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ADHD and retrieval-induced forgetting: Evidence for a deficit in the inhibitory control of memory

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Research on retrieval-induced forgetting has shown that the selective retrieval of some information can cause the forgetting of other information. Such forgetting is believed to result from inhibitory processes that function to resolve interference during retrieval. The current study examined whether individuals with ADHD demonstrate normal levels of retrieval-induced forgetting. A total of 40 adults with ADHD and 40 adults without ADHD participated in a standard retrieval-induced forgetting experiment. Critically, half of the items were tested using category cues and the other half of the items were tested using category-plus-one-letter-stem cues. Whereas both ADHD and non-ADHD participants demonstrated retrieval-induced forgetting on the final category-cued recall test, only non-ADHD participants demonstrated retrieval-induced forgetting on the final category-plus-stem-cued recall test. These results suggest that individuals with ADHD do have a deficit in the inhibitory control of memory, but that this deficit may only be apparent when output interference is adequately controlled on the final test.

Keywords: Inhibition; Retrieval-induced forgetting; ADHD.

Forgetting is perceived as a failure of memory. Research suggests, however, that forgetting can also reflect the adaptive processes of inhibition (Bjork, 1989). One context in which inhibition is believed to play a particularly important role is that of retrieval. In order to retrieve a target item from memory, competing items must be selected against, or inhibited. Although inhibition may facilitate the retrieval of target items, it may also impair the retrieval of non-target items, a phenomenon referred to as retrieval-induced forgetting (Anderson, Bjork, & Bjork, 1994). If inhibitory processes do underlie retrieval-induced forgetting, individuals who have a deficiency in those processes should show less or even no such forgetting. We test this possibility in the current study, specifically focusing on individuals with attention-deficit/hyperactivity disorder (ADHD). One of the key impairments in ADHD is thought to be poor inhibitory control, which makes it difficult to focus attention on relevant aspects of a task at hand (Barkley, 1997; Nigg, 2001). When attempting to select a target memory in the face of interference from competing memories, individuals with ADHD may fail to inhibit those competing memories, thus preventing retrieval-induced forgetting from occurring.

RETRIEVAL-INDUCED FORGETTING

The paradigm typically used to study retrieval-induced forgetting involves three phases: study, retrieval practice, and test (Anderson et al., 1994).

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After studying a series of category–exemplar pairs (e.g., *fruit: lemon*, *drinks: gin*, *fruit: orange*, *drinks: rum*), participants retrieve half of the exemplars from half of the categories during retrieval practice (e.g., *fruit: le*_____). Then, after a brief delay, memory for all items from the study phase is tested, often by presenting each category cue and having participants recall associated exemplars. Items receiving retrieval practice are referred to as Rp+ items (*lemon*), and items from practised categories that are not themselves practised are referred to as Rp− items (*orange*). Non-practised items from non-practised categories serve as a baseline to measure any change in accessibility for Rp+ and Rp− items, and are referred to as Nrp items (*gin & rum*). Rp+ items are often better recalled than are Rp− and Nrp items. More surprisingly, Rp− items are often worse recalled than are Nrp items, thus demonstrating retrieval-induced forgetting. Retrieval-induced forgetting has been shown to be a highly robust and general phenomenon, occurring in many contexts and with many types of materials (for a review see Anderson, 2003).

The inhibitory account of retrieval-induced forgetting asserts that Rp− items are actively inhibited during retrieval practice. According to this view the attempt to retrieve a target item from memory also activates other items, creating competition, and requiring that the items causing that competition be inhibited. In this sense retrieval-induced forgetting is the consequence of active processes that function to resolve interference during retrieval. Some oppose the inhibitory account, arguing instead that retrieval practice simply strengthens the association between practised items and their associated retrieval cues; and that by strengthening a subset of items, non-practised items associated with the same cues may suffer from response competition or interference at the time of test. However, demonstrations that retrieval-induced forgetting is cue independent (e.g., Anderson & Spellman, 1995), competition dependent (e.g., Storm, Bjork, & Bjork, 2007), strength independent and retrieval specific (e.g., Bäuml, 2002), are difficult for interference-based accounts to explain. Even failed retrieval attempts—where nothing is retrieved, and therefore nothing is strengthened—can cause forgetting (Storm, Bjork, Bjork, & Nestojko, 2006; Storm & Nestojko, 2010). Taken together, along with recent neuroimaging work (e.g., Kuhl, Dudkovic, Kahn, & Wagner, 2007), there is now compelling evidence supporting the inhibitory account of retrieval-induced forgetting.

ADHD AND INHIBITION

ADHD is associated with a deficit in executive inhibitory control (Barkley, 1997; Nigg, 2001), which has been linked to its core symptoms (i.e., distractibility, impulsivity, and hyperactivity) and executive function impairments, such as poor working memory (Sheridan, Hinshaw, & D'Esposito, 2007). ADHD-related inhibitory deficits are believed to involve poor interference control (Palladino, 2006) and difficulty preventing prepotent responses (Schachar et al., 2007; Wodka et al., 2007). For example, using variations of the stop-signal task, Schachar et al. (2007) found that individuals with ADHD demonstrate poor response restraint (the ability to withhold a strong response tendency), as well as an impaired ability to cancel an ongoing response (response cancellation).

Because the ability to suppress prepotent responses is deficient in ADHD, it is not surprising that individuals with ADHD are impaired on memory tasks that involve inhibition. This impairment generally manifests in the form of intrusion errors and proactive interference. For example, adults with ADHD do not show normal levels of directed forgetting on a list-method directed forgetting task (White & Marks, 2004). And, whereas adults without ADHD can successfully inhibit previously relevant categories in a semantic inhibition of return task, adults with ADHD demonstrate semantic facilitation, or positive priming (White, 2007). These observations suggest that individuals with ADHD may be less able to update and control long-term memory.

Given this inhibitory deficit, there is good reason to believe that individuals with ADHD will not demonstrate normal levels of retrieval-induced forgetting. Although there are no published studies on retrieval-induced forgetting and ADHD, several studies have explored retrieval-induced forgetting with populations that are believed to have inhibitory deficits. Interestingly, the majority of these studies have found such populations to show significant effects of retrieval-induced forgetting (e.g., Alzheimer's patients, Moulin et al., 2002; frontal lobe patients, Conway & Fthenaki, 2003; young children, Ford, Keating, & Patel, 2004; Zellner & Bäuml, 2005). The fact that populations with well-established inhibitory

deficits demonstrate normal levels of retrieval-induced forgetting has led researchers either to doubt the inhibitory account, or to argue that the inhibition underlying retrieval-induced forgetting is of a more automatic type—that it does not reflect the processes of executive control. Moreover, these findings have led some researchers to reinterpret the nature and extent to which these populations have inhibitory deficits.

LOGIC OF THE PRESENT STUDY

If inhibition does underlie retrieval-induced forgetting, and if individuals with ADHD do have an inhibitory deficit in memory, then individuals with ADHD should demonstrate significantly less retrieval-induced forgetting. However, whether or not such a pattern of results is observed may depend on the nature of the final test. When a category-cued recall test is employed, the order of final recall is not controlled. Consequently, items strengthened by retrieval practice are likely to be recalled first, thereby causing output interference and impairing the recall of non-practised Rp− items (e.g., Roediger, 1978). Thus retrieval-induced forgetting effects observed in studies employing a category-cued recall test may reflect interference dynamics, not inhibition. In fact individuals who lack normal inhibitory function may be even more susceptible to interference on the final test (see Anderson & Levy, 2007), thereby leading to large effects of interference-based retrieval-induced forgetting. Unfortunately, most studies examining retrieval-induced forgetting in populations with inhibitory deficits have employed a category-cued recall test (including the studies cited above).

A simple way to control for output interference on the final test is to test items individually using category-plus-single-letter-stem cues (*fruit: l*_____), thus dictating recall order and preventing practised items from being recalled first and interfering with the recall of non-practised items. Studies employing this type of test with young healthy adults have demonstrated significant levels of retrieval-induced forgetting, even when Rp− items are tested prior to Rp+ items (e.g., Anderson et al., 1994; Bäuml, 2002; Storm et al., 2006, 2007). However, individuals with an inhibitory deficit should show significantly less retrieval-induced forgetting on such a test. We tested this hypothesis in the current study by having adults with and without ADHD take part in the standard retrieval-induced forgetting experiment. Critically, half of the categories were tested using category cues, and the other half of the categories were tested using category-plus-stem cues. We predicted that both groups of participants would show significant levels of retrieval-induced forgetting on the category-cued recall test, but that only non-ADHD participants would show significant levels of retrieval-induced forgetting on the category-plus-stem-cued recall test.

METHOD

Participants

Participants were 80 undergraduate students enrolled in an introductory psychology course (70 at the University of Memphis; 10 at Eckerd College). Participants in the ADHD group were diagnosed with ADHD combined-type by a clinician *and* qualified for inclusion on the basis of two self-report assessment measures. The following procedure was employed to recruit participants for the ADHD group ($n = 40$) and the non-ADHD group ($n = 40$).

The *Current and Childhood Symptom Scales* (Barkley & Murphy, 1998) was administered to approximately 900 students. Respondents were eligible for participation in the ADHD group if they met DSM-IV criteria for ADHD combined-type, exceeded threshold for diagnosis based on normative data (Barkley & Murphy, 1998), *and* reported a previous diagnosis of ADHD. Respondents were eligible for participation in the non-ADHD group if they did *not* meet DSM-IV criteria for diagnosis, did not exceed the threshold for diagnosis, and reported no history of ADHD. The *Conners Adult ADHD Rating Scales, Screening Version* (CAARS-S:SV) was also administered to provide further confirmation of ADHD status (Conners, Erhardt, & Sparrow, 1999). Participants in the ADHD and non-ADHD groups scored comparably to adults diagnosed with ADHD and healthy adult controls, respectively.

ADHD groups were comparable in terms of gender and academic ability. Specifically, the ADHD group was composed of 12 males and 28 females (age = 20.9, ACT score = 24.2, GPA = 2.98) and the non-ADHD group was composed of 11 males and 29 females (age = 20.2, ACT score = 23.9, GPA = 3.06). Participants in both groups reported no history of learning disability, depression, or any other psychiatric condition.

Materials

A total of 48 exemplars of high taxonomic strength were selected from eight categories (e.g., *metals: silver*, *metals: brass*, *fruit: orange*, *fruit: lemon*). The category–exemplar pairs were the same as those employed by Anderson et al. (1994, Experiment 3), with a mean rank order of 8 according to Battig and Montague's (1969) category norms. No two exemplars from the same category began with the same letter. For counterbalancing purposes each category was divided into two subsets of three exemplars, and each participant received retrieval practice for one subset from each of four categories. The particular categories and subset of items within those categories receiving retrieval practice was counterbalanced across participants.

Two final tests were employed. One test involved participants recalling exemplars when provided category cues (e.g., *metals?*); the other test involved participants recalling exemplars when provided category-plus-one-letter-stem cues (e.g., *metals: s*_____). The order in which the tests were administered was counterbalanced across participants. For both tasks the categories were tested in blocks such that all items from one category were tested before proceeding to the next category. It is important to note that on the category-plus-stem test, Rp− items, and a matched subset of Nrp items, were always tested first. Nrp items tested in the first half of a block versus those tested in the second half of a block are referred to as Nrp− and Nrp+ items, respectively. This procedure ensured that Rp− items were always tested prior to Rp+ items, and that recall performance for both sets of items could be compared with an appropriate baseline.

Procedure

The experiment consisted of three phases: study, retrieval practice, and test. During study, 48 category-exemplar pairs were presented for 5 seconds each. The presentation order was random with the constraint that no two consecutive pairs were from the same category. Following study, participants engaged in retrieval practice for half of the exemplars from half of the categories. A series of category-plus-two-letter-stem cues (e.g., *metals: si*_____) appeared on the screen for 5 seconds, and participants were instructed to say the cued exemplar out loud for the experimenter to record. Each to-be-practised item received retrieval practice three times, with the order of the practice trials determined via blocked randomisation. After an unrelated 10-minute distractor task, the final tests were administered. The category-cued recall test consisted of each of four category cues appearing on the screen for 30 seconds, and participants were directed to retrieve as many of the exemplars from those categories as possible. The category-plus-stem-cued recall test consisted of a series of category-plus-one-letter-stem cues from the other four categories appearing on the screen for 5 seconds, and participants were instructed to retrieve each cued exemplar. Responses on both tests were made vocally to the experimenter.

RESULTS AND DISCUSSION

Performance during retrieval practice

ADHD and non-ADHD participants performed equivalently during retrieval practice, successfully retrieving 89% ($SE = 2\%$) and 91% ($SE = 1\%$) of the exemplars, respectively, $t(78) < 1$.

Final category-cued recall performance

Consequences of retrieval practice on practised items. Performance on the final category-cued recall test was analysed as a function of retrieval practice status and group using a 2 (Rp+ vs Nrp+) × 2 (ADHD vs non-ADHD) mixed design Analysis of Variance (ANOVA). Exemplars receiving retrieval practice (Rp+ items: $M = .81$, $SE = .02$) were recalled significantly better than their baseline counterparts (Nrp+ items: $M = .51$, $SE = .02$), $F(1, 78) = 124.62$, $MSE = 3.17$, $p < .001$, $d = 1.29$. This benefit of retrieval practice did not interact with participant group. And although not a significant difference, performance was somewhat better for non-ADHD participants ($M = .68$, $SE = .02$) than for ADHD participants ($M = .64$, $SE = .02$).

Consequences of retrieval practice on non-practised items. Recall performance on the final category-cued recall test as a function of retrieval practice status and group was analysed using a 2 (Rp− vs Nrp−) × 2 (ADHD vs non-ADHD) mixed-design ANOVA. A main effect of retrieval-induced forgetting emerged such that recall performance for non-practised items from baseline

TABLE 1
Recall performance

	Retrieval practice effect			*Retrieval-induced forgetting*		
Final test group	*Rp+*	*Nrp+*	*Difference*	*Rp−*	*Nrp−*	*Difference*
Category-cued recall						
ADHD	.79 (.02)	.48 (.04)	+31%	.39 (.03)	.49 (.04)	−10%
Non-ADHD	.83 (.02)	.53 (.04)	+30%	.42 (.03)	.52 (.04)	−10%
Category-plus-stem-cued recall						
ADHD	.82 (.03)	.54 (.03)	+28%	.61 (.03)	.58 (.03)	+3%
Non-ADHD	.86 (.03)	.67 (.03)	+19%	.59 (.03)	.69 (.03)	−10%

Recall performance as a function of type of test for ADHD and non-ADHD participants. Standard errors are in parentheses.

categories (Nrp items: $M = .50$, $SE = .03$) was significantly better than for non-practised items from practised categories (Rp− items: $M = .40$, $SE = .02$), $F(1, 78) = 11.02$, $MSE = .40$, $p < .001$, $d = 0.38$. As can be seen in Table 1, retrieval-induced forgetting did not interact with group—both ADHD and non-ADHD participants demonstrated significant levels of forgetting; $t(39) = 2.58$, $p < .05$, $d = 0.41$ and $t(39) = 2.14$, $p < .05$, $d = 0.34$, respectively.

Final category-plus-stem-cued recall performance

Consequences of retrieval practice on practised items. Recall performance on the final category-plus-stem-cued recall test was analysed as a function of retrieval practice status and group using a 2 (Rp+ vs Nrp+) × 2 (ADHD vs non-ADHD) mixed-design ANOVA. Exemplars receiving retrieval practice (Rp+ items: $M = .84$, $SE = .02$) were recalled significantly better than their baseline counterparts (Nrp+ items: $M = .61$, $SE = .02$), $F(1, 78) = 60.78$, $MSE = 2.24$, $p < .001$, $d = 0.87$. Once again, both ADHD participants and non-ADHD participants demonstrated a substantial benefit from retrieval practice. Importantly, performance was significantly better for non-ADHD participants ($M = .77$, $SE = .02$) than for ADHD participants ($M = .68$, $SE = .02$), $F(1, 78) = 7.20$, $MSE = .28$, $p < .01$, $d = 0.60$.

It makes sense that participants with ADHD were impaired on the category-plus-stem-cued recall test. The relatively short, experimenter-paced trials likely posed additional difficulty for individuals with ADHD. ADHD is characterised by high intra-individual variability in response time and processing speed (e.g., Castellanos & Tannock, 2002). The pattern of poorly regulated, erratic responding may be a function of brief interruptions or lapses in attention that result from fluctuations between a task-negative default mode and a task-positive attentive mode (Kelly, Uddin, Biswal, Castellanos, & Milham, 2008). Consequently, ADHD participants may have responded more slowly and less accurately, especially since the test required an immediate response within a short time frame (Russell et al., 2006). As such, we believe that the difference in category-plus-stem-cued recall performance between ADHD and non-ADHD participants reflects a true difference in baseline recall.

Consequences of retrieval practice on non-practised items. Recall performance on the final category-plus-stem-cued recall test was analysed as a function of retrieval practice status and group using a 2 (Rp− vs Nrp−) × 2 (ADHD vs non-ADHD) mixed-design ANOVA. A two-way interaction emerged such that non-ADHD participants demonstrated significantly more retrieval-induced forgetting than ADHD participants, $F(1, 78) = 7.05$, $MSE = .18$, $p < .01$, $\eta^2 = .08$. As can be seen in Table 1, non-ADHD participants demonstrated a significant effect of retrieval-induced forgetting, $t(39) = 3.07$, $p < .01$, $d = 0.49$, whereas ADHD participants demonstrated a non-significant effect of retrieval-induced facilitation, $t(39) = .88$, $p > .05$, $d = 0.14$.

GENERAL DISCUSSION

The present results demonstrate that whether individuals with ADHD suffer from retrieval-induced forgetting depends on the nature of the final test. Whereas both ADHD and non-ADHD participants demonstrated significant levels of retrieval-induced forgetting on the category-cued

recall test, only non-ADHD participants demonstrated significant levels of retrieval-induced forgetting on the category-plus-stem-cued recall test. These results suggest that individuals with ADHD do have a deficit in the inhibitory control of memory, but that this deficiency may only be apparent in studies that employ a final test that controls for output interference (e.g., category-plus-stem-cued recall). When output interference is not controlled, individuals with inhibitory deficiencies may demonstrate significant retrieval-induced forgetting as a result of interference on the final test, and not inhibition during retrieval practice. This finding is important from a methodological standpoint, as it suggests that researchers do not need to employ independent probes to determine whether differences in retrieval-induced forgetting reflect differences in inhibitory function (cf. Anderson & Levy, 2007).

ADHD-related deficits in prepotent motor response inhibition (e.g., go/no-go task) are well documented (e.g., Schachar et al., 2007). Given that similar mechanisms may be involved in the suppression of prepotent representations in memory (Anderson, 2005), the absence of inhibitory-based effects of retrieval-induced forgetting for ADHD participants is not surprising. Inhibition may be necessary for any goal-oriented activity that requires the active suppression of prepotent responses, regardless of whether the instruction to forget is explicit (e.g., directed forgetting) or implied (e.g., retrieval-induced forgetting). Thus ADHD-related inhibitory control deficits may affect not only overt, observable processes (e.g., motor control), but also covert, internal cognitive operations such as the control of memory. Such a deficit may explain many of the memory problems associated with ADHD, such as why individuals with ADHD are more likely to retrieve irrelevant information while attempting to retrieve relevant information.

The present results also have clinical significance. For example, an inhibitory deficit may constitute an important risk factor for the formation of intrusive memories following a traumatic event (Verwoerd, Wessel, & de Jong, 2009). Indeed, there is significant overlap between the diagnoses of ADHD and post-traumatic stress disorder (PTSD), and retrospective studies have determined that ADHD is a vulnerability factor for PTSD (see e.g., Adler, Kunz, Chua, Rotrosen, & Resnick, 2004; Cuffe, McCullough, & Pumariega, 1994). Because individuals with ADHD may be less able to inhibit prepotent or traumatic memories, those memories may be more likely to become intrusive.

Finally, on a theoretical note, the current results provide new and compelling support for the inhibitory account of retrieval-induced forgetting. If inhibitory processes do underlie retrieval-induced forgetting, then individual differences in inhibitory function should predict individual differences in forgetting. However, as the current results also suggest, researchers studying individual differences in this context should be careful to consider non-inhibitory causes of forgetting, such as output interference. The failure to do so may jeopardise the interpretability of their findings or, even worse, make them entirely misleading.

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