Journal of Attention Disorders
Volume 13 Number 5
March 2010 505-515

10.1177/1087054708329970
http://jad.sagepub.com
hosted at
http://online.sagepub.com

Memory for Object Locations in Boys With and Without ADHD

Sarah G. Reck
Alycia M. Hund
Steven Landau
Illinois State University

Objective: To determine whether 7- to 12-year-old boys with ADHD, relative to non-ADHD age-mates, exhibit greater difficulty learning and remembering object locations. The second purpose was to examine the functional utility of mnemonic strategies, specifically speech-to-self, used by boys with and without ADHD. **Method:** Boys with and without ADHD were videotaped while completing a well-established, laboratory-based object location learning and memory task. **Results:** Boys with ADHD evinced a deficit while learning the location of objects and employed less sophisticated forms of private speech during the memory task. **Conclusion:** These findings reveal details about the utility of private speech during spatial working memory performance and further a theoretical understanding of ADHD. *(J. of Att. Dis. 2010; 13(5) 505-515)*

Keywords: *ADHD; spatial working memory; private speech*

Children with attention-deficit/hyperactivity disorder (ADHD) are at elevated risk for achievement delays and other academic difficulties (DuPaul & Weyandt, 2006; Rapport, Scanlan, & Denney, 1999). Because of inappropriate classroom behavior and deficient cognitive (i.e., vigilance and memory) performance, up to one-third of these children repeat an elementary grade, and 30% to 40% have contact with special education services (DuPaul & Stoner, 2003). In recent years, theorists have proposed that a deficit in working memory contributes in large part to the disorder and is associated with the academic difficulties experienced by many of these children (Barkley, 1997; Rapport, Chung, Shore, & Isaacs, 2001). The purpose of this investigation was to further clarify the nature of a deficit in working memory among children with ADHD.

Barkley's (1997) unifying theory of ADHD emphasizes a core deficit in behavioral inhibition that affects four areas of neuropsychological functioning: self-regulation of affect/motivation/arousal, internalization of speech, reconstitution, and working memory. In Barkley's model, working memory deficits result from behavioral disinhibition or the inability to regulate and suppress a prepotent response. Because this model emphasizes difficulties in executive functioning, it does not apply to children whose problems primarily involve inattention (i.e., those with predominantly inattentive [PI] subtype of ADHD). Children with ADHD-PI are known to present qualitatively different inattention symptoms than those found among children with ADHD-combined subtype, and experience different correlates and comorbid problems associated with their disorder (Barkley, 1997; Carlson & Mann, 2002; Milich, Balentine, & Lynam, 2001).

In contrast to Barkley's theory, Rapport et al. (2001) suggest that a core deficit in working memory underlies the disorganized behavior and sensation seeking evident among children with ADHD. That is, because details fade quickly from the working memory of these children,

Authors' Note: We thank Erin Miller, Rebecca Georgis, Casey Wyant, and Alicia Pachla for help with data collection and coding. We thank Heyworth Elementary School in Heyworth, Illinois; Ridgeview Elementary School in Colfax, Illinois; and Brigham Elementary School, Epiphany Elementary School, Fairview Elementary School, Northpoint Elementary School, Oakdale Elementary School, Pepper Ridge Elementary School, and Prairieland Elementary School in Bloomington-Normal, Illinois for their cooperation. We also thank all of the children and parents for their participation. This work was supported in part by a Research Award from the Graduate Student Association at Illinois State University. Address correspondence to Alycia M. Hund, Department of Psychology, Illinois State University, Campus Box 4620, Normal, IL 61790-4620; e-mail: amhund@ilstu.edu.

behaviors appear disorganized, and responses such as boredom, inattention, and frustration are common. Moreover, sensation-seeking behaviors occur when children with ADHD seek input to replace rapidly fading details in working memory. These manifestations lead to difficulties on cognitive and behavioral tasks that require working memory, such as those involving vigilance, social judgment, and academic skills. The Rapport et al. model differs from Barkley's and other deficit models because the perceived deficit is not *within* the child, but instead involves a diathesis-stress view in which deficient working memory (the diathesis) interacts with surrounding environmental conditions (the stressor). Although this ontological debate is far from resolved, empirical tests confirm that working memory is a core deficit among children with ADHD, and that it affects behavioral, emotional, and school functioning (e.g., Lee, Riccio, & Hynd, 2004; Martinussen, Hayden, Hogg-Johnson, & Tannock, 2005).

Working memory is the ability to maintain and manipulate information in one's immediate awareness in the service of other tasks. It is necessary for the successful completion of many everyday tasks, including reading, learning the names of classmates or the locations of rooms in a new school, and completing homework assignments. Baddeley's model of working memory (Baddeley & Hitch, 1974) is widely acknowledged in the field. In this model, working memory includes three components: the central executive, the phonological loop, and the visuospatial sketchpad. The central executive coordinates and controls the specialized storage systems. The phonological loop handles the rehearsal and storage of verbal information, such as remembering a telephone number by repeating it until it can be dialed. The visuospatial sketchpad, in contrast, handles the rehearsal and storage of visual and spatial information, such as remembering how one's teacher looks or how the desks are arranged in a classroom. Research confirms the existence of these three systems, as well as specific deficits related to each system (e.g., Baddeley, 1990; Chein & Fieze, 2001; Cornoldi & Vecchi, 2003).

Difficulties in working memory appear in different expressions, including an impaired sense of time (Mullins, Bellgrove, Gill, & Robertson, 2005), lack of hindsight and foresight, sequential difficulties in storytelling and arithmetic computation, and failure to remember rules that govern behavior. Clearly, these are problems characteristic of children with ADHD (Barkley, 1997). Psychometric research shows robust evidence of working memory difficulties among children with ADHD (Schwean & Saklofske, 2005); however, the clinical assessment of working memory tends to focus primarily on the child's auditory sequential ability (e.g., digit span). For instance, Perugini, Harvey, Lovejoy, Sandstrom, and Webb (2000) demonstrated that boys with ADHD exhibited significantly smaller digit spans than boys without ADHD.

Nonetheless, working memory is a complex multidimensional construct that includes, among other factors, remembering visual and spatial aspects of the environment (i.e., visuospatial memory). Visuospatial working memory involves remembering the locations of objects in many contexts, such as student desks in a classroom, food items in the kitchen, and clothing items in a closet, and is essential for everyday living. Children must be able to remember locations to carry out basic tasks such as getting dressed in the morning or locating a pencil and workbook at school. These memory tasks require the child's attention to object-related cues, location-related cues, as well as the relation between objects and locations. Often, it is necessary to retain in memory multiple locations to complete a task (e.g., locating all of the clothing and accessories needed to prepare for the day ahead or finding all of the supplies needed to complete an assignment). Remembering the locations of multiple objects draws on both visual aspects (i.e., the identity of the individual objects) and spatial aspects (i.e., where the objects are located in relation to one another, to landmarks, or to oneself). Moreover, it requires both precise coding of individual locations as well as strategic coding of multiple locations (given the overall number exceeds one's memory capacity in the absence of such strategic processing).

During the past 20 years, researchers have specified the normative development of location memory during childhood (e.g., Hund & Plumert, 2002; Huttenlocher, Hedges, & Duncan, 1991; Huttenlocher, Newcombe, & Sandberg, 1994; Newcombe & Huttenlocher, 2000; Schutte & Spencer, 2002). Much of this work has used a location memory paradigm that involves asking children and adults to learn and later remember the locations of 20 objects in an open, square box (Plumert & Hund, 2001). Results have revealed three important developmental changes that occur during middle childhood. First, the amount of experience needed to achieve mastery during learning decreases across childhood. In particular, older children and adults make fewer errors during learning and require fewer learning trials to reach mastery than younger children (Plumert & Hund, 2001; Recker, Plumert, Hund, & Reimer, 2007). Second, the precision of location coding (i.e., remembering the metric details of particular locations) improves between the ages of 7 and 11 years (and through early adulthood), leading to a pronounced decrease in placement errors across developmental stages (Hund & Foster, 2008;

Recker et al., 2007; see also Hund & Spencer, 2003; Newcombe, Huttenlocher, Drummey, & Wiley, 1998; Spencer & Hund, 2003). Third, strategic coding of spatial information (i.e., using spatial details regarding groups of locations in strategic ways) increases across childhood (see Plumert, Hund, & Recker, 2007; Spencer & Plumert, 2007, for recent reviews). Adults readily incorporate spatial category information (i.e., region or group membership) into an explicit spatial clustering strategy designed to reduce the demands of remembering multiple object–location pairings. Although children notice the groups of locations, they are less likely to use this information strategically (Hund & Foster, 2008; Hund & Plumert, 2005). This broad understanding of the development of location memory during middle childhood sets the stage for examining differences in normative and nonnormative trajectories, focusing particularly on boys with and without ADHD.

In spite of considerable anecdotal evidence suggesting that individuals with ADHD experience difficulty when attempting to locate important objects, no known study has examined how children with ADHD function in their memory for object locations. As such, the first purpose of this investigation was to determine whether boys with ADHD, relative to non-ADHD age-mates, evince a deficit in object–location memory. In particular, we probed errors during learning and memory trials following mastery (focusing on both precise coding for individual locations and strategic coding of groups of locations) to specify the nature of memory processes. Because this investigation focused on those with a deficit in executive functioning, boys with ADHD-combined type were selected to serve as participants, whereas children with the PI subtype of ADHD were excluded. Using a method to assess memory of locations that has proven successful with school-age through adult populations (see Plumert & Hund, 2001), it was hypothesized that boys with ADHD would make significantly more errors and require significantly more learning trials to reach mastery prior to the implementation of the memory task, and would evince significant delay relative to contrast boys in their object location memory after reaching the mastery criterion. In other words, it was expected that boys with ADHD would show a *performance deficit* while learning the memory task, as well as a *skill deficit* in their object–location memory following their successfully completed trials of learning.

Private Speech as a Mnemonic Strategy

When one is confronted with challenging memory tasks, mnemonic strategies tend to be invoked. According to Vygotskian theory (Vygotsky, 1934/1987), talking to self (i.e., private speech) is one such mnemonic tactic. Private speech occurs when children talk to themselves to guide their thinking and direct their ongoing activity. Private speech follows a predictable developmental trajectory that begins with social dialogue and activity directed by others and ends with these same activities directed by oneself through internalized means. During this internalization process, private speech shifts from task-irrelevant self-stimulating forms (e.g., word play and expression of affect) to audible task-relevant speech that guides behavior, to more internalized forms (e.g., inaudible mutterings). In this way, children gain internalized control of their behavior. The incidence of private speech increases in demanding task situations, as children attempt to control their attention and problem-solving behavior.

Private speech has received limited research attention among children with ADHD (e.g., Berk & Landau, 1993; Berk & Potts, 1991; Landau, Berk, & Mangione, 1996). Relative to age-mates, those with ADHD tend to engage in more frequent, albeit less mature forms of private speech, and rely on it more heavily as task demands increase. When solving math problems or completing puzzles, for example, this private speech tends to facilitate attention to task and reduce motor activity. As such, it improves performance. However, no investigation has yet examined ADHD children's use of private speech for mnemonic purposes. Thus, the second purpose of this investigation was to assess participants' use of private speech during a location memory task. It was anticipated that children's use of private speech would facilitate learning and memory performance. However, consistent with previous research, we predicted that boys with ADHD would engage in more frequent but less mature forms of private speech compared to non-ADHD boys.

Method

Participants

Thirty-eight 7- to 12-year-old boys served as participants. Boys alone were selected for study because ADHD is a male-dominated disorder, and because cognitive difficulties among children with ADHD may differ for boys versus girls (Hinshaw, Owens, Sami, & Fargeon, 2006). Seventeen boys met categorical and dimensional research diagnostic criteria for ADHD (age mean = 10 years 2 months; *SD* = 1 year 8 months), and 21 boys, determined to be free of ADHD-related problems, served as non-ADHD comparison participants (age mean = 10 years 9 months; *SD* = 1 year 7 months). Given that psychostimulant medications attenuate symptoms of ADHD (Fabiano et al., 2007), parents of boys receiving medication

Table 1
Demographic Details (Means) for Boys With and Without ADHD

	Boys With ADHD	Boys Without ADHD
Age (in years)	10.19 (1.70)	10.74 (1.57)
Digit span	8.65 (2.85)	11.57 (3.74)
Vocabulary	10.24 (2.61)	13.72 (3.68)
Full scale IQ	97.47 (13.03)	115.71 (19.95)
Inattention total	17.94 (3.68)	4.29 (3.08)
Hyperactivity total	15.23 (5.61)	3.19 (2.16)
Oppositional-defiant total	13.35 (7.91)	3.38 (2.29)

Note: Standard deviations are listed in parentheses.

for ADHD (n = 17) refrained from administering this treatment on the day of their son's research participation.

Participants were recruited from a child research participant database maintained by a Midwestern university and from area elementary schools. To be selected for the ADHD group, a parent confirmed that his or her son had been diagnosed with the disorder and provided ratings on Hyperactivity Impulsivity and/or Total scales of the *ADHD Rating Scale–IV–Home Version* (DuPaul, Power, Anastopoulos, & Reid, 1998) that exceed the 85th percentile (see Table 1).[1] This cut-off score has demonstrable clinical utility in the efficient discrimination of clinical versus nonclinical children due to its high positive predictive power and high negative predictive power (Power, Costigan, Leff, Eiraldi, & Landau, 2001). Boys whose ratings exceeded the 85th percentile on the Inattention scale only were excluded based on the theoretical premise that behavioral disinhibition, not inattention, is the primary impairment among children with ADHD (Barkley, 1997).

Boys who served as non-ADHD participants were rated by a parent on all three scales of the *ADHD Rating Scale–IV* (DuPaul et al., 1998) below the 60th percentile (see Table 1). For logistical reasons, including difficulties obtaining adequate sample size, ADHD boys with comorbid oppositional-defiant disorder (ODD) were not systematically excluded from study. However, a measure of ODD symptom severity (i.e., *Conners' Parent Rating Scale–Long Version–Oppositional-defiant Items* (Conners, 1997)) was administered to parents to serve as a potential covariate in analyses. As expected, boys with ADHD were significantly more symptomatic of ODD (M = 13.35, SD = 7.91) than boys without ADHD (M = 3.38, SD = 2.29), $F(1, 36) = 30.44$, $p < .001$, partial $\eta^2 = .46$. However, preliminary analyses revealed that ODD symptom severity was not significantly associated with boys' learning or memory performance. Thus, ODD symptom severity was not considered a covariate in subsequent analyses.

Two subtests (Vocabulary and Digit Span) from the *Weschler Intelligence Scale for Children*, Fourth Edition (Wechsler, 2003) were chosen to estimate the child's Full Scale IQ (FSIQ). Vocabulary was chosen because it is the subtest with the highest correlation with FSIQ (Wechsler, 2003) and Digit Span because working memory was the focus of this investigation. The mean FSIQ for ADHD boys was 97.47 (SD = 13.03), whereas the mean FSIQ for non-ADHD boys was 115.71 (SD = 19.95), $F(1, 36) = 10.54$, $p < .005$, partial $\eta^2 = .23$. In spite of this interpolated FSIQ difference, FSIQ was not significantly correlated with the outcome measures of learning and memory composite scores. Thus, it was not considered a covariate in subsequent analyses.

Apparatus and Materials

A 32 in. × 32 in. × 13in. (length × width × height) open square box with white walls was used as the experimental space. The floor of the box consisted of a layer of Plexiglas and a layer of plywood separated by a 0.5-in. space. Removable boards could be inserted below the Plexiglas to change the appearance of the floor. Three floors were used in this experiment: (a) a blue carpeted floor with 20 yellow dots on it, (b) a blue carpeted floor with no dots, and (c) a grid of x- and y-coordinates at 0.5-in. intervals. White lines (32 in. × 0.25 in. × 0.25 in.; length × width × height) on the floor of the box divided the box into quadrants during the learning phase.

The box contained 20 locations marked by 0.75-in. yellow dots. The locations were arranged so there were five locations in each quadrant. Twenty miniature objects were used to help participants learn the locations: a pot, a bear, a birdhouse, an iron, a paint can, a shoe, a picture, a bunch of bananas, a book, a purse, a watering can, a present, a hat, a pail, a toy plastic person, a bag of chips, a train, a flowering plant, a piggy bank, and a beverage carton. The average length and width of the objects was .76 in. and .60 in., respectively.

A Canon Optura60 digital camcorder, a Panasonic DMR-T6070 DVD recorder, and ProVideo VM-1005C monitor were used to record sessions. Private speech during the sessions was later coded using a PowerMac G4 computer and a Planar PL2010 21-in. monitor.

Design and Procedure

Participants were tested individually in a university laboratory room. The square box was placed on the floor of the experimental room. The experimenter stood in front of the box, and participants were seated to the right of the experimenter facing an adjacent side of the box.

Each 30- to 50-minute session was divided into a learning phase and a test phase. During the learning phase, participants learned the locations of the 20 objects in the box. At the beginning of the session, the experimenter told participants that 20 objects would be placed in the box (on the dots) and that they should try to remember their locations because they would be asked to replace the objects later. Participants watched as the experimenter named the objects and placed them in the box one at a time. The pairing of objects and locations and order of object placements were randomized for each participant.

Immediately after the experimenter placed all 20 objects, participants turned around while the experimenter removed the objects from the box. Then, the experimenter gave the objects to participants one at a time (in a new random order) and asked them to place objects in the correct locations. Participants were allowed to move around the outside of the box during these learning trials. The experimenter immediately corrected any placement errors. The objects were removed after the last one had been placed. Learning trials continued until participants could correctly place all 20 objects on the dots in a single trial.

The test phase began immediately following the learning phase. First, the experimenter asked participants to turn away from the box while the objects were removed. The experimenter also removed the boundaries, removed the floor with the yellow dots, and inserted the plain blue floor. Participants then were asked to face the box and try to replace the objects in the correct locations without the aid of boundaries and yellow dots. Participants replaced the objects in any order they chose. After participants left, the experimenter used the grid floor to record the position of each object (i.e., x- and y-coordinates) to the nearest 0.5 in.

Coding and Measures

Learning error composite. Learning errors included the number of same-quadrant errors during the first learning trial, the number of different-quadrant errors during the first learning trial, the number of same-quadrant errors during the last non-errorless learning trial, the number of between-quadrant errors during the last nonerrorless learning trial, total object perseveration errors during learning (placing the same object in different incorrect locations at least twice in a row), total location perseveration errors during learning (placing different objects in the same incorrect location at least twice in a row), total object + location perseveration errors during learning (placing the same object in the same incorrect location at least twice in a row), and the number of learning trials needed to reach errorless performance. For the sake of data reduction, these eight scores were subjected to Z-score transformations and combined to form a learning error composite that evinced adequate internal consistency (α = .71). By focusing on errors during learning, this composite score assessed one of the core aspects of location memory derived from empirical and theoretical work.

Memory error composite. Memory errors included metric error of placements (distance between each remembered location and the corresponding actual location), center displacement (degree to which all objects were displaced toward the region centers), displacement of target locations (degree to which eight target locations were displaced toward the region centers), and spatiotemporal clustering of placement orders (degree to which participants placed the objects quadrant by quadrant during the test phases; Roenker, Thompson, & Brown, 1971). These scores have been used extensively in previous developmental research, demonstrating their utility for assessing cognitive processing (e.g., Hund & Foster, 2008; Plumert & Hund, 2001). Focusing on errors during the test phase assessed two core aspects of location memory derived from previous empirical and theoretical work (e.g., the precision of individual location coding and the strategic coding of groups of locations). These four memory error scores were subjected to Z-score transformations and consolidated into a memory error composite with adequate internal consistency (α = .70).

Remembered placements were considered "correct" if each object was in the correct position relative to the other objects. As in previous studies (e.g., Hund & Plumert, 2003; Hund, Plumert, & Benney, 2002; Plumert & Hund, 2001), we used the x- and y-coordinates for these locations, regardless of whether the correct objects were placed in the locations. We substituted 4.71% of the locations for the ADHD group (16 of 340) and 1.90% for the non-ADHD group (8 of 420). These substituted locations were included in all analyses. Consistent with previous research (e.g., Plumert & Hund, 2001), objects placed in the wrong configuration were omitted from analyses. As such, 3.53% of locations for the ADHD group (12 of 340) and 3.81% for the non-ADHD group (16 of 420) were omitted.

Intercoder reliability estimates of object placement were calculated for eight randomly selected participants (21% of the sample) using exact percentage agreement (i.e., the percentage of judgments on which two raters exactly agreed). For each of these participants, two coders judged which object was placed at each of the 20 locations. Coders agreed on 99% of the 160 locations that were coded.

DVD recordings of the location learning and memory task were used to code private speech in a method similar to that used in previous research (i.e., Berk, 1986; Berk & Landau, 1993; Landau et al., 1996). Private speech was defined as verbalizations that were not clearly and unquestionably addressed to another person (see Berk, 1986). Private speech throughout learning and testing phases was coded during alternating 10-second intervals according to three levels developed by Berk (1986). *Level 1: Self-stimulating, task-irrelevant private speech* included word play and repetition; task-irrelevant affect expression; and comments to absent, imaginary, or nonhuman others. *Level 2: Task-relevant externalized private speech* included describing one's own activity and self-guiding comments; task-relevant, self-answered questions; and task-relevant affect expression (e.g., "I did it!" "This is hard!"). *Level 3: Task-relevant external manifestations of inner speech* included inaudible muttering (remarks involving clear mouthing of words which cannot be heard) and lip and tongue movement. Private speech scores were derived by dividing the proportion of intervals participants exhibited each level of private speech by the total number of observation intervals during the session. Intercoder reliability correlations for private speech were calculated for eight randomly selected participants (21% of the sample), and indicated adequate reliability (Level 1 $r = .95$; Level 2 $r = .94$; Level 3 $r = .88$).

DVD recordings of the location learning task were also coded for boys' attention-to-task. In particular, direction of gaze was used to determine the extent to which boys attended to the apparatus while the experimenter was placing the objects for the first time. *StopWatch* v3.01 was used to record visual attention to task to the nearest one-hundredth of a second. Total time also was coded to facilitate calculation of the percentage of time boys attended to task. Intercoder reliability estimates for attention-to-task were calculated for five randomly selected participants (13% of the sample), and found to be high ($r = .99$). As expected, boys' observed attention to task was inversely related with parent symptom ratings of Inattention, $r(37) = -.38$, $p < .05$, and Hyperactivity, $r(37) = -.35$, $p < .05$, on the *ADHD Rating Scale–IV* (DuPaul et al., 1998).

Results

One goal of this investigation was to examine how spatial working memory differs for boys with and without ADHD. Analyses of learning and memory composite scores revealed no differences between the two groups. In other words, if given a sufficient number of trials to learn the memory task, boys with and without ADHD were comparable in object location memory. However, boys with ADHD exhibited twice as many errors while learning locations of objects (same-quadrant errors during the first learning trial: $M = 2.47$, $SD = 1.74$) than boys without ADHD ($M = 1.24$, $SD = 1.14$), $F(1, 36) = 6.94$, $p < .05$, Partial $\eta^2 = .16$.

A second goal was to determine how private speech profiles differed for boys with and without ADHD. As expected, boys with ADHD exhibited significantly more task-irrelevant private speech ($M = 5.74\%$ of intervals, $SD = 8.37$) than boys without ADHD ($M = .41\%$ of intervals, $SD = .96$), $F(1, 36) = 8.44$, $p < .01$, Partial $\eta^2 = .19$. Similarly, boys with ADHD exhibited significantly more task-relevant private speech ($M = 6.60\%$ of intervals, $SD = 8.12$) than boys without ADHD ($M = 1.48\%$ of intervals, $SD = 3.69$), $F(1, 36) = 6.69$, $p < .05$, Partial $\eta^2 = .16$, and significantly less percentage of time attending to the task during the learning phase ($M = 78\%$, $SD = 15$) than boys without ADHD ($M = 86\%$, $SD = 8$), $F(1, 36) = 5.05$, $p < .05$, Partial $\eta^2 = .12$. These findings support the notion that object location learning, private speech, and attention profiles differ for boys with and without ADHD. Specifically, boys with ADHD exhibited significantly less attention to task, more errors during learning, and more private speech than boys without ADHD.

To clarify the relations among attention to task, private speech, and learning and memory performance for boys with and without ADHD, correlational analyses were conducted within each group. For non-ADHD boys, attention to task was significantly associated with task-relevant private speech, $r(20) = .45$, $p < .05$, and marginally correlated with inaudible (task-relevant) private speech, $r(20) = .41$, $p < .07$ (see Table 2). These findings indicate that, among boys without ADHD, task-relevant private speech enhanced attention.

For boys with ADHD, in contrast, both audible, $r(16) = -.65$, $p < .01$, and inaudible task-relevant private speech, $r(16) = -.55$, $p < .05$, were inversely related to attentional performance (see Table 3). Thus, for these boys, the use of task-relevant private speech did not function as a mnemonic strategy because it may have compromised their attention to the task. Moreover, irrelevant mutterings among these boys led to more memory errors, $r(16) = .71$, $p < .005$. In sum, the task-relevant private speech used by non-ADHD boys facilitated attention to the memory task, whereas the private speech emitted by boys with ADHD interfered with their attention, and led to greater error making if these audible comments were irrelevant to the memory task.

Table 2
Correlations Among Task Variables for Non-ADHD Boys ($N = 21$)

	1	2	3	4	5	6
(1) Attention to task	—	.13	.45*	.41⁺	–.08	.19
(2) Task-irrelevant private speech		—	.05	.10	.08	.31
(3) Task-relevant private speech			—	.17	.15	–.01
(4) Inaudible private speech				—	–.04	.06
(5) Learning errors					—	.32
(6) Memory errors						—

*$p < .05$. **$p < .01$. ⁺$p < .07$.

Table 3
Correlations Among Task Variables for Boys With ADHD ($N = 17$)

	1	2	3	4	5	6
(1) Attention to task	—	–.39	–.65**	–.55*	.22	–.43
(2) Task-irrelevant private speech		—	.08	–.22	–.01	.71**
(3) Task-relevant private speech			—	.53*	.07	–.07
(4) Inaudible private speech				—	-.40	–.02
(5) Learning errors					—	–.32
(6) Memory errors						—

*$p < .05$. **$p < .01$.

Discussion

One purpose of this investigation was to determine whether unmedicated boys with ADHD, relative to non-ADHD age-mates, evince a deficit in object–location learning and memory. Although no differences were detected in learning or memory composite scores, boys with ADHD exhibited significantly more same-quadrant errors during the first learning trial than boys without ADHD. Thus, contrary to reports indicating that children with ADHD have a deficit in working memory (see Rapport et al., 2001), the current pattern of findings indicates this may not be the case when using a well-established method to assess object–location memory. Indeed, when given sufficient opportunity to learn the memory task, the visuospatial memory of unmedicated boys with ADHD fell within normal limits. This finding was unexpected but is consistent with Barkley's (1997) assertion that the functional difficulties experienced by children with ADHD may result from performance, rather than skill, deficits.

Even though boys with ADHD made more errors than non-ADHD boys when attempting to place objects in their respective locations the first time, this difference attenuated across trials. This suggests that visuospatial processing (i.e., coding and rehearsal of spatial information via the visuospatial sketchpad) differs for boys with and without ADHD. In particular, it suggests that preliminary processing, such as early attempts to rehearse spatial details, may be more laborious for boys with ADHD relative to non-ADHD age-mates. Nonetheless, current findings indicate that subsequent processing may not differ for boys with and without ADHD. Previous research and theory suggests that visuospatial rehearsal involves processes akin to spatial attention (e.g., revisiting locations in sequence, much like subvocal verbal rehearsal involves repeating verbal details in sequence (Awh, Jonides, & Reuter-Lorenz, 1998). Moreover, inhibition plays a large role in the engagement of attentional focus in the presence of distractors (Tipper, 1992). Thus, it is possible that the spatial rehearsal difficulties among boys with ADHD stem from deficits in inhibition that hinder the functioning and efficiency of spatial attention (see also Wilding, 2003; Wilding, Munir, & Cornish, 2001). It is also possible that these difficulties result from differences in central executive functioning among boys with and without ADHD, particularly the integration of information from multiple sources over space and time (see also Karatekin, 2004; Martinussen & Tannock, 2006; Roodenrys, Koloski, & Grainger, 2001).

The present findings are consistent with results from previous investigations that have examined patterns of normative development in which younger children make more errors during learning and require more learning trials to reach mastery than older children and adults (Plumert & Hund, 2001; Recker et al., 2007). Because the precision of location coding and strategic coding of spatial information following mastery did not differ for boys with and without ADHD, an ADHD-related performance deficit in spatial working memory may be most evident during preliminary learning, and may ameliorate once mastery has been reached. As such, our findings indicate that researchers and practitioners should focus on learning profiles (e.g., number and types of errors, emergence of strategies) to further understand the nature of learning and memory processes among children with ADHD. We join a large contingent of researchers who assert that such focus on the dynamics of learning and memory processes is critical (e.g., Recker et al., 2007; Siegler, 2000; Thelen & Smith, 1994). Clearly, additional research is needed to further understand how children, including those with ADHD, learn and remember object locations.

The second purpose of this investigation was to assess participants' use of private speech during the object location memory task. As expected, boys with ADHD exhibited significantly more task-irrelevant private speech than boys without ADHD, and their use of irrelevant speech was associated with less attention to the memory task. This preponderance of task-irrelevant private speech among boys with ADHD corresponds with findings from studies in other domains of functioning, such as math problem solving (Landau et al., 1996), indicating that boys with ADHD exhibit less mature forms of private speech in a variety of task contexts. In the Landau et al. study, boys with ADHD also exhibited significantly more audible and inaudible task-relevant private speech than boys without ADHD. However, contrary to Vygotskian (Vygotsky, 1934/1987) predictions, current findings did not indicate that overall use of task-relevant private speech facilitated attention or improved memory performance. Thus, it did not function as a mnemonic strategy for these boys with ADHD.

It is possible that the between-group difference in task-relevant private speech emerged because, in the current study, the experimenter and participant interacted freely throughout the task. In previous private speech investigations that focused on impulsive children or children with ADHD, data were collected in solitary contexts (e.g., solving math worksheet problems or solving puzzles) with the experimenter out of the room. In the current study, boys with ADHD had greater opportunity to converse with the experimenter, and may have simply been more talkative during data collection. In fact, boys with ADHD emitted higher rates of all levels of private speech, and their use of audible and inaudible task-relevant private speech were significantly related, $r(16) = .53$, $p < .05$. However, this was not the case among non-ADHD boys, $r(20) = .17$, $p > .05$.

Moreover, it is possible that the learning and memory task used in the current investigation was considerably more challenging than tasks used in previous studies, leading to increased verbalizations throughout the task. In the Landau et al. (1996) study, for example, great care was used to ensure that each participant was confronted with math problems at an "instructional" level for that child (i.e., those that could be accomplished with 70% accuracy). However, it is apparent that boys with ADHD in the current study initially experienced greater challenge than non-ADHD boys as evidenced by their higher rate of error making during learning. According to Vygotskian theory (Vygotsky, 1934/1987), this between-group difference in task difficulty may have led to the increased incidence of private speech.

One limitation of the present work is the relatively small sample size included in our between-groups design. Practical limitations precluded the inclusion of a larger sample of boys with ADHD. Nonetheless, our sample size is similar to those used in previous published reports involving this memory paradigm (e.g., Plumert & Hund, 2001), as well as reports from other labs involving children with ADHD (i.e., Maedgen & Carlson, 2000). Thus, we are confident that the results provide an important first step in understanding how boys with and without ADHD learn and remember locations. A related limitation involves the relatively high intellectual abilities evident among those in our sample but especially evident among boys with ADHD. This limitation requires caution when generalizing our findings to broader populations. Moreover, conclusions based on our findings are limited by the sampling techniques used here. Our community-based sample may not be representative of the ADHD population in general. One goal of future work is to broaden the sample (in number and diversity) to increase the overall generalizability of obtained findings.

Another caution is that drawing conclusions regarding the functional nature of working memory processes in general, and visuospatial working memory in particular, is difficult because of the diverse perspectives within the field. Indeed, across investigations, working memory tends to be operationalized almost entirely by its method of measurement. Thus, our findings draw attention to the need to more fully integrate a variety of empirical methods and theoretical models of working memory to understand the complexities of learning and remembering objects and their locations. For instance, empirical researchers focusing on location memory often use behavioral research paradigms that require participants to view a location (or set of locations) and then reproduce the specified location(s) following a short delay (Newcombe et al., 1998; Plumert & Hund, 2001; Spencer & Hund, 2002). Such paradigms have been very useful in understanding the factors that affect location memory in general, such as spatial context (Spencer & Hund, 2002), the number of locations and pattern of visits (Hund et al., 2002), and the nature of objects presented at the locations (Hund & Plumert, 2003); however, investigators have not tracked particular patterns of deficits or their relation to other intellectual abilities. On the other hand, researchers and practitioners focusing on individual differences in learning and memory often employ psychometric tasks that provide details about memory variability and its relation to academic skills and/or intelligence (e.g., digit span; Conway & Engle, 1996; Daneman & Carpenter, 1980). Their findings track individual patterns of skills (and deficits) but provide little detail about general explanations of underlying processes.

One possible solution is to combine multiple paradigms to provide a more complete assessment of working memory. For instance, the present investigation included both a common psychometric measure of working memory (i.e., digit span), and a normative empirical paradigm (i.e., the object location task). Because boys' digit span performance was not correlated with learning or memory composite scores, $rs(37) < .21$, $ps > .22$, however, our findings show that these tasks do not tap identical aspects of working memory. Adding to this empirical complexity is the large number of theories currently proposed to explain working memory in general, and spatial working memory in particular (e.g., Baddeley & Hitch, 1974; Cowan, 1988; Huttenlocher et al., 1991; Miyake & Shah, 1999; Schutte, Spencer, & Schöner, 2003). In many cases, empirical paradigms become associated with particular theories or models, leading to little true integration in the field. Thus, we recognize the growing need to concurrently use multiple empirical methods to both analyze and synthesize diverse theoretical assertions regarding working memory.

Our findings have important practical implications for teachers and practitioners working with children with ADHD. First, results from this investigation indicate that boys with ADHD may be able to perform just as well as non-ADHD age-mates on tasks of working memory when given sufficient time to practice. However, many teachers expect all children in their classes to perform at the same functional level with similar opportunities to practice. Consistent with anecdotal reports, our research indicates that boys with ADHD may experience particular difficulty during early learning that necessitates more time to "catch on" to tasks. This may be especially true with mathematics tasks because these tasks generally require working memory skills to be successful (i.e., holding digits in mind while performing a next-step operation). Giving more practice time to children with ADHD may significantly increase their performance on tasks that require some type of working memory. Second, our findings indicate that boys with ADHD evince more frequent private speech than do boys without ADHD. Although the functional utility of such speech-to-self requires additional empirical examination, it is clear that teachers and practitioners should be aware of children's preponderance to talk to themselves to solve problems and regulate their own behavior. As such, teachers should keep this phenomenon in mind when asserting to certain students, ". . . you need to work quietly at your desk!"

In summary, the present findings reveal a robust performance deficit in visuospatial working memory among elementary-age boys with ADHD, as these boys engaged in twice the error making as their same-age non-ADHD counterparts. Nonetheless, this deficit attenuated once boys with ADHD reached mastery and did not seem to intrude on their ultimate object location memory. Our findings also indicate that boys with ADHD evince more private speech than boys without ADHD. For non-ADHD boys, task-relevant private speech seemed to facilitate attention to task, thereby serving as a mnemonic strategy. For boys with ADHD, in contrast, task-irrelevant private speech seemed to compromise attention to task and memory performance. Thus, the functional utility of private speech in a memory context may differ for children with and without ADHD.

Note

1. Two participants' parents reported their sons had a diagnosis of ADHD, but their rating scale data did not exceed the 85th percentile. Data from these participants were maintained, and group membership was determined by categorical criteria (i.e., parental report of psychiatric diagnosis). Analyses excluding these participants yielded an identical pattern of findings.

References

Awh, E., Jonides, J., & Reuter-Lorenz, P. A. (1998). Rehearsal in spatial working memory. *Journal of Experimental Psychology: Human Perception and Performance, 24*, 780-790.

Baddeley, A. (1990). *Human memory: Theory and practice.* Boston: Allyn & Bacon.

Baddeley, A. D., & Hitch, G. L. (1974). Working memory. In G. H. Bower (Ed.), *The psychology of learning and motivation: Advances in research and theory* (Vol. 8, pp. 47-89). New York: Academic Press.

Barkley, R. A. (1997). Behavioral inhibition, sustained attention, and executive functions: Constructing a unifying theory of ADHD. *Psychological Bulletin, 121*, 65-94.

Berk, L. E. (1986). Relationship of elementary school children's private speech to behavioral accompaniment to task, attention, and task performance. *Developmental Psychology, 22*, 671-680.

Berk, L. E., & Landau, S. (1993). Private speech of learning disabled and normally achieving children in classroom academic and laboratory contexts. *Child Development, 64*, 556-571.

Berk, L. E., & Potts, M. K. (1991). Development and functional significance of private speech among attention-deficit hyperactivity disordered and normal boys. *Journal of Abnormal Child Psychology, 19*, 357-377.

Carlson, C. L., & Mann, M. (2002). Sluggish cognitive tempo predicts a different pattern of impairment in the attention deficit hyperactivity disorder, predominantly inattentive type. *Journal of Clinical Child and Adolescent Psychology, 31*, 123-129.

Chein, J. M., & Fiez, J. A. (2001). Dissociation of verbal working memory system components using a delayed serial recall task. *Cerebral Cortex, 11*, 1003-1014.

Conners, C. K. (1997). *Conner's Rating Scales–Revised.* North Tonawanda, NY: Multi-Health Systems.

Conway, A. R. A., & Engle, R. W. (1996). Individual differences in working memory capacity: More evidence for a general capacity theory. *Memory, 4*, 577-590.

Cornoldi, C., & Vecchi, T. (2003). *Visuo-spatial working memory and individual differences.* New York: Psychology Press.

Cowan, N. (1988). Evolving conceptions of memory storage, selective attention, and their mutual constraints within the human information processing system. *Psychological Bulletin, 104*, 163-191.

Daneman, M., & Carpenter, P. A. (1980). Individual differences in working memory and reading. *Journal of Verbal Learning and Verbal Behavior, 19*, 450-466.

DuPaul, G. J., Power, T. J., Anastopoulos, A. D., & Reid, R. (1998). *ADHD Rating Scale-IV. Checklists, norms, and clinical interpretation.* New York: Guilford Press.

DuPaul, G. J., & Stoner, G. (2003). *ADHD in the schools: Assessment and intervention strategies* (2nd ed). New York: Guilford Press.

DuPaul, G. J., & Weyandt, L. L. (2006). School-based intervention for children with attention deficit hyperactivity disorder: Effects on academic, social, and behavioural functioning. *International Journal of Disability, Development and Education, 53*, 161-176.

Fabiano, G. A., Pelham, W. E., Jr., Gnagy, E. M., Burrows-MacLean, L., Coles, E. K., Chacko, A., et al. (2007). The single and combined effects of multiple intensities of behavior modification and methylphenidate for children with attention deficit hyperactivity disorder in a classroom setting. *School Psychology Review, 36*, 195-215.

Hinshaw, S. P., Owens, E. B., Sami, N., & Fargeon, S. (2006). Prospective follow-up of girls with attention-deficit/hyperactivity disorder into adolescence: Evidence for continuing cross-domain impairment. *Journal of Consulting and Clinical Psychology, 74*, 489-499.

Hund, A. M., & Foster, E. K. (2008). The stability and flexibility of spatial categories based on object relatedness. *Developmental Psychology, 44*, 218-232.

Hund, A. M., & Plumert, J. M. (2002). Delay-induced bias in children's memory for location. *Child Development, 73*, 829-840.

Hund, A. M., & Plumert, J. M. (2003). Does information about what things are influence children's memory for where things are? *Developmental Psychology, 39*, 939-948.

Hund, A. M., & Plumert, J. M. (2005). The stability and flexibility of spatial categories. *Cognitive Psychology, 50*, 1-44.

Hund, A. M., Plumert, J. M., & Benney, C. J. (2002). Children's ability to form spatial groups: The role of spatial and temporal contiguity. *Journal of Experimental Child Psychology, 82*, 200-225.

Hund, A. M., & Spencer, J. P. (2003). Developmental changes in the relative weighting of geometric and experience-dependent location cues. *Journal of Cognition and Development, 4*, 3-38.

Huttenlocher, J., Hedges, L. V., & Duncan, S. (1991). Categories and particulars: Prototype effects in estimating spatial location. *Psychological Review, 98*, 352-376.

Huttenlocher, J., Newcombe, N., & Sandberg, E. H. (1994). The coding of spatial location in young children. *Cognitive Psychology, 27*, 115-147.

Karatekin, C. (2004). A test of the integrity of the components of Baddeley's model of working memory in attention-deficit/hyperactivity disorder (ADHD). *Journal of Child Psychology and Psychiatry, 45*, 912-926.

Landau, S., Berk, L. E. & Mangione, C. (1996). *Private speech as a problem-solving strategy in the face of academic challenge: The failure of impulsive children to get their act together.* Paper presented at the annual meeting of the National Association of School Psychologists, Atlanta, GA.

Lee, D., Riccio, C. A., & Hynd, G. W. (2004). The role of executive functions in attention deficit hyperactivity disorder: Testing predictions from two models. *Canadian Journal of School Psychology, 19*, 167-189.

Maedgen, J. W., & Carlson, C. L. (2000). Social functioning and emotional regulation in the attention deficit hyperactivity disorder subtypes. *Journal of Clinical Child Psychology, 29*, 30-42.

Martinussen, R., Hayden, J., Hogg-Johnson, S., & Tannock, R. (2005). A meta-analysis of working memory impairments in children with attention-deficit/hyperactivity disorder. *Journal of the American Academy of Child & Adolescent Psychiatry, 44*, 377-384.

Martinussen, R., & Tannock, R. (2006). Working memory impairments in children with attention-deficit hyperactivity disorder with and without comorbid language learning disorders. *Journal of Clinical and Experimental Neuropsychology, 28*, 1073-1094.

Milich, R., Balentine, A. C., & Lynam, D. R. (2001). ADHD combined type and ADHD predominantly inattentive type are distinct and unrelated disorders. *Clinical Psychology: Science and Practice, 8*, 463-488.

Miyake, A., & Shah, P. (Eds.). (1999). *Models of working memory: Mechanisms of active maintenance and executive control.* Cambridge, UK: Cambridge University Press.

Mullins, C., Bellgrove, M. A., Gill, M., Robertson, I. H. (2005). Variability in time reproduction: Difference in ADHD combined and inattentive subtypes. *Journal of the American Academy of Child & Adolescent Psychiatry, 44*, 169-176.

Newcombe, N., & Huttenlocher, J. (2000). *Making space: The development of spatial representation and reasoning.* Cambridge: MIT Press.

Newcombe, N., Huttenlocher, J., Drummey, A. B., & Wiley, J. G. (1998). The development of spatial location coding: Place learning and dead reckoning in the second and third years. *Cognitive Development, 13*, 185-200.

Perugini, E. M., Harvey, E. A., Lovejoy, D. W., Sandstrom, K., & Webb, A. H. (2000). The predictive power of combined neuropsychological measures of attention deficit hyperactivity disorder in children. *Child Neuropsychology, 6*, 101-114.

Plumert, J. M., & Hund, A. M. (2001). The development of location memory: What role do spatial prototypes play? *Child Development, 72*, 370-384.

Plumert, J. M., Hund, A. M., & Recker, K. M. (2007). Organism-environment interaction in spatial development: Explaining categorical bias in memory for location. In J. M. Plumert & J. P. Spencer (Eds.), *Emerging landscapes of mind: Mapping the nature of change in spatial cognitive development* (pp. 25-52). Oxford, UK: Oxford University Press.

Power, T. J., Costigan, T. E., Leff, S. S., Eiraldi, R. B., & Landau, S. (2001). Assessing ADHD across settings: Contributions of behavioral assessment to categorical decision making. *Journal of Clinical Child Psychology, 30*, 399-412.

Rapport, M. D., Chung, K.-M., Shore, G., & Isaacs, P. (2001). A conceptual model of child psychopathology: Implications for understanding attention deficit hyperactivity disorder and treatment efficacy. *Journal of Clinical Child Psychology, 30*, 48-58.

Rapport, M. D., Scanlan, S. W., & Denney, C. B. (1999). Attention-deficit/hyperactivity disorder and scholastic achievement: A model of dual developmental pathways. *Journal of Child Psychology and Psychiatry, 40*, 1169-1183.

Recker, K. M., Plumert, J. M., Hund, A. M., & Reimer, R. (2007). How do biases in spatial memory change as children and adults are learning locations? *Journal of Experimental Child Psychology, 98*, 217-232.

Roenker, D. L., Thompson, C. P., & Brown, S. C. (1971). Comparison of measure for the estimation of clustering in free recall. *Psychological Bulletin, 76*, 45-48.

Roodenrys, S., Koloski, N., & Grainger, J. (2001). Working memory function in attention deficit hyperactivity disordered and reading disabled children. *British Journal of Developmental Psychology, 19*, 325-337.

Schutte, A. R., & Spencer, J. P. (2002). Generalizing the dynamic field theory of the A-not-B error beyond infancy: Three-year-olds' delay- and experience-dependent location memory biases. *Child Development, 73*, 377-404.

Schutte, A. R., & Spencer, J. P., & Schöner, G. (2003). Testing the dynamic field theory: Working memory for locations becomes more spatially precise over development. *Child Development, 74*, 1393-1417.

Schwean, V. L., & Saklofske, D. H. (2005). Assessment of attention deficit hyperactivity with the WISC-IV. In A. Prifitera, D. H. Saklofske, & L. G. Weiss (Eds.), *WISC-IV clinical use and interpretation: Scientist-practitioner perspectives* (pp. 236-280). Burlington, MA: Academic Press.

Siegler, R. S. (2000). The rebirth of children's learning. *Child Development, 71*, 26-35.

Spencer, J. P., & Hund, A. M. (2002). Prototypes and particulars: Geometric and experience-dependent spatial categories. *Journal of Experimental Psychology: General, 131*, 16-37.

Spencer, J. P., & Hund, A. M. (2003). Developmental continuity in the processes that underlie spatial recall. *Cognitive Psychology, 47*, 432-480.

Spencer, J. P., & Plumert, J. M. (2007). What makes thinking about development so hard? In J. M. Plumert & J. P. Spencer (Eds.), *Emerging landscapes of mind: Mapping the nature of change in spatial cognitive development* (pp. 375-386). Oxford, UK: Oxford University Press.

Thelen, E., & Smith, L. B. (1994). *A dynamic systems approach to the development of cognition and action.* Cambridge: MIT Press.

Tipper, S. P. (1992). Selection for action: The role of inhibitory mechanisms. *Current Directions in Psychological Science, 1*, 105-109.

Vygotsky, L. S. (1987). Thinking and speech. In R. E. Rieber & A. S. Carton (Eds.), *The collected works of L. S. Vygotsky: Vol. 1. Problems of general psychology* (N. Minick, Trans.). New York: Plenum Press. (Original work published 1934)

Wechsler, D. (2003). *Weschler Intelligence Scale for Children, Fourth Edition (WISC-IV): Administration and scoring manual.* San Antonio, TX: Psychological Corporation.

Wilding, J. M. (2003). Attentional difficulties in children: Weakness in executive function or problems in coping with difficult tasks? *British Journal of Psychology, 94*, 427-436.

Wilding, J., Munir, F., & Cornish, K. (2001). The nature of attentional differences between groups of children differentiated by teacher ratings of attention and hyperactivity. *British Journal of Psychology, 92*, 357-371.

Sarah G. Reck is an advanced Ph.D. student in the APA-approved School Psychology program at Illinois State University. She is currently completing her internship at the North Suburban Special Education District (NSSED) in Highland Park, IL. Her research interests include early childhood attention and executivefunctioning.

Alycia M. Hund is an Assistant Professor of Psychology at Illinois State University. Her research focuses on spatial cognition, particularly the development of location memory, spatial communication, and wayfinding.

Steven Landau is Professor of Psychology at Illinois State University, with research interest in the disturbed peer relations of children with ADHD.