differences in SI were secondary to potential demographic or clinical correlates of ADHD and WM, we repeated the above ANCOVA including gender, age, and FSIQ as covariates. Once again, the results survived these stringent covariates and were consistent with unadjusted models. Specifically, diagnostic status was unrelated to the total number of correct words recalled and the total score, but it was associated with selectivity, such that the ADHD-C group was significantly less selective than both the control and ADHD-I groups, who did not differ from each other.

The relationship between number of words recalled, overall score (the total value of all the recalled items in a list), SI, number of intrusions, age, FSIQ, sex, and reading ability is presented in Table 3. It is important to note that the number of words recalled and SI were not correlated, suggesting the divergent validity of SI from aggregate WM (see similar results from Hanten et al., 2007). Age was related to memory capacity and total score, but it was not correlated with SI (this may have been because of the somewhat restricted age range in the present study, as Hanten et al., 2007 has shown that SI was related to age in a sample of 6–18 year old children). Males were significantly more selective after controlling for ADHD status and other covariates, although there were relatively few girls in the sample. FSIQ positively predicted SI after controlling for ADHD status, and in addition to age, also predicted words recalled and total score. Finally, raw reading ability was not significantly correlated with any of the measures, but FSIQ was related to all measures with the exception of age.

The Overall Effect of Value on Recall

Figure 1 displays the mean probability of recalling a word based on the point value of each word. An averaging technique was used (see Jones & Roediger, 1995) that takes into account the mean of neighboring point values. Overall, participants' recall was sensitive to point value, with higher value words being recalled more often than lower value words. The shape or slopes of these functions for each group provides insight regarding the degree of selectivity, or sensitivity to value. To examine whether ADHD status varied by overall effect of value on recall, we conducted a 3 (group) × 12 (word point value) repeated measures ANOVA. No main effect was found for group, $F(2, 113) = 0.35$, $MSE = 0.09$,

Table 3
The Correlation Matrix for the Measures in the Present Study

Variables	Words	Score	SI	Intrusions	Age	FSIQ	Sex
Words	1						
Score	.90***	1					
SI	.07	.50***	1				
Intrusions	−.30***	−.34***	−.15	1			
Age	.44***	.43***	.14	−.09	1		
FSIQ	.19*	.30***	.31***	−.38***	−.16	1	
Sex (male = 1)	−.09	.03	.23*	.02	−.14	−.31***	1
Raw reading ability	−.10	−.08	.04	−.16	.16	−.11	−.03

Note. Words = total correct words recalled; Score = total score; SI = Selectivity Index; and Intrusions = number of intrusions.
* $p < .05$. *** $p < .001$.

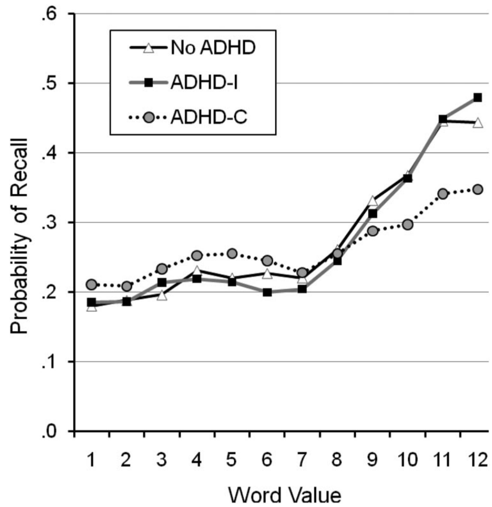

Figure 1. The mean probability of recall as a function of point value in the selectivity task for the three groups.

$\eta_p^2 = .01$, $p = .703$; however, there was a main effect for point value, $F(11, 103) = 16.67$, $MSE = 0.03$, $\eta_p^2 = .64$, $p < .001$, indicating that overall, memory performance was influence by point value. The interaction of group and point value was marginally significant, $F(11, 104) = 1.84$, $MSE = 0.05$, $\eta_p^2 = .16$, $p = .05$, suggesting that the group differed in the degree to which point value influenced recall. This trend is also illustrated by larger group differences in the recall of high-value words, relative to the lower value words, for the ADHD-C group relative to the other two groups (see Figure 1). This observation is consistent with the finding that children with ADHD-C have a lower SI than children in the other two groups.

Performance by Task Half

To examine group performance across the task, we divided the eight lists into two groups, or halves (Lists 1–4 = Half 1, and Lists 5–8 = Half 2) and conducted a repeated measures ANOVA to examine group performance on each half (see Figure 2A). There was no main effect of group. Performance for words recalled was found to significantly vary by task half, $F(1, 113) = 9.02$, $MSE = 0.42$, $\eta_p^2 = .07$, $p = .003$, such that fewer words were remembered on the second half of the task relative to the first half (3.43 vs. 3.14), perhaps because of proactive interference or use of value-directed strategies on later lists. No group by task half interaction was found ($p = .89$), suggesting that the decrease in performance was consistent across all groups. Although memory for words diminished in the second half, SI (see Figure 2B) was found to vary significantly by half, $F(1, 112) = 6.75$, $MSE = 0.04$, $\eta_p^2 = .06$, $p = .011$, such that performance was significantly more efficient on the second half of the task (.21 vs. .27). The main effect for group was significant, $F(2, 112) = 3.86$, $MSE = 0.14$, $\eta_p^2 = .06$, $p = .024$, and no group-by-half interaction was observed ($p = .521$). Participants' total score across the two halves did not significantly differ, $F(1, 113) = 1.45$, $MSE = 27.71$, $\eta_p^2 = .01$, $p = .231$, and half-by-group interaction was not significant ($p = .88$). It appears that the increased selectivity in the second half of the task may have compensated for participants' overall reduction in recalled words, thereby resulting in no overall difference in the total score by list half. These findings suggest that all three groups likely understood and followed the instructions, and learned to become more selective with task experience.

Exploratory Factor Analysis

According to the value-directed remembering framework (Castel, 2008), participants selectively encode items according to their (higher) value. If this is the case, low- and high-value items should comprise distinct factors. This has been shown in a previous study of younger and older adults (Castel et al., 2009). In addition, recent models of memory capacity and attention (e.g., Cowan, 2001) suggest that people can maintain a fixed number of items (e.g.,

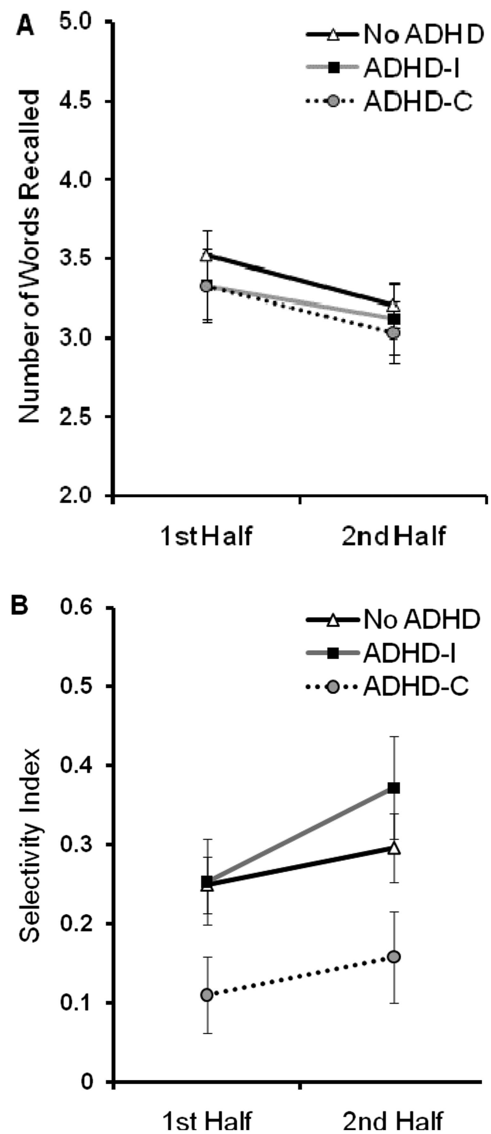

Figure 2. The mean number of words recalled (Figure 2A, top panel) and selectivity index (Figure 2B, bottom panel) as a function of the first half (Lists 1–4) and the second half (Lists 5–8) of the task for the three groups.

four, plus or minus one unit) in a short-term activated working memory store. To empirically examine the underlying structure of recalled word values, the average recall level of items of each value, 1–12, were submitted to an exploratory factor analysis. Exploratory factor analysis (or EFA) reduces a large number of variables, or items, to a smaller number of factors based on similarities among those items. In the present context, factor analysis can be used to examine whether the 12 items of differing values in each list could be reduced to a smaller number of factors, and furthermore, whether low- and high-value items created separate factors that could be distinguished from one another. We conducted an initial EFA on the entire sample, using a principal components analysis, keeping factors with eigenvalues greater than one, and then submitting the factors to a varimax rotation.

In the overall sample, the EFA distinguished two factors that accounted for a total of 48.45% of the variance in recall performance. The stronger of the two factor loadings for each item is highlighted in bold text in the Table 4. It was necessary to combine the two ADHD subtypes into a single ADHD group to give the EFA sufficient power. The factor loadings can be interpreted as the strength of the relationship between that item and the factor, in much the same way that a correlation coefficient would be interpreted. As shown in Table 4, the first factor clearly included items of Values 1–7, and the second factor included items of Values 8–12. Thus, based on the pattern of recall across all individuals, there was a clear division between the five highest value items and the seven lower value items. This two-factor solution was then applied to children who did not have ADHD, and children who have ADHD separately (the two ADHD groups were combined to form a single ADHD group to have sufficient power for the EFA). As shown in Table 4, the findings from the overall sample are consistent with the factor loadings of children who did not have ADHD. However, the ADHD group showed a slightly different pattern, as only the top four values formed one factor, whereas the other eight values formed another factor. Although very similar to the children without ADHD, it seems as if the ADHD group may have a slightly smaller "high importance span," and/or potentially a different "high-value threshold" for this group, given that factor only included the four highest value items, whereas the five most important value formed a factor for controls. We should note that the results from EFA should be treated with some caution given the need to combine the two ADHD groups and the relatively small sample size. However, it is interesting to note that a similar two-factor solution was also obtained by Castel et al. (2009) with a sample of younger adults (ages 18–25) and older adults (ages 65–85), adding some useful insight regarding how these factors contribute to the efficient use of memory, given constraints on memory capacity.

General Discussion

The present study examined how children with and without ADHD performed on an incentive-based selectivity memory task. In general, the results suggest that overall memory capacity and the ability to selectively encode high-value items are empirically distinct. Although all children recalled more high-value items than low-value items (see Figure 1) and showed improvements in selectivity with practice (see Figure 2B), children with ADHD-C did not efficiently maximize memory performance (as measured by a selectivity index) relative to children with ADHD-I and healthy controls, who had similar performance (see Table 1). This pattern of results suggests a specific deficit in the strategic and efficient encoding and recall of high-value items for children with ADHD-C, although it is important to note that all groups showed improvements in selectivity with practice (see Figure 2B).

The findings have important implications for theories of cognitive control and working memory dysfunction in children with ADHD. Whereas this value-directed remembering approach may share some resources with WM, the selectivity task specifically examines the strategic deployment of memory capacity, and the awareness of limited memory capacity; a form of metacognition. The strategic control of attention may be a key mechanism in the context of value-directed remembering and cognitive control, and the present study examined how this may be impaired in children with different subtypes of ADHD. Previous research (Douglas, 1988; O'Neill & Douglas, 1996) has suggested that ADHD is

Table 4
Factor Analysis of Words Recalled as a Function of Point Value for All Groups, Showing the Two Primary Factors Underlying Recall Performance for Low-Value (1–7) and High-Value Items (8–12)

	All groups		Controls		ADHD (both)	
	V1–V7	V8–V12	V1–V7	V8–V12	V1–V7	V8–V12
Value 1	**.56**	.02	**.69**	−.03	**.43**	.14
Value 2	**.64**	−.02	**.60**	−.13	**.70**	.07
Value 3	**.66**	−.39	**.63**	−.39	**.66**	−.41
Value 4	**.64**	.01	**.67**	−.02	**.60**	.05
Value 5	**.67**	−.13	**.70**	−.11	**.65**	−.19
Value 6	**.60**	.17	**.63**	.61	**.55**	.43
Value 7	**.69**	.08	**.56**	−.75	**.80**	−.05
Value 8	.36	**.52**	.11	**.23**	**.60**	.30
Value 9	.36	**.70**	.12	**.39**	.56	**.60**
Value 10	−.02	**.73**	−.18	**.77**	.18	**.63**
Value 11	−.29	**.76**	−.42	**.68**	−.14	**.83**
Value 12	−.15	**.74**	−.16	**.64**	−.09	**.81**
% Variance	26.66	21.79	26.17	21.74	29.89	21.69

Note. The stronger of the two factor loadings for each item is in bold text.

associated with the utilization of ineffective strategies in memory tasks and/or a failure to sustain effortful processing over time, which may also be related to impairments in goal maintenance (Kane & Engle, 2003). In addition, research indicates that inhibitory control changes considerably across the life span (Bedard, Nichols, Barbosa, Schachar, Logan, & Tannock, 2002; Zelazo, Craik, & Booth, 2004), and that children with ADHD may exhibit specific impairments in inhibitory control (Barkley, 1997). The present findings add to this literature, and further show that children with ADHD-C, but not ADHD-I, may have a specific deficit in the ability to selectively focus on and recall high-value information. This deficit may be because of impairments in both allocating attention to high-value information, as well as inhibiting lower-value information. However, the observed impairment could be influenced by the higher impairment (e.g., elevated comorbidity) associated with ADHD-C. Incorporating multiple clinical comparison groups (e.g., anxiety, depression, disruptive behavior disorders) would provide insight into the *specificity* of these deficits (e.g., ADHD only or associated with child psychopathology more generally; see also Øie, Sundet, & Rund, 1999). Current research suggests that children with ADHD-C may exhibit greater planning deficits relative to children with ADHD-I (Klorman et al., 1999) and healthy controls (Nigg et al., 2002). The present study extends these findings to situations in which children must successfully allocate attention to high-value information and have an agenda that guides encoding and metacognitive processes (Ariel, Dunlosky, & Bailey, 2009; Castel, 2008; Castel et al., 2009); functions that are all likely related to executive control. In addition, the present findings may be useful in differentiating ADHD subtypes, particularly in early childhood, by using selectivity and metacognitive measures that capture the ability to strategically encode high-value information.

It is important to note that all groups showed some improvement in selectivity with task experience (Figure 2B), which suggests that each group understood the task instructions, and could implement some degree of value-directed remembering. In addition, all groups were able to maximize their score with successive study-test cycles, and this may be because of the use of feedback and monitoring performance. Although the ADHD-C group displayed significantly lower selectivity than the ADHD-I and control groups, it is promising to note that children with ADHD-C improved their selectivity with task experience. It should be noted that we assumed that the incentives (point values) were equally motivating to both children with and without ADHD. However, it may be the case that the SI would improve more dramatically in ADHD children if other more enticing or meaningful incentives (e.g., money, or time on a video game) were used (see also Kohls, Peltzer, Herpertz-Dahlmann, & Konrad, 2009). In addition, the putative role of specific goals and motivation in potentially enhancing SI may be of great importance for training selectivity in children with ADHD. Thus, this type of modification could provide some future direction for training studies that involve directing attention to important information, in the context of meaningful and achievable goals. In general, it might be the case that ADHD leads to certain impairments in selectivity and attentional control, but with experience and feedback, children with ADHD can learn to attend to important information (at least in the present task, and perhaps more so in tasks with diversified incentives). This type of observation has important implications for future research and training interventions (see also Klingberg et al., 2005), as well as the potential for educational remediation. Thus, further studies might address whether children with ADHD-C are able to retain improvements in this skill over a longer-term (e.g., hours, days), and if appropriate incentives can greatly enhance the ability to selectively attend to important information.

Another noteworthy finding emerged from an exploratory factor analysis that revealed two distinct factors related to recall of high- and low-value items. Generally speaking, the five highest value items loaded on one factor and the seven lowest value items loaded on another. A similar result has been found for older adults (Castel et al., 2009). This factor structure can be seen, to some extent, by a visual inspection of Figure 1, which shows a relatively flat recall function for low-value items for all groups, with a sharp increase in recall somewhere between items of values 7–9. However, for the ADHD group, the factor loading was slightly different, with fewer items being grouped with the high-value factor. Recent models of working memory capacity and attention (e.g., Cowan, 2001) suggest that people can maintain a fixed number of items (e.g., four, plus or minus one unit) in a short-term activated working memory store. The present findings from the EFA may suggest that ADHD leads to a slightly reduced memory span in the present task, or perhaps the ADHD individuals had a different "value threshold" in terms of determining what values were important to remember, and thus strategically focused on these higher values, which may reflect accurate metacognitive monitoring. However, in general, the EFA should be treated with some caution given the need to combine the two ADHD groups, and the relatively small sample size for these groups.

One important theoretical issue is whether the deficit observed in the ADHD-C is one of impairments in encoding operations or retrieval dynamics. Given that the ADHD-C group displayed poorer recall of high value items, but greater recall of lower value items, relative to the other groups, our data suggest that attentional control at the encoding phase is implicated in lower selectivity, However, to clearly address the retrieval aspects, it would be necessary to employ both a free recall test (as done in the present study), as well as a final recognition test, to determine if the ADHD-C group was still impaired in identifying high-value items. Previous research in the cognitive aging literature has shown that older adults display a specific deficit in tests of free recall, but to a much lesser extend on tests of recognition (e.g., Craik & McDowd, 1987). In the context of value-directed remembering, Castel et al. (2007) use both recall and recognition, and found that compared to younger adults, older adults were slightly worse at recognizing high-value items, but were in fact slightly better at identifying low-value items, an interesting finding that is consistent with the inhibitory deficit hypothesis (Hasher et al., 2001). In the present study, if a recognition test was used, then ADHD children might successfully identify high-value items, suggesting that retrieval dynamics are not impaired, and play a key role; however, if the ADHD group showed a similar pattern to older adults (poorer recognition for high-value items, and better recognition for lower value items, relative to the control group), then this would be consistent with an inhibitory deficit at encoding (e.g., Barkley, 1997). Thus, further research with different types of orienting tasks and memory tests would be useful to more accurately identify the locus of the impairment.

In a broader context, the present findings are in line with Hanten and colleagues (2007), who found that selective learning improves with age in healthy children (ages 6–18), and impairments in selective learning are associated with brain injury and autism (Hanten et al., 2002, 2004). The present study reflects previous research (Hanten et al., 2007) that indicates that the number of words recalled and selectivity were at least partially independent, suggesting that perhaps different neural systems may contribute to memory capacity and the selective control of attention to high-value items. Speculatively, this selectivity process may be related to frontal lobe development and function (West, 1996), and with age this process become more efficient, with pronounced changes accompanied by pathological cognitive aging, such as the case with Alzheimer's disease (Castel et al., 2009).

We should note several important caveats regarding the present study, as well as potential future directions. First, the sample size was somewhat restrictive in terms of age range and while comparable to other similar studies, additional representation of the ADHD subtypes, as well as a larger sample of girls with ADHD, might yield greater insight. The current findings suggest that there may be differences in male and female children in the ability to selectively remember words on this task (as suggested by the correlation between gender and SI in Table 3). Future research could explicitly test whether there are significant sex differences, given that previous research has yielded inconsistent findings (e.g., Lowe, Mayfield, & Reynolds, 2002; Lynn & Irwing, 2008). Second, it would be useful to further relate performance on the present task to other higher-level measures of cognitive functions, as well as long-term retention of valuable information. Third, future studies could use prospective, longitudinal designs to test whether selectivity is predictive of important outcomes, including academic achievement and other neuropsychological dimensions. Finally, the present work uses incentive-based learning in the context of value-directed remembering, and it would be important to determine whether training in various forms of value-based encoding can be used to reduce deficits that are typically exhibited in children with ADHD in more applied classroom settings.

In summary, the present study used a novel approach to examine the selective learning of high-value information in children with and without ADHD. More specifically, although all groups were still capable of remembering high-value information, we found that children with ADHD-C have an impairment in selectivity and the efficient use of memory, relative to an age-matched children with ADHD-I and a control group, although all groups were still capable of remembering high value information. The present findings are consistent with theories regarding impairments in inhibition and working memory capacity in ADHD (Barkley, 1997; Bedard et al., 2002), but also suggest that value-directed remembering may be impaired in children with ADHD-C. The role of cognitive control in various special populations has been of considerable interest, and the study of selective learning has the potential to provide more precise conclusions regarding the specific aspects of cognitive control (e.g., working memory, inattention) that are impaired in these populations. The findings may also provide some insight regarding the early diagnosis and differentiation of ADHD subtypes, and may also contribute to the development of intervention and treatment techniques in clinical and educational settings.

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