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Collaborative memory and part-set cueing impairments: The role of executive depletion in modulating retrieval disruption

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When people are exposed to a subset of previously studied list items they recall fewer of the remaining items compared to a condition where none of the studied items is provided during recall. This occurs both when the subset of items is provided by the experimenter (i.e., the part-set cueing deficit in individual recall) and when they are provided during the course of a collaborative discussion (i.e., the collaborative inhibition effect in group recall). Previous research has identified retrieval disruption as a common mechanism underlying both effects; however, less is known about the factors that may make individuals susceptible to such retrieval disruption. In the current studies we tested one candidate factor: executive control. Using an executive depletion paradigm we directly manipulated an individual's level of executive control during retrieval. Results revealed no direct role of executive depletion in modulating retrieval disruption. In contrast, executive control abilities were indirectly related to retrieval disruption through their influence at encoding. Together these results suggest that executive control des not directly affect retrieval disruption at the retrieval stage, and that the role of this putative mechanism may be limited to the encoding stage.

Keywords: Memory; Part-set cueing; Collaborative inhibition; Retrieval disruption; Executive depletion.

As a social species we spend the majority of our lives with others and many of our memories are both encoded and recalled in interactive group contexts. However, cognitive research on memory has typically focused on individuals working in isolation and group memory has largely been studied within the domains of sociology, social psychology, and anthropology (e.g., Halbwachs, 1950/80; Wegner, 1986; Wertsch, 2002; see also Echterhoff, Higgins, & Levine, 2009). It is only in the last decade that cognitive psychology research has begun to focus on identifying both how and why an individual's memory changes when recalling information as a member of a collaborating group (for reviews, see Barnier & Sutton, 2008; Rajaram, 2011; Rajaram & Pereira-Pasarin, 2010; Weldon, 2001). This rapidly emerging domain of research has linked the deficit associated with collaborative recall to the part-set cueing phenomenon in individual memory research by way of a common mechanism of retrieval disruption that we will describe shortly (Basden, Basden, Bryner, & Thomas, 1997). The present research tested the role of executive control abilities in modulating this mechanism.

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COLLABORATIVE INHIBITION

To examine how collaboration affects memory, the comparison is made between the recall of interacting, or *collaborative*, groups with the recall of *nominal* groups of equal size. Nominal groups are groups in name only where the individual recall of participants is pooled together in a non-redundant fashion with overlapping items counted only once. For example, in a typical collaborative memory experiment, all participants first study a list of items such as A, B, C, D, E, F, G, H, I. If there are three participants in each group, collaborative recall is calculated as the number of answers produced by three individuals working together. In contrast, nominal recall is calculated as the number of non-redundant answers produced by three individuals working alone: if Participant 1 recalls items A, B, and C, Participant 2 recalls A, D, and E, and Participant 3 recalls A, E, F, and G, then the pooled non-overlapping nominal recall is seven items: A, B, C, D, E, F G. This nominal recall product is then compared with the recall of the collaborative group, and the outcome of this comparison is counterintuitive: collaborative groups recall significantly *less* than nominal groups, a phenomenon known as *collaborative inhibition* (Weldon & Bellinger, 1997).

Why does collaborative inhibition occur? Although social loafing may seem like an obvious explanation, collaborative inhibition does not occur because of diffusion of responsibility or reduced motivation (e.g., Weldon, Blair, & Huebsch, 2000). In fact, increasing motivation within a group (by offering monetary incentives, increasing group cohesion, and increasing personal accountability) does not eliminate the collaborative inhibition effect (Weldon et al., 2000). Rather, it appears that collaborative inhibition is primarily a *cognitive* phenomenon and is similar to the *part-set cueing deficit* that occurs in individual recall (see Basden et al., 1997; Nickerson, 1984).

COLLABORATIVE INHIBITION IS SIMILAR TO THE PART-SET CUEING DEFICIT

The part-set cueing deficit refers to a counter-intuitive phenomenon in which cueing is detrimental to memory performance. In general, memory is improved when adequate retrieval cues are provided (e.g., Tulving, 1974). For example, after studying a categorised list of words, people remember more if they receive one studied item from each category (compared to no items) as a memory cue (Hudson & Austin, 1970). However, when people receive *more* than one studied item from each category, they recall fewer of the remaining items compared to a condition where none of the studied items is provided as a cue during recall. This phenomenon is known as the part-set cueing deficit.

Since the part-set cueing deficit was first reported (Slamecka, 1968) numerous explanations about the underlying mechanism have been proposed (for reviews see Bäuml, 2007; Nickerson, 1984; Roediger & Neely, 1982). One of the first explanations was that of *retrieval competition* (Rundus, 1973). According to this view, retrieval is determined probabilistically by strength-dependent competition. Re-exposure to the cue items strengthens their representations, and this hyper-accessibility leads participants to covertly retrieve the cue items before the non-cued items during the memory test. After successive failures to retrieve the non-cued items participants prematurely stop their retrieval process. Although this view is consistent with many findings in the literature (for a review, see Roediger & Neely, 1982), more recent evidence shows that strengthening of a subset of items does not necessarily lead to forgetting of other items (e.g., Bäuml & Aslan, 2004).

An alternative explanation of the part-set cueing deficit is that of r*etrieval disruption.* According to this view, individuals develop their own idiosyncratic organisation of studied materials and use this organisational strategy to guide retrieval (Roenker, Thompson, & Brown, 1971; Rundus, 1971; Tulving, 1962). Later, the presence of part-set cues disrupts these organisational and retrieval strategies and leads to suboptimal recall performance (Basden & Basden, 1995; Basden, Basden, & Galloway, 1977). Two lines of research support the retrieval disruption account. First, part-set cues are less detrimental when the cues are in line with, rather than inconsistent with, the individual's organisational strategy (Basden, Basden, & Stephens, 2002; Basden & Basden, 1995; Sloman, Bower, & Rohrer, 1991). Second, there is often a "release" from part-set cueing such that once the cues are removed (e.g., on a later memory test) participants elicit previously "blocked" studied words (Basden et al., 1977; but see Bäuml & Aslan, 2004). Thus the memory impairment on the first recall test is often temporary and does not reflect poorer encoding or storage in the part-set cued condition.

Although considerable evidence supports the retrieval disruption account of the part-set cueing deficit, there has also been empirical support of a different mechanism, namely *retrieval inhibition* (e.g., Bäuml & Aslan, 2004). The retrieval inhibition account centres on the assumption that participants covertly retrieve the part-set cues as they are presented. This in turn leads to inhibition of items with similar features to the part-set cues (Aslan & Bäuml, 2009) in the same way that overt retrieval of half of a studied list will lead to inhibition of the remaining items, an effect known as *retrieval-induced forgetting* (for a review of retrieval-induced forgetting, see Anderson, 2003). In contrast to the retrieval disruption account, the retrieval inhibition account posits that the memory representations of the non-cued target words are themselves damaged by covert retrieval of the cue items. This in turn leads to lasting memory impairment of the non-cued target items such that there is no ''release'' from part-set cueing once the cues are removed (Bäuml, 2008).

A recent two-mechanism account (Bäuml & Aslan, 2006) reconciles the reports of empirical evidence in support of each account by positing that the part-set cueing deficit occurs due to retrieval inhibition when the encoded items have a low degree of inter-item associations and due to retrieval disruption when the encoded items have a high degree of inter-item associations. In the current experiments we focused specifically on the retrieval disruption mechanism. We did this because evidence supports the proposal that retrieval disruption underlies not only the part-set cueing deficit (when the encoded items have a high degree of inter-item associations; Bäuml & Aslan, 2006), but also the collaborative inhibition effect (Basden et al., 1997). Within a collaborative group each group member has their own unique organisational and retrieval strategies. During a collaborative recall session, the responses produced by other group members serve as part-set cues and disrupt each individual's idiosyncratic retrieval strategies, leading to lowered group recall. Supporting evidence comes from the fact that collaborative inhibition is only present on free-recall memory tests that rely on an individual's idiosyncratic retrieval strategy. In contrast, collaborative inhibition is absent when the memory test format imposes a set organisational structure such as cued-recall (Finlay, Hitch, & Meudell, 2000; see also Barber, Rajaram, & Aron, 2010) or recognition (Clark, Abbe, & Larson, 2006; Clark, Hori, Putnam, & Martin, 2000), presumably because this creates equivalent retrieval disruption in both the collaborative and nominal groups.

THE ROLE OF EXECUTIVE CONTROL IN RETRIEVAL DISRUPTION

The amount of retrieval disruption an individual experiences may be modulated by the individual's level of executive control. The current research focuses on this relationship. Although no single definition captures all theoretical views, executive control (also referred to as the ''central executive'' or ''supervisory attention system'') typically refers to the collection of interrelated abilities that are involved in controlling and directing attention, thoughts, and actions according to one's goals (e.g., Baddeley, 1986; Norman & Shallice, 1986; Posner & DiGirolamo, 2000; for a review see Gathercole, 2008). Put another way, executive control can be thought of as an attentional construct (e.g., Blair, 2006; Duncan, Emslie, Williams, Johnson, & Freer, 1996; Heitz, Unsworth, & Engle, 2005; McCabe, Roediger, McDaniel, Balota, & Hambrick, 2010; Shallice & Burgess, 1993), or collection of abilities (e.g., Friedman et al., 2006, 2008; Miyake, Friedman, Emerson, Witzki, & Howerter, 2000; Sylvester et al., 2003) that allow people to inhibit some thoughts and purposely pursue others in a goal-directed manner. Strikingly, extant work suggests negative, neutral, and positive relationships between executive control and susceptibility to retrieval disruption.

A NEGATIVE RELATIONSHIP BETWEEN EXECUTIVE CONTROL AND SUSCEPTIBILITY TO RETRIEVAL DISRUPTION

Some prior work suggests a rather paradoxical outcome such that individuals with high executive control exhibit a part-set cueing deficit in recall whereas individuals with low executive control do not (Cokely, Kelley, & Glichrist, 2006). This result that higher executive control corresponds to greater retrieval disruption (Cokely et al., 2006) appears to be driven by encoding differences between high and low executive control individuals. Previous work has shown that executive control is related to the ability to integrate information during learning (Cantor & Engle, 1993; Radvansky & Copeland, 2006). As such, better executive control promotes encoding strategies that create inter-item associations among the unrelated studied items, while low executive control does not produce such idiosyncratic organisation (McNamara & Scott, 2001, Turley-Ames & Whitfield, 2003). Given that the part-set cueing deficit is prevalent when inter-item associations are strong (Basden et al., 2002), these differences in encoding strategy presumably lead to a part-set cueing deficit for individuals with high, but not low, executive control.

While executive control indirectly produces an impact on retrieval disruption through its role at encoding it is not clear whether it plays a direct role in modulating retrieval disruption at the retrieval stage. Some evidence suggests that it does not. For example, Cokely et al. (2006) found that the relationship between executive control and retrieval disruption disappears when encoding is equated across participants. In particular, during the encoding phase of their Experiment 2B they asked all participants to link the to-be-remembered words in a story. This manipulation encouraged all participants, regardless of their executive control abilities, to create strong inter-item associations. Later all participants, regardless of their executive control abilities, exhibited a part-set cueing deficit in recall. This result was taken as evidence that encoding strategies play a causal role in predicting retrieval disruption (Cokely et al., 2006, Expt 2B). Furthermore, given that the relationship between executive control and retrieval disruption disappeared when encoding strategies were equated, this suggests that executive control exerts no direct impact on retrieval disruption through its role at retrieval.

The conclusion that executive control only modulates retrieval disruption through its role at encoding, but not at retrieval, is further supported by research on divided attention. A large body of literature has shown that dividing attention during encoding results in poorer memory compared to having full attention during encoding (e.g., Baddeley, Lewis, Eldridge, & Thomson, 1984; Craik, Govoni, Naveh-Benjamin, & Anderson, 1996; Fernandes & Moscovitch, 2000, 2002; Murdock, 1965; Naveh-Benjamin, 1987, 1988, 1990; Naveh-Benjamin & Jonides, 1986). In contrast, dividing attention during retrieval exerts little effect on memory performance compared to having full attention during retrieval (e.g., Baddeley, et al., 1984; Kellogg, Cocklin, & Bourne, 1982; Naveh-Benjamin, Craik, Guez, & Dori, 1998; for a review see Craik, 2001). Given that executive control is often conceptualised as an attentional construct (e.g., Kane & Engle, 2000; McCabe et al., 2010; Shallice, 1988), and given that attentional resources do not seem to substantially impact memory retrieval performance, it is possible that executive control plays no direct role in modulating retrieval disruption at the retrieval stage.

A positive relationship between executive control and susceptibility to retrieval disruption

Other lines of research lead to an opposite prediction and suggest that better executive control enables suppression of distraction and should therefore *decrease* retrieval disruption even when encoding is equated. In particular, one can think of the part-set retrieval cues or items recalled by other group members during collaborative recall as "intrusive memories" once they have been successfully recalled. The participant must therefore attempt to "suppress" or "ignore" the cues and continue searching their own memory for new target items according to their own retrieval scheme. Several lines of research suggest that the ability to ignore no longer relevant information by controlling attention in a goal-directed manner should be dependent on executive control capacity.

First, many studies show that individuals with higher working memory spans (i.e., better executive control) are better able to ignore distractions during a cognitive task than individuals with lower working memory spans (e.g., Connelly, Hasher, & Zacks, 1991). Similarly, other evidence suggests that as working memory capacity increases, interference decreases such that low-capacity individuals seem to have difficulty suppressing related, but irrelevant, information during a memory task (Cantor & Engle, 1993; Radvansky & Copeland, 2006).

Second, participants with high working memory spans are also better able to avoid "cue" words (and continue searching memory for non-cue words) than participants with low working memory spans. For example, in a study by Hansen and Goldinger (2009) participants were asked to play the board game ‘‘Taboo’’. During this game one player supplies clues to their team-mates about a target word (e.g., ‘‘Bacon’’) while avoiding the ‘‘taboo’’ words (e.g., ‘‘Pig’’, ‘‘Eat’’, ‘‘Breakfast’’, ‘‘Sausage’’, and ‘‘Eggs’’). Thus, in order to complete this task, the player must hold the taboo words in mind while continuing to search memory for alternate methods to describe the target word (e.g., ‘‘A something-lettuce-and-tomato sandwich’’). Results indicated that participants with high working memory spans were better able to avoid the ‘‘taboo’’ words and find alternate methods to describe the target word than participants with low working memory spans.

In brief, previous evidence clearly shows that executive control influences retrieval disruption. But the findings are contradictory with respect to the nature of relationship between executive control and retrieval disruption. While some research has suggested that executive control plays no direct role in predicting retrieval disruption except through its role at encoding (e.g., Baddeley et al., 1984; Cokely et al., 2006), other lines of research suggest that high executive control should be associated with decreased retrieval disruption (e.g., Cantor & Engle, 1993; Hansen & Goldinger, 2009). In order to achieve a decisive understanding of the stage at which executive control influences retrieval disruption, it is critical to devise experimental conditions where the operation of executive control is manipulated solely at the retrieval stage. That is, in order to clearly examine executive control’s role in moderating retrieval processes an individual differences approach does not provide a decisive test. This is because individuals with high (or low) executive control have high (or low) control during both encoding and retrieval. Thus an individual differences approach does not allow for a focused examination of how executive control affects retrieval independent of its role at encoding.

EXECUTIVE DEPLETION: MANIPULATION OF EXECUTIVE CONTROL AFTER ENCODING

Evidence for differences in the executive control capacity *across* individuals has motivated the individual differences approach in many studies. However, there is also evidence that executive capacity can change *within* individuals across time, with fewer resources to deploy when cognitive load increases (e.g., Hester & Garavan, 2005; Lavie, Hirst, de Fockert, & Viding, 2004; Ward & Mann, 2000), or when measured subsequent to a previous task demanding executive control (Persson, Welsh, Jonides, & Reuter-Lorenz, 2007; Richeson & Trawalter, 2005; Schmeichel, 2007; van der Linden, Frese, & Meijman, 2003). One explanation of this within-individual fluctuation is that executive control is a limited resource that can be temporarily depleted (for a meta-analytic review of depletion effects, see Hagger, Wood, Stiff, & Chatzisarantis, 2010).

Of interest to the current studies, previous research has shown that both working memory (e.g., Johns, Inzlicht, & Schmader, 2008; Scheibe & Blanchard-Fields, 2009; Schmeichel, 2007) and the ability to conduct a maintained search through memory (e.g., Neshat-Doost, Dalgleish, & Golden, 2008) are negatively affected by prior efforts at executive control. For example, after performing a difficult task that requires the control of attention, participants are ‘‘depleted’’ and score lower on both a working memory span test (e.g., Johns et al., 2008; Schmeichel, 2007), and on the Autobiographical Memory Test. In the Autobiographical Memory Test participants are asked to recall specific autobiographical memories in response to a cue word. Findings indicate that depleted participants are unable to set aside overly general memories and continue the search for a more specific recollection (Neshat-Doost et al., 2008). A search process is also needed in situations in which retrieval disruption operates during retrieval. Participants must ignore the cues (provided either by the experimenter as in the case of part-set cued recall or by other participants as in the case of collaborative recall) and continue to search memory for the studied items that have not yet been recalled. This maintained search through memory should therefore depend on the amount of executive resources that the individual has available (i.e. their level of depletion).

OVERVIEW OF THE CURRENT EXPERIMENTS

The present studies were designed to assess the relationship between executive control and retrieval disruption. On the one hand, research on divided attention and on individual differences of executive control abilities suggests that executive control may modulate retrieval disruption only indirectly through its role at encoding. That is, this research suggests a rather counterintuitive prediction of no relationship between executive control and retrieval disruption when executive control is manipulated solely at the retrieval stage. On the other hand, research on the ability to ignore distractions suggests that executive control may enable individuals to successfully pursue the retrieval of studied items in line with their own retrieval organisation while simultaneously managing the disruption created by previously recalled items. In other words, this suggests a negative relationship between executive control and retrieval disruption such that individuals with high executive control should be less susceptible to retrieval disruption than individuals with low executive control.

These competing predictions were tested in two experiments. Executive control capacity at retrieval was directly manipulated using the depletion method just described. Importantly, given that the present focus is on the retrieval disruption process and retrieval disruption is thought of as a retrieval effect (see Rajaram & Barber, 2008), the current studies focused specifically on the role of executive control at retrieval rather than at encoding.

In brief, participants studied a list of items that was designed to elicit strong inter-item associations. This ensured that the subsequent memory tests focused on the operation of the retrieval disruption mechanism (see Bäuml & Aslan, 2006). After the completion of the study phase, participants were assigned either to the executive depletion conditions or the control conditions within each experiment. In the executive depletion conditions participants completed a depleting executive control task prior to the part-set cued task/collaborative retrieval task whereas in the control conditions participants performed a comparable, but not depleting, task. The effects of this manipulation on retrieval disruption were assessed in both a part-set cueing paradigm (Experiment 1) and in a collaborative memory paradigm (Experiment 2). Thus this manipulation allowed direct examination of how executive depletion affects retrieval disruption when it specifically targets executive control during retrieval in both a part-set cueing and a collaborative memory paradigm. Finally, at the end of the experiment individual differences in executive control were assessed. This measure allowed for an examination of how existing variations in executive control throughout the entire experiment (rather than levels of executive depletion isolated to the retrieval stage through experimental manipulation) relate to subsequent retrieval disruption (as in Cokely et al., 2006).

EXPERIMENT 1

Method

Participants. A sample of 152 (70% female) undergraduate students (38 per condition) from Stony Brook University participated in exchange for partial course credit (mean age 19.97; $SD = 3.94$).

Materials. Study items consisted of six categorised lists of 14 high-frequency exemplars each drawn from the Van Overschelde, Rawson, and Dunlosky, 2006 (which is an update of Battig & Montague, 1969) norms. Exemplar frequency was matched across the six lists. Within each list, the seven exemplars with the relatively higher category frequency (average rank order of 5.6; range of 1–10) were designated as the "target" words, and the seven exemplars with the relatively lower frequency (average rank order of 19.5; range of 13–27) were designated as the non-target "cue" words. This was done to produce large disruption effects. Previous research has shown that using the lower-frequency exemplars as the cues produces more retrieval disruption than using the higher-frequency exemplars as cues (Bäuml, Kissler, & Rak, 2002; Kissler & Bäuml, 2005).

Further, these materials were also chosen to have a high degree of inter-item associations, and thereby ensure that the present experiment taps the retrieval disruption mechanism. In previous experimental studies this has been done by asking participants to complete multiple study-test sessions, or to link the to-be-remembered items in a story during encoding (Bäuml & Aslan, 2006). In the current study we used high-frequency category exemplars to similarly produce a high degree of inter-item associations. Previous research has shown that when people are presented with a list containing high-frequency category exemplars from multiple categories, they tend to both rehearse and recall the items according to their category structure (Rundus, 1971, Expt 4). In summary, by using categorised word lists where the selected exemplars are relatively high in their category membership and as such facilitate a high degree of inter-item associations, the current experiment focused specifically on the operation of the retrieval disruption mechanism.

Design. Two factors, executive depletion (depleted or not depleted) and test format (part-set cued or free recall) were manipulated between participants.

Study phase. Participants were first shown the exemplars from all six lists in one of three random orders. That is, during encoding the six categorised lists (each with 14 exemplars) were presented to participants as a single study list (with 84 items), with no more than three items from any category appearing in succession. Each item was displayed for 3 seconds in lower-case letters and centred on the computer screen. Category names were not provided during study and intentional study instructions were used such that participants were told to study the words for an upcoming (unspecified) memory test.

Depletion manipulation (or control distractor task). After completing the study phase, half of the participants completed an activity (adapted from Schmeichel, 2007, Expt 2) designed to deplete their executive resources and half of the participants completed a control activity. Participants in the depletion group spent 5 minutes writing a story about a trip or vacation while avoiding the frequently occurring letters "a" and "n". For example, during this task it would *not* have been acceptable to write about a "vacation to the beach" since the word "vacation" has the letters "a" and "n" and the word "beach" has the letter "a". However, it would have been acceptable to write about a "trip to the shore" since these words do not contain the forbidden letters. This task forced the participants to find alternate means of expressing their thoughts while inhibiting the first responses that come to mind. In contrast, participants in the no-depletion condition spent 5 minutes writing a story without using the letters "q" or "z". Given the relatively low occurrence of these letters in the English language, participants should not have to override their first responses. Previous research has shown that this depletion task reduces subsequent executive control abilities, as measured by the operation span and reverse digit span tasks, but that this "control" task does not (Schmeichel, 2007).

Test phase #1: The part-set cueing deficit. Half of the participants were tested in a part-set cued recall test. Participants received a sheet of paper listing each of the six category names along with seven of the studied items (which served as part-set cues) from each category. Cues were presented in a different order from study (e.g., Luek, McLaughlin, & Cicala, 1971; Sloman et al., 1991) and were blocked by category (Basden et al., 2002) in order to maximise the part-set cueing deficit. Furthermore, participants were asked to read the cues aloud in order to ensure that all participants processed the cues (see Cokely et al., 2006), and they were instructed to think of the cues as helpful hints for aiding their recall (e.g., Aslan, Bäuml, & Grundgeiger, 2007; Basden, Basden, Church, & Beaupre, 1991; Marsh, Dolan, Balota, & Roediger, 2004). After reading the cues participants were asked to write down as many of the remaining studied words as possible. The remaining participants were tested using an uncued free recall test. During this test participants were simply given a blank sheet of paper and were asked to recall as many items as possible. In both the depleted and non-depleted conditions participants worked on this task alone for 10 minutes. While free recall also requires the use of one's own idiosyncratic organisation—and therefore, executive resources—for successful completion, the absence of external cues does not demand additional executive resources that are required in the part-set cueing task where external cues that disrupt one's idiosyncratic organisation must be ignored. In line with this, previous research has shown that depletion of executive resources does not affect performance on a free recall task (Schmeichel, Vohs, & Baumeister, 2003). In summary, four groups completed this test phase: (1) Depleted participants tested using part-set cued recall, (2) Depleted participants tested using free recall, (3) Non-depleted (Control) participants tested using part-set cued recall, and (4) Non-depleted (Control) participants tested using free recall.

Test phase #2: Free recall test. Immediately following the first test phase all participants completed an uncued free recall test. Participants were given a blank sheet of paper and 10 minutes to recall as many of the words as possible from the previous study list (even if they recalled the word during the previous test and even if the word had been provided as a "cue" during the previous test).

Assessment of executive control. Executive control was assessed using an automated version of the operation span task (Turner & Engle, 1989; Unsworth, Heitz, Schrock, & Engle, 2005). During this task participants were asked to mentally solve incomplete arithmetic equations (e.g., 5 * 7 = ?). After clicking the mouse to verify that they had solved the equation they were presented with a single number on the screen (e.g., 35) and they had to decide whether this number was the correct or incorrect solution to the previous equation. Immediately following this choice, a letter was presented on the screen. This cycle was repeated until participants had seen between three and seven letters. They were then asked to recall the letters they had seen in the order they had seen them. Timing for this task was based on a practice session in order to account for individual differences in arithmetic problem solving. In particular, participants were limited in the length of time they had to solve each arithmetic question to the average length they took to answer arithmetic questions during a practice block plus 2.5 standard deviations. As recommended by Conway et al. (2005), for all of the following analyses operation span was calculated as the number of letters recalled in their correct serial position (regardless of whether the participant recalled the entire set of items correctly). This test possesses good test–retest reliability (.83) and internal consistency ($\alpha = .78$; Unsworth et al., 2005).

Two additional points about the operation span task should be noted. First, while there are many measures of executive control, the operation span task was chosen because it was the measure used by Cokely and colleagues (2006) to demonstrate differences in the part-set cueing deficit as a function of executive control abilities at encoding. Second, this assessment was included at this time point in the experiment to ensure that it would be unaffected by the previous executive depletion manipulation (which occurred 20 minutes prior). Previous research has shown the time course of executive depletion to be limited (Converse & DeShon, 2009). Thus this measure was used for subsequent analyses examining how executive control abilities indirectly affect retrieval disruption through encoding because of individual differences (as in Cokely et al., 2006) and was not intended to be a manipulation check of the executive depletion manipulation.

Final questionnaire. At the end of the experiment participants completed a final questionnaire in which they rated how difficult each of the tasks had been to complete and to provide their general thoughts and impressions about the experiment.

Results

An $\alpha = .05$ significance level was used for all analyses in both Experiment 1 and Experiment 2.

Manipulation check. One participant from the depletion free recall condition was removed from all subsequent analyses for failure to follow instructions during the story-writing task. In particular, this participant used the forbidden letters "a" and "n" a total of 68 times in her story.

Depletion task performance. Based on the remaining participants, there was a significant difference across the conditions in how difficult participants rated the story-writing task, $F(3, 147) = 136.51$, $MSE = 1.55$. Participants in the depletion conditions, who avoided the letters "a" and "n" in their stories, rated the task as much more difficult ($M = 6.01$; a maximum score of 7 corresponded to "very difficult") than participants in the control conditions, who avoided the letters "q" and "z" in their stories ($M = 1.92$; a minimum score of 1 corresponded to "very easy"), $t(147) = 20.21$, $SE = .41$. Furthermore, participants in the depletion conditions made more mistakes by accidentally using the forbidden letters during the story-writing task ($M = .91$ forbidden letters used), and wrote shorter stories ($M = 27.01$ words) than participants in the control conditions ($M = .05$ forbidden letters used and $M = 102.88$ words), $t(147) = 4.54$, $SE = .38$ and $t(147) = -21.91$, $SE = 6.93$, respectively (see Appendix for example stories). This pattern is consistent with the notion that avoiding the common letters "a" and "n" during a story-writing task is a cognitively effortful task that likely requires executive control.

Test phase #1: The part-set cueing deficit. A part-set cueing deficit would be evidenced as superior recall for the noncued, critical words during an uncued free recall test compared to during a part-set cued recall test. For example, for a study list items A, B, C, D, E, F, G, H, I, and J, where later part-set cues would consist of items A, B, C, D, and E, part-set cueing deficit would be evidenced if recall of items F, G, H, I, and J was higher during the uncued free recall than the part-set cued recall test (Reysen & Nairne, 2002).[1]

A one-factor (Test format: Part-set cued recall vs Uncued free recall) between-participants ANOVA on recall of non-cued words revealed a significant difference in recall as a function of test condition, $F(1,\ 149) = 13.82$, $MSE = 0.02$ (see Table 1). That is, cueing impaired recall. Participants recalled a greater proportion of the non-cued, critical words during the uncued free recall tests ($M = .37$) compared to during the part-set cued recall tests ($M = .29$). Furthermore, follow-up analyses confirmed that the advantage of free recall test conditions over part-set cued recall test conditions held for both participants in the control, non-depleted, conditions, $t(147) = 2.25$, $SE = .03$, and for participants in the depleted conditions, $t(147) = 2.98$, $SE = .03$.

A test of the direct effect of executive depletion on retrieval disruption at the retrieval stage. We next examined the role of executive depletion in modulating the observed part-set cueing deficits. If low executive control increases susceptibility to interference (e.g., Hansen & Goldinger, 2009) and therefore increases retrieval disruption, then depleted participants should display a larger part-set cueing deficit than control participants. This would be evidenced by a significant difference in part-set cued recall, but not in free recall, as a function of depletion. In contrast, if executive control plays no direct role in retrieval disruption other than through its role at encoding, depleted and control participants should display an equivalent part-set cueing deficit. In other words, it is possible that executive control is only related to retrieval disruption because it mediates the degree of inter-item associations created at encoding which in turn affects the amount of retrieval disruption experienced (Cokely et al., 2006). Because the effects of executive control at encoding were not manipulated across the conditions in this experiment, the current findings isolate the role of executive control during retrieval.

Planned comparisons showed no effect of depletion on the number of critical, non-cued words recalled by participants on either the free recall test, $t(147) = 0.30$, $SE = .03$, $p = .77$, or on the part-set cued recall test, $t(147) = -0.44$, $SE = .03$, $p = .66$. That is, depleted participants ($M = .37$) recalled as many of the critical, non-cued words during the free recall test as the non-depleted control participants ($M = .36$). Similarly, depleted participants ($M = .29$) recalled as many of the critical, non-cued words during the part-set cued recall test as the non-depleted control participants ($M = .30$). Thus, executive depletion did not exert a direct influence at the retrieval stage on susceptibility to retrieval disruption.

Test phase #2: Free recall test. All participants took a free-recall memory test immediately following the previous test phase. Some previous studies have documented a ''rebound'' effect such that performance on a final free recall test is equivalent between participants who have previously taken free recall and part-set cued recall tests. That is, the performance decrement in the part-set cueing conditions is often temporary and not evident once the part-set cues are removed (e.g., Basden & Basden, 1995). However, in the current experiment the decrement associated with part-set cueing persisted. Participants who had previously taken a part-set cued recall test ($M = .32$) recalled significantly fewer of the critical non-cued items on a final free recall test than participants who had previously taken a free recall test ($M = .38$), $F(1,\ 149) = 7.06$, $MSE = .02$ (see Table 1). Furthermore, follow-up analyses confirmed that the disadvantage of having previously taken a part-set cued recall test rather than a free recall test held for participants in the control, non-depleted, conditions, $t(147) = 2.12$, $SE = .03$, and marginally for participants in the depleted conditions, $t(147) = 1.61$, $SE = .03$, $p = .11$. The lack of a full ''rebound'' effect here is not entirely unexpected; while several studies have documented a ''rebound'' effect (e.g., Basden & Basden, 1995, Expts 1, 3, 4, 5; Basden et al., 1977; Bäuml & Aslan, 2006), its absence has also been observed under conditions where

[1]We assessed the part-set cueing deficit by comparing memory on a part-set cued test versus on a free recall test. Although this comparison has been used by previous studies (e.g., Marsh, et al., 2000), it is more common to compare recall on a part-set cued test versus on a category-cued recall test (e.g., Basden & Basden, 1995; Bauml & Aslan, 2006). As noted by a reviewer, our choice to use free recall rather than category cued recall likely means that we *underestimate* the magnitude of the part-set cueing deficit. This is because participants in the part-set cued condition gain a benefit of have category cues, and this benefit is absent to participants in the free recall condition. However, it is important to note that our analysis of executive depletion's role in retrieval disruption focuses solely on performance in the part-set cued test conditions. Thus, our methodological choice does not impact our ability to draw conclusions about executive depletion's role in modulating retrieval disruption.

retrieval disruption is theorised to occur (e.g., Basden & Basden, 1995, Expt 2; Oswald, Serra, & Krishna, 2006).

However, an examination of the changes in recall from the first to the second memory test did demonstrate that the part-set cueing deficit was at least attenuated, if not eliminated, after the cues were removed. In particular, for each participant the "reminiscence" and "forgetting" rates were calculated. The reminiscence rate refers to the proportion of critical, non-cued items recalled during the second memory test (i.e., the final free recall test) that were not recalled during the first memory test (i.e., either the free recall test or the part-set cued recall test). In contrast, the forgetting rate refers to the proportion of critical, non-cued items recalled during first memory test but not during the second memory test (see Payne, 1987). If the part-set cueing deficit is attenuated once the cues are removed, then participants in the part-set cued recall test conditions should show a net gain in items remembered that is greater than that of participants in the free recall test conditions.

In support of this, there was a significant difference in reminiscence as a function of whether participants had previously taken a part-set cued or free recall test, $F(1, 149) = 4.09$, $MSE = .002$. Participants who had previously taken a part-set cued recall test ($M = .06$) gained more critical items from the first memory test to the second memory test than participants who had previously taken a free recall test ($M = .04$). This gain was not offset by losses in the form of forgetting. There was no significant difference in forgetting rates of critical items between participants who had previously taken a part-set cued recall test ($M = .03$) and participants who had previously taken a free recall test ($M = .03$), $F(1, 149) = .01$, $MSE < .01$, $p = .92$. However, further analyses suggest that the reminiscence rates (but not the forgetting rates) were modulated by executive depletion. The reminiscence advantage of participants who had taken a part-set cued recall test rather than a free recall held for participants in the depletion conditions, $t(147) = -2.83$, $SE = .01$, but not for participants in the control conditions, $t(147) = -.08$, $SE = .01$, $p = .94$. This is in line with some recent research by Converse and DeShon (2009) showing that while executive depletion is harmful in the short term (on a task administered immediately after the depletion), it can lead to benefits in the long term (on a task administered later in the experiment). Thus there was an attenuation of the part-set cueing deficit on the second, always free-recall, memory test for participants in the depletion condition.

Memory errors. Recall error rates on both memory tests were predictably very low (see Table 1). Error rates varied as a function of condition on the first memory test, $F(3, 147) = 2.64$, $MSE < .01$, $p = .05$; participants in the free recall conditions had a higher intrusion rate ($M = .03$) than participants in cued recall conditions ($M = .02$), $t(147) = 2.20$, $SE = .01$. However, error rates did not vary as a function of depletion condition, $t(147) = 0.42$, $SE = .01$, $p = .67$. Error rates did not continue to vary as a function of condition on the second, always free recall, memory test, $F(3, 147) = 1.45$, $MSE < .01$, $p = .23$.

Individual differences in executive control. At the end of the experiment all participants completed the automated operation span test (Unsworth et al., 2005) as a measure of executive control. Five participants (3% of participants) were not included in the following analyses due to high error rates on the operation span test that

TABLE 1
Experiment 1

		Memory Test 1 (free or cued recall)		*Memory Test 2 (always free recall)*	
		Proportion correct	*Intrusion rate*	*Proportion correct*	*Intrusion rate*
Control participants	Free recall	.36 (.14)	.02 (.03)	.39 (.15)	.03 (.05)
	Part-set cued recall	.30 (.12)	.02 (.03)	.32 (.13)	.03 (.04)
Depleted participants	Free recall	.37 (.12)	.03 (.04)	.37 (.14)	.04 (.06)
	Part-set cued recall	.29 (.13)	.01 (.02)	.32 (.13)	.02 (.03)

Mean proportion of critical items correctly recalled and the intrusion rates on both the first and second memory tests of Experiment 1 as a function of condition. During memory test 1 the participants either completed a free recall test or a part-set cued recall test. During memory test 2 all participants completed a free recall test. Numbers in parentheses are standard deviations.

rendered their scores uninterpretable (i.e., their error rates were more than three standard deviations greater than the mean).

As mentioned earlier, the operation span task was placed at the end of the experiment in order to ensure that it would not be affected by the prior depletion manipulation. A one-factor ANOVA confirmed this; performance on the operation span test did not vary as a function of depletion condition, $F(1, 144) = 0.36$, $MSE = 118.06$, $p = .55$. This is in line with some recent research suggesting that the time course of executive depletion is limited (Converse & DeShon, 2009).

The indirect effect of executive control on retrieval disruption through the encoding stage. We next examined the relationship between performance on the operation span test and memory performance. Previous research by Cokely et al. (2006) concluded that operation span scores are related to retrieval disruption. In particular, in their experiments individuals with high operation span scores (in the upper quartile) demonstrated a part-set cueing deficit, but individuals with lower operation span scores (in the bottom quartile) did not. These results were replicated in the current study; there was a significant interaction between operation span group and test type (free versus cued recall), $F(1, 58) = 5.04$, $MSE = .01$ (see Figure 1). While individuals with high operation span scores (defined as scores in the upper quartile with more than 67 letters recalled) demonstrated a significant part-set cueing deficit, $F(1, 32) = 19.08$, $MSE = .01$, individuals with low scores (defined as scores in the bottom quartile with less than 55 letters recalled) did not, $F(1, 26) = 0.43$, $MSE = .02$, $p = .52$.

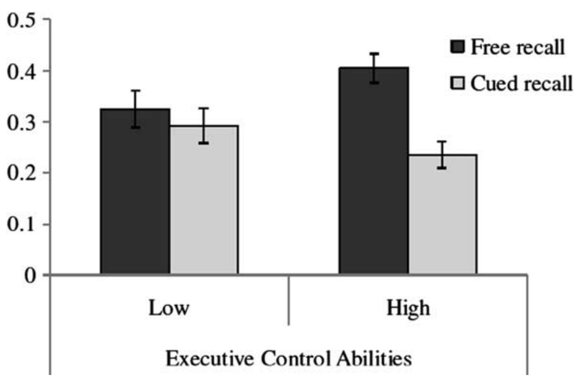

Figure 1. Mean proportion of critical items correctly recalled on the first memory test of Experiment 1 as a function of individual differences in executive control abilities and type of test. High executive control individuals scored in the upper quartile of the operation span test, while low executive control individuals scored in the bottom quartile of the operation span test. While high executive control individuals exhibit a part-set cueing deficit, low executive control individuals do not.

Discussion

Experiment 1 demonstrated no direct relationship at the retrieval stage between executive depletion and retrieval disruption in a part-set cueing paradigm. That is, changes in executive control at retrieval (instantiated through an executive depletion manipulation) did not affect the part-set cueing deficit. This finding occurred in the context of simultaneously replicating the results of Cokely and colleagues (2006) where increases in executive control at encoding (measured through existing individual differences) corresponded to increases in the part-set cueing deficit. As elaborated in the Introduction, this pattern of individual differences was likely due to differences in encoding task strategies. Individuals with high executive control are more likely than individuals with low executive control to encode items relationally, which, problematically, leaves them more susceptible to retrieval disruption. This conclusion is supported by previous research showing that when encoding strategies are controlled by the experimenter (e.g., by asking participants to link the items in a story) the individual differences in part-set cueing as a function of executive control disappear (Cokely et al., 2006). Taken together with the current results (i.e. that executive depletion at the post-encoding stage does not affect retrieval disruption), we conclude that executive control exerts its role on retrieval disruption in a part-set cueing paradigm only indirectly via encoding.

EXPERIMENT 2

The current research examines how executive control affects retrieval disruption. Experiment 1 was designed to answer this question by examining the effects of executive control on the part-set cueing deficit in recall. Experiment 2 addressed this question by examining the effects of executive control on collaborative inhibition in recall. Given that both the part-set cueing deficit and the collaborative inhibition effect are considered to usually occur due to retrieval disruption, together these experiments provide a strong test of the direct role that executive control might play in retrieval disruption.

Although the results from Experiment 1 indicated there was no significant role of executive depletion in modulating retrieval disruption, some previous research suggests that the effects of executive depletion on retrieval disruption may be more pronounced during a collaborative memory task than during a part-set cued memory task. There are several reasons to hypothesise that this is the case. First, executive depletion can decrease various forms of prosocial behaviour such as helpfulness (DeWall, Baumeister, Gailliot, & Maner, 2008) and accommodation of others (Finkel & Campbell, 2001). Problematically, the negative social consequences of depletion can lead to further depletion since difficult, or unsynchronised, social interactions can themselves deplete executive resources (Dalton, Chartrand, & Finkel, 2010; Finkel et al., 2006). During a collaborative recall task participants must both recall information and also coordinate their social efforts. The ability to perform social coordination (a dual task that is not required when working in isolation) should therefore require additional executive resources. Second, influences on memory are often different when they are viewed as coming from social, rather than nonsocial, sources. For example, people are more likely to incorporate misinformation into their memories if the misinformation came from another person rather than from the computer (Gabbert & Memon, 2004; Meade & Roediger, 2002). That is, effects in an individual memory paradigm are not always identical, and can be weaker, than those in a collaborative memory paradigm. Taken together, this evidence suggests that executive depletion may be more strongly related to retrieval disruption during a collaborative memory test than during a part-set cued individual memory test. If this is the case, then executive depletion may impact the collaborative inhibition effect even though it had no significant impact on the part-set cueing deficit in Experiment 1.

However, the extant literature also supports the alternate prediction. Previous research has shown the collaborative inhibition effect to be relatively unaffected by manipulations of social variables. In fact, in previous experiments neither increased group cohesion, increased personal accountability, nor monetary incentives have eliminated the collaborative inhibition effect (Weldon et al., 2000). Thus it is also possible that the presumed increase in executive depletion from social sources may not influence the collaborative inhibition effect given that it did not influence the part-set cueing deficit in Experiment 1.

Method

Participants.. A new sample of 192 undergraduate students (mean age 19.95 years; $SD = 3.22$); 47.92% women; a total of 16 triads per condition) was recruited from Stony Brook University. Participants completed the experiment in triads of strangers.

Materials. The same study items from Experiment 1 were used.

Design. This experiment had a two-factor, executive depletion (depleted or not depleted) and group format (collaborative or nominal groups), between-participants design.

Study phase. Each participant was individually shown the exemplars from all six categorised lists in one of three random orders. As in Experiment 1, each participant saw the exemplars from all six lists intermixed into a single study list consisting of 84 items (with the restriction that no more than 3 exemplars from any list appear successively). Although participants worked individually, all three members that were to be assigned to a given group saw a different presentation order as this is known to increase collaborative inhibition (Finlay et al., 2000). As in Experiment 1, each word was displayed for three seconds, in lowercase letters, centred on the computer screen. Category names were not provided. Intentional study instructions were used such that participants were told about the upcoming (unspecified) memory test where no mention was made of the collaborative or individual (to form nominal groups) nature of the later recall task.

Depletion manipulation (or control distractor task). After completing the study phase, half of the participants completed the executive depletion task adapted from Schmeichel (2007) described in Experiment 1 (i.e. story writing without using the letters "a" or "n"). The other half of the participants completed the control, no-depletion task (i.e. story writing without using the letters "q" or "z"). A more detailed description can be found in Experiment 1.

Test phase #1: The collaborative inhibition effect. After completing the tasks described above, participants next completed the first memory test phase, either collaboratively or individually (the latter to compute nominal group recall). In the collaborative memory condition participants were asked to work together in a naturalistic way to recall studied items and resolve their differences among themselves (e.g., Blumen & Rajaram, 2008; Weldon & Bellinger, 1997). All recalled items (both correct and incorrect) were written down by one randomly selected group member and were readily visible to all group members throughout the memory test. This recall test continued for 10 minutes.

The participants in the nominal groups were asked to individually recall as many words as possible and wrote down their own responses. This recall test continued for 10 minutes. It should be noted that previous research shows no differences between levels of recall when the participants record their own answers versus when participants recall verbally and someone else records their answer (Weldon & Bellinger, 1997, Expt 2). Thus the difference in modalities of recall between the collaborative and nominal participants should not be a confounding variable.

A nominal score was created from these individual recalls by combining the non-redundant answers of individuals. As in most published collaborative memory experiments, nominal groups were created based on the order in which they participated in the experiment (e.g., the first three individuals in a condition were paired together as a nominal group).

Test phase #2: Individual free recall test. At the end of the experiment all participants completed an individual free recall test. Participants were given a blank sheet of paper and 10 minutes to recall as many of the words as possible from the previous study list (even if they themselves, or a group member, recalled the word during the previous test). All participants worked individually on this second free recall test.

Assessment of executive control. Immediately following the second memory test, all participants completed the automated operation span task (Turner & Engle, 1989; Unsworth et al., 2005). A more detailed description can be found in Experiment 1.

Final questionnaire. Participants completed the same final questionnaire that was used in Experiment 1. This questionnaire assessed participant's subjective ratings about the difficulty of each task during the experiment.

Results

Manipulation check. Participants differed in how difficult they perceived the story-writing task to have been, $F(3, 188) = 237.34$, $MSE = 1.22$. Participants in the depletion conditions, who had avoided the letters "a" and "n", rated the story-writing task as much more difficult ($M = 5.99$; a maximum score of 7 corresponded to "very difficult") than participants in the control conditions, who had avoided the letters "q" and "z" ($M = 1.74$; a minimum score of 1 corresponded to "very easy"), $t(188) = 26.65$, $SE = .32$. Participants in the depletion conditions also made more errors by

TABLE 2
Experiment 2

		Memory Test 1 (group recall performance) n = 16 groups		Memory Test 2 (individual recall performance) n = 48 individuals	
		Proportion correct	*Intrusion rate*	*Proportion correct*	*Intrusion rate*
Control participants	Nominal groups	.61 (.07)	.04 (.04)	.29 (.10)	.01 (.01)
	Collaborative groups	.54 (.10)	.01 (.01)	.40 (.12)	.01 (.01)
Depleted participants	Nominal groups	.66 (.11)	.03 (.02)	.31 (.15)	.01 (.02)
	Collaborative groups	.57 (.09)	.01 (.01)	.39 (.12)	.02 (.02)

Mean proportion of items correctly recalled and the intrusion rates on both the first and second memory tests of Experiment 2 as a function of condition. During memory test 1 the participants either completed the test individually or in a collaborative group. Individual scores from this test were combined into nominal group scores. During memory test 2 all participants completed an individual free recall test. Numbers in parentheses are standard deviations.

accidentally using the forbidden letters ($M = 1.34$ mistakes) and wrote shorter stories ($M = 29.76$ words) than participants in the control conditions ($M = 0.21$ mistakes and $M = 97.95$ words), $t(188) = 5.40$, $SE = .49$ and $t(188) = -24.59$, $SE = 5.55$, respectively. This pattern indicates that the story-writing task in the depletion conditions likely required greater executive control to complete than the story-writing task in the control conditions.

Test phase #1: The collaborative inhibition effect. A one-factor ANOVA revealed a significant difference in the proportion of studied words recalled as a function of condition, $F(3, 60) = 4.88$, $MSE = .01$, such that nominal groups recalled a significantly higher proportion of items ($M = .64$) than collaborative groups ($M = .56$), $t(60) = 3.37$, $SE = .05$ (see Table 2). Furthermore, follow-up analyses confirmed that the advantage of nominal groups over collaborative groups held for not only participants in the control conditions (nominal groups: $M = .61$, collaborative groups: $M = .54$), $F(1, 30) = 4.12$, $MSE = .01$, $p = .05$, but also for participants in the depletion conditions (nominal groups: $M = .66$, collaborative groups: $M = .57$), $F(1, 30) = 7.31$, $MSE = .01$. Thus a collaborative inhibition effect was demonstrated in both the control conditions and in the depletion conditions.

A test of the direct effect of executive depletion on retrieval disruption at the retrieval stage. We next examined whether executive depletion modulates the collaborative inhibition effect. If increases in executive control correspond to decreases in distractibility, then depleted participants should show a greater collaborative inhibition effect than control participants. In contrast, if increases in executive control only influence encoding strategy but not retrieval disruption itself, then depleted participants should show similar levels of collaborative inhibition as control participants. To test these competing predictions, we conducted a 2 (Executive Depletion: Depleted vs Not depleted) × 2 (Group format: Collaborative vs Nominal) ANOVA on the proportion of words correctly recalled. This analysis revealed no significant interaction between executive depletion status and group format, $F(1, 60) = 0.51$, $MSE = .01$, $p = .48$. There was no significant difference in either nominal group recall, $t(60) = -1.68$, $SE = .03$, $p = .10$, or collaborative group recall, $t(60) = -.66$, $SE = .03$, $p = .51$, as a function of depletion status. As in Experiment 1, these results fail to support the hypothesis that deficits in executive control affect retrieval disruption at the retrieval stage.

Test phase #2: Individual free recall test. All participants took an individual free-recall memory test immediately following the previous test phase. Previous studies have documented a benefit of collaboration on this post-collaborative free recall test (e.g., Basden, Basden, & Henry, 2000; Blumen & Rajaram, 2008; Weldon & Bellinger, 1997). In other words, the performance on this test is often higher for participants who were previously part of a collaborative group than for participants who were previously part of a nominal group. This pattern was replicated in the current experiment. A one-factor ANOVA revealed a significant difference in recall as a function of condition, $F(3, 188) = 9.74$, $MSE = .02$ (see Table 2). Participants who had previously been part of a collaborative group recalled more items ($M = .39$) than participants who had previously been part of a nominal group ($M = .30$), $t(188) = 5.27$, $SE = .04$. This held both for participants in the control conditions (previously in collaborative group: $M = .40$; previously in nominal group: $M = .29$), $t(188) = 4.50$, $SE = .03$ and for participants in the depletion conditions (previously in collaborative group: $M = .39$; previously in nominal group: $M = .31$), $t(188) = 2.95$, $SE = .03$. Furthermore, the benefit of having previously been in a collaborative group rather than a nominal group did not vary as a function of depletion condition, $t(188) = .40$, $SE = .03$, $p = .69$.

Memory errors. Error rates varied as a function of condition on the first memory test, $F(3, 60) = 4.78$, $MSE < .01$, but were also very low. As in previous experiments (e.g., Basden et al., 2000; Rajaram & Pereira-Pasarin, 2007; Ross, Spencer, Blatz, & Restorick, 2008; Ross, Spencer, Linardatos, Lam, & Perunovic, 2004), participants in the nominal groups had a higher intrusion rate ($M = .03$) than participants in collaborative groups ($M = .01$), $t(60) = 3.78$, $SE = .01$. However, error rates did not vary as a function of depletion condition, $t(60) = 0.00$, $SE = .01$, $p = 1.00$. Furthermore, as in Experiment 1, error rates did not vary as a function of condition on the second, always individual free recall, memory test, $F(3, 188) = 0.61$, $MSE < .01$, $p = .61$.

Individual differences in executive control. Participants completed the automated operation span test (Unsworth et al., 2005) as a measure of executive control. Seven participants (4%)

were not included in the following analyses due to high error rates on the operation span test (i.e. their error rates were more than three standard deviations greater than the mean).

The relationship between group members' operation span scores and group memory performance could not be directly assessed. This is because these data are hierarchically nested such that individuals (whose operation span scores were assessed) are nested within groups (whose recall scores were assessed). This pattern of non-independent data would suggest analysis through hierarchical linear modelling (HLM). Problematically, HLM analyses require the dependent variable to be operationalised at the individual level rather than at the group level. Thus, individual operation span scores cannot be used to predict group memory scores in an HLM design (for discussions of this issue see Beaubien, Hamman, Holt, & Boehm-Davis, 2001; Castro, 2002).

However, we were able to assess the relationship between operation span scores and final memory (Recall #2) performance. Some previous research on individual memory suggests that performance on a second memory test (such as the final individual memory test in this experiment) may depend on the attentional resources available during the previous memory test. For instance, in Dudukovic, DuBrow, and Wagner (2009) participants individually performed a recognition memory test under full or divided attention conditions. After a delay all participants then took a second, individual recognition memory test under full attention conditions. On this second test participants who took the first test under full attention conditions outperformed participants who took the first memory test under divided attention conditions. One implication of these findings is that the benefits of having previously been part of a collaborative group might depend on an individual's level of executive control. In support of this, results indicated a significant positive correlation between operation span score and final individual memory performance for participants in the collaborative groups, $r = .27$. Collaborative group participants with higher operation span scores tended to outperform those with lower operation span scores on a later individual memory test. Thus the extent to which the collaborative memory test served as a relearning opportunity may vary as a function of individual differences in executive control.

GENERAL DISCUSSION

This study tested competing predictions about the relationship between executive control and retrieval disruption in two theoretically related memory paradigms: a part-set cueing paradigm that involves individual recall and a collaborative memory paradigm that involves group recall. The experiments were motivated by conflicting findings in the literature about the relationship between these variables. On the one hand, some previous research (including research on divided attention) has suggested that executive control does not exert a direct role on retrieval disruption at the retrieval stage (e.g., Baddeley et al., 1984; Cokely et al., 2006). Thus changes in executive control only at retrieval should produce little change in retrieval disruption. On the other hand, other research has suggested that increases in executive control correspond to decreases in distractibility (e.g., Connelly et al., 1991) and with increases in the ability to search memory for non-cued words (e.g., Hansen & Goldinger, 2009). Thus increases in executive control should produce less retrieval disruption at the retrieval stage. Both lines of evidence come from studies on individual memory. However, the role of executive control on retrieval disruption is critical not only for understanding the memory of individuals working in isolation but also those working in collaborative settings. The proposal that retrieval disruption serves as a common mechanism underlying part-set recall in individual recall paradigms and collaborative recall in the group paradigm makes a test of role of executive control at retrieval a timely test across both paradigms.

To answer this question, the current studies introduced a methodology for separately examining the role of executive control at retrieval from that at encoding. Previous cognitive research on executive control has used an individual differences approach (i.e., participants with low vs high executive control). However, this approach cannot separately examine the role of executive control at encoding and retrieval since individuals with low (or high) executive control have low (or high) executive control throughout the entire experimental procedure. By experimentally manipulating executive control through an executive depletion manipulation it is possible to circumvent this problem and examine the unique contributions of executive control at the retrieval stage. Thus, the current studies examined the role of executive depletion at retrieval in individual recall settings (the part-set cueing deficit; Experiment 1) and group recall settings (the collaborative inhibition effect; Experiment 2).

Across two experiments, no effects of executive depletion on retrieval disruption were found. In Experiment 1 a standard part-set cueing deficit was observed such that free recall performance was greater than part-set cued recall performance. However, the magnitude of the part-set cueing deficit was not dependent on the depletion manipulation. Similarly, in Experiment 2 a standard collaborative inhibition effect was observed such that participants performed better in the nominal groups than in the collaborative groups. Once again, the magnitude of this effect was unaffected by executive depletion. Thus manipulations of executive control via a depletion manipulation at retrieval do not seem to exert a direct influence on retrieval disruption in either a part-set cueing paradigm or a collaborative memory paradigm.

However, executive control, as measured through individual differences in operation span, did exert an indirect influence on retrieval disruption through its role at encoding. In Experiment 1 only participants with higher operation span scores encoded information in such a way that led them susceptible to retrieval disruption. Participants with lower operation span scores were unaffected by retrieval disruption (see also Cokely et al., 2006). In summary, these results demonstrate differential effects of executive control on retrieval disruption. Increases in executive control, as assessed through individual differences in operation span scores, correspond to higher retrieval disruption at retrieval, but changes in executive control at the post-encoding stage, as manipulated through a depletion procedure, do not affect retrieval disruption directly.

In the present studies we focused specifically on the relationship between executive depletion and retrieval disruption. However, retrieval disruption is not the sole factor underlying the part-set cueing deficit (see Bäuml & Aslan, 2006) or the collaborative inhibition effect (see Rajaram & Pereira-Pasarin, 2010), as inhibitory processes can also affect these phenomena under certain conditions. To maximise the likelihood that our studies targeted retrieval disruption, our stimuli consisted of high-frequency category exemplars, as part-set cueing is known to rely on retrieval disruption when the items have a high degree of inter-item associations (Bäuml & Aslan, 2006). Despite this, in Experiment 1 we failed to observe a "rebound" effect on the final free recall test. Although this would be consistent with the notion of retrieval inhibition, we do note that there are other previously published reports of continued impairment (i.e. no "rebound"; see Basden & Basden, 1995; Expt 2; Oswald et al., 2006) even under conditions that typically produce retrieval disruption. Hence, the lack of "rebound" does not necessitate that our chosen study conditions were ineffective in producing retrieval disruption, but does raise the possibility that retrieval inhibition may also have played a role. Future research is needed to directly compare the relationship between executive depletion and retrieval inhibition versus retrieval disruption.

In conclusion, the current studies represent a systematic effort to examine how working memory components such as executive control impact retrieval disruption during recall in both individual and group settings. While executive control is known to play a powerful role in purely cognitive tasks little is known about its influence in cognitive tasks that have to be performed in socially interactive settings. Across two experiments, results showed no effect of executive control in modulating retrieval disruption through its role at retrieval. This was true in both a part-set cued memory paradigm (Experiment 1) and a collaborative memory paradigm (Experiment 2) thereby demonstrating similarities in interference effects between individual and group memory. Thus, while executive control may play an indirect role in modulating retrieval disruption through its role at encoding, it is much less likely to directly influence retrieval disruption through its role at retrieval.

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APPENDIX

Example stories written by participants in Experiment 1 as a function of depletion condition

Stories from two participants in the depletion condition:

Example 1 (16 words long, contains no errors): ''This semester I rode to Jersey. There were lots of trees. My mother's employer lives there.''

Example 2 (31 words long, contains one error): ''I visited the south of the U.S. to see my mom's brother's kids. We visited the shore, visited other people, it was good. We visited the zoo. We digested good food.''

Stories from two participants in the control condition:

Example 1 (117 words long, contains no errors): ''This past spring, my friends and I went to Spain and France on a school trip. I had the most incredible time. We went to numerous cities and saw an insane amount of old architecture and even a castle in France. The water was beautiful! We saw Bono's island as well, which was pretty great. In Barcelona things were more fast pace and busy, especially on Las Ramblas, the street we were by. Eating ice cream every day, sometimes twice a day, and just being in a foreign country was so much fun. I would do that trip again in a second if the opportunity presented itself. Next time though, I'd like to visit Italy as well.''

Example 2 (88 words long, contains no errors): ''One trip I took with my family was to California. We visited many sights. The first place we stopped was San Francisco. We participated in all the touristy things such as Pier 51, a ride on the trolley car, the famous prison, etc. Next we went to the famous national park with all the redwood trees. The trees towered into the sky, blotting out most of it. We also went to the marine museum at Monterey Bay. It's a famous museum and houses a huge variety of fish.''