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Collaborative memory and part-set cuing impairments:

The role of executive control

A Dissertation Presented

by

Sarah Jane Barber

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Abstract of the Dissertation

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Providing memory cues can sometimes hurt memory performance rather than enhance it. More specifically, when people are exposed to a subset of previously studied list items they will recall fewer of the remaining items compared to a condition where none of the studied items are provided during recall. This occurs both when the subset of list items is provided by the experimenter (as in the part-set cuing deficit) and when the subset of list items is provided during the course of a collaborative discussion by other individuals (as in the collaborative inhibition effect). Previous research has identified retrieval disruption as the mechanism underlying both the part-set cuing deficit and the collaborative inhibition effect. However, little is known about the factors that may make individuals particularly susceptible to retrieval disruption. This dissertation tested one such candidate factor, namely, executive control. Two competing hypotheses about the relationship between executive control and retrieval disruption were tested. Some

previous research suggests that executive control plays only an indirect role in modulating retrieval disruption through its role at encoding and should therefore exert little effect when it is varied at only the retrieval stage. In contrast, other research suggests that increases in executive control at the retrieval stage should be associated with decreases in retrieval disruption. These hypotheses were tested in both a part-set cuing paradigm (Experiment 1) and in a collaborative memory paradigm (Experiment 2) using the novel approach of directly manipulating an individual's level of executive control during retrieval with an executive depletion manipulation. Across experiments, results indicated that executive depletion played no direct role in modulating retrieval disruption. That is, neither the part-set cuing deficit (Experiment 1) nor the collaborative inhibition effect (Experiment 2) was increased by the executive depletion manipulation. In contrast, executive control abilities were indirectly related to retrieval disruption through their role at encoding (Experiment 1). Together, these results suggest that executive control does not directly affect retrieval disruption at the retrieval stage, and that the role of this putative mechanism may be limited to the encoding stage.

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1. Introduction

The collaborative inhibition effect.

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; also see Echterhoff, Higgins, & Levine, 2009). It is only in the last decade that research has begun to focus on how an individual's memory changes when recalling information as a member of a collaborating group (Barnier & Sutton, 2008; Weldon, 2001).

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). This result is similar to brainstorming research showing that collaborative groups generate fewer novel ideas than nominal groups (Paulus, 2000).

Collaborative inhibition is a robust finding, occurring routinely in free recall and with a wide variety of study materials (Weldon, 2001). Although collaborative inhibition sometimes declines in well-acquainted groups (such as friends or couples), it is rarely reversed. Collaborating friends recall no more information than nominal groups, and often recall less (Andersson & Ronnberg, 1995; Johansson, Andersson, & Ronnberg, 2000; Peker & Tekcan, 2009). In fact, within the extant literature the only demonstration of collaborative facilitation showed that collaborating groups of expert pilots recall more aviation-related information than nominal groups of expert pilots (Meade, Nokes, and Morrow, 2009) and even here the facilitation effect was marginal and did not occur for collaborating groups of novice pilots or non-pilots.

While collaborative facilitation is rare, collaboration almost always has a positive effect on later individual memory (Basden, Basden, & Henry, 2000; Blumen & Rajaram, 2008; Rajaram & Pereira-Pasarin, 2007; Weldon & Bellinger, 1997, but see also Finlay, Hitch, & Meudell, 2000). For example, in Weldon and Bellinger's (1997) first experiment, participants completed two successive recall tests, each either in a collaborative group or individually. The comparison of interest is between the group that recalled first in a collaborative setting followed by an individual recall session (CI) and the group that recalled first individually followed by a second individual recall session (II). The second, individual, recall session was higher when preceded by collaborative

recall (CI) than when preceded by individual recall (II). Thus, recalling information in a group setting does confer a subsequent individual memory benefit. This benefit is composed of both an increase in correct responding and a decrease in false alarms (Rajaram & Pereira-Pasarin, 2007). Furthermore, final individual memory benefits more from repeated recalls in a group setting (two collaborative recalls preceding a final individual recall -- CCI) than by either repeated individual recall (two individual recalls preceding a final individual recall -- III) or by a combination of previous collaborative and individual recalls (a collaborative and individual recall preceding a final individual recall -- either ICI or CII) (Blumen & Rajaram, 2008; see also Blumen & Rajaram, 2009).

While collaboration improves subsequent individual memory, this occurs despite the fact that collaborative inhibition was present in the studies described above (nominal recall was higher than collaborative recall on the first memory test). Why is individual recall lowered within a group setting? While 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 cuing deficit* that occurs in individual recall (see Basden, Basden, Bryner, & Thomas., 1997; Nickerson, 1984).

Collaborative inhibition is similar to the part-set cuing deficit.

The part-set cuing deficit refers to a counterintuitive phenomenon in which cuing 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 categorized 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, cuing becomes detrimental (Slamecka, 1968). In this situation, people recall fewer of the remaining items compared to a condition where none of the studied items are provided as cues during recall. This phenomenon is known as the part-set cuing deficit; when people are given access to part of the studied list, it lowers their recall of the remaining items. The part-set cuing deficit is a robust phenomenon and has now been demonstrated across a wide-variety of experimental contexts (for reviews, see Nickerson, 1984, Roediger & Neely, 1982, or Bäuml, 2007, 2008), and for a wide-variety of populations, including children (Zellner & Bäuml, 2005), older adults (e.g. Marsh, Dolan, Balota, & Roediger, 2004), and people with amnesia (Bäuml, Kissler, & Rak, 2002).

Since the part-set cuing 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). Of these, considerable evidence has been reported in favor of the *retrieval disruption* mechanism, the focus of the present investigation. According to this view, individuals develop their own idiosyncratic organization of studied materials and use this organizational strategy to guide retrieval (Roenker, Thompson, & Brown, 1971; Rundus, 1971; Tulving, 1962). Later, the presence of part-set cues disrupts these organizational 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 organizational strategy (Basden, Basden, & Stephens, 2002; Basden & Basden, 1995; Sloman, Bower, & Rohrer, 1991). Second, there is often a 'release' from part-set cuing 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.

Evidence supports the proposal that the retrieval disruption mechanism underlies not only the part-set cuing deficit (e.g. Basden & Basden, 1995), but also the collaborative inhibition effect (Basden, et al., 1997). Within a collaborative group, each group member has their own unique organizational 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 organizational structure such as cued-recall (Finlay, et al., 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 retrieval disruption account of collaborative inhibition is also supported by a 'release' from collaborative inhibition on subsequent memory tests. As described earlier, several studies show that collaboration typically has a positive effect on later individual

memory such that prior group recall improves later individual recall of each member from a collaborative group compared to each member from a nominal group (Basden, Basden, & Henry, 2000; Blumen & Rajaram, 2008; Rajaram & Pereira-Pasarin, 2007; Weldon & Bellinger, 1997, but see Finlay, Hitch, & Meudell, 2000). In other words, there is often a ‘rebound’ effect, such that items ‘lost’ during the collaborative recall session are successfully retrieved on the later individual memory test. Taken together, these findings suggest that retrieval disruption is a key underlying mechanism of the collaborative inhibition effect.

The role of executive control in retrieval disruption.

The current research focuses on the role of executive control in modulating retrieval disruption. 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, et al., 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, or neutral, relationship between executive control and susceptibility to retrieval disruption. Some prior work suggests that retrieval disruption is modulated by an individual's level of executive control. In particular, differences in executive control are related to performance on a part-set cued test such that individuals with high executive control exhibit a part-set cuing deficit in recall whereas individuals with low executive control do not (Cokely, Kelley, & Gilchrist, 2006). This result that higher executive control corresponds to greater retrieval disruption (Cokely, et al., 2006) seems paradoxical and 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 organization (McNamara & Scott, 2001, Turley-Ames & Whitfield, 2003). Given that the part-set cuing deficit is prevalent when inter-item associations are strong (Basden, et al., 2002), these differences in encoding strategy presumably lead to a part-set cuing deficit for individuals with high, but not low, executive control. Thus, 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, Kelley, and Gilchrist (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 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 cuing deficit in recall. This result was taken as evidence that encoding strategies play a causal role in predicting retrieval disruption (Cokely, et al., 2006; Experiment 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; Naveh-Benjamin, 1987, 1988, 1990; Naveh-Benjamin & Jonides, 1986; Murdock, 1965). In contrast, dividing attention during retrieval exerts little, or no 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 conceptualized as an attentional construct (e.g. McCabe, et al., 2010), and given that attentional resources do not seem to impact memory retrieval performance, it is therefore 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 memory for new target items according to their own retrieval scheme. Several prominent theories suggest that working memory acts as an attention regulator (e.g. Shallice, 1988; Kane & Engle, 2000). It therefore follows that the ability to ignore no-longer-relevant information by controlling attention in a goal directed manner should be dependent upon working memory (and thus, executive control) capacity (e.g. Darowski, et al., 2008). Three lines of research support this hypothesis.

First, many studies show that, individuals with higher working memory spans are better able to ignore distractions during a cognitive task than individuals with lower working memory spans. For example, one typical task involves reading text that includes additional, irrelevant, words or phrases. The irrelevant, to-be-ignored, items are printed in a different font (e.g. italics) and the participant is asked to read aloud only the words in the normal format. As working memory span increases reading speed on this irrelevant text task get faster (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 teammates 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.

Finally, research with older adults further supports the conclusion that participants with high working spans are better able than participants with low working memory spans to continue searching memory in the presence of cues. Older adults, who are known to have difficulties with inhibiting irrelevant items from the past (e.g. Hamm & Hasher, 1992; Hartman & Dusek, 1994; Hartman & Hasher, 1991; Hasher, Lustig, & Zacks, 2007; Hasher & Zacks, 1988; Hasher, Zacks, & May, 1999; May & Hasher, 1998; May, Zacks, Hasher, & Multhaup, 1999) and who therefore have deficits in working memory span (Darowski, et al., 2008), sometimes exhibit a greater part-set cuing deficit for recently studied items than younger adults (Marsh, Dolan, Balota, & Roediger, 2004; but see Andres, 2009; Foos & Clark, 2000). This is in line with previous findings

showing that aging preferentially reduces the ability to perform tasks that require executive control (e.g. Andres, Guerrini, Phillips, & Perfect, 2008). Thus, when individuals find it difficult to ignore distractions (an aspect of executive control) retrieval disruption increases (but see Meade & Roediger, 2009). However, this is in conflict with the finding described earlier where high executive control individuals exhibited a greater part-set cuing deficit than low executive control individuals (Cokely et al., 2006), a point considered further below.

In brief, previous evidence clearly show 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. 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; Marsh, et al., 2004). One reason for this discrepancy may arise from the individual differences approach used in previous studies to manipulate executive control. In some instances described above the 'low' executive control group was selected from a sample of young adults whereas in other instances older adults comprised this group. Problematically, these two groups are not comparable in other critical respects. While young adults with low executive control utilize poor encoding strategies (and thus have impaired memory overall but no part-set cuing deficit, Cokely et al., 2006), older adults remain adept at engaging in elaborative encoding strategies (Bryan, Luszcz, & Pointer, 1999). These elaborative encoding strategies may enable older adults to develop better idiosyncratic organization and, in

turn, leave them susceptible to part-set cuing deficits despite their reduced executive control. In other words, the presence or absence of a pronounced part-set cuing deficit in individuals with low executive control in previous studies may be as much a function of encoding factors (such as whether or not the low executive control group tends to create inter-item associations during encoding) as of retrieval factors (such as retrieval disruption). Thus, it is critical to devise experimental conditions where the operation of executive control is equated during encoding and its manipulation is isolated to the retrieval stage. A decisive understanding of how executive control influences retrieval disruption, and in turn, the phenomena of both the part-set cuing deficit and collaborative inhibition in recall, hinges on this effort. The current studies aim to provide such evidence.

Executive depletion: Manipulation of executive control after encoding.

Considerable evidence shows that executive control capacity differs *across* individuals and 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), and when measured subsequent to another task demanding executive control (Persson, Welsh, Jonides, & Reuter-Lorenz, 2007; Richeson, & Trawalter, 2005; Schmeichel, 2007; Schmeichel, Demaree, Robinson, & Pu, 2006; 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. In particular, performing a task that demands executive control leaves people less able to perform a subsequent task that also demands

executive control (e.g. Apfelbaum & Sommers, 2009; Schmeichel, Vohs, & Baumeister, 2003). This seems to be driven by changes in blood glucose levels (but see Schmeichel & Vohs, 2009). Although all cognitive operations require glucose, the ability to perform executive control tasks is especially dependent upon blood glucose levels. Acts of executive control are metabolically expensive and require a large amount of blood glucose and brain glycogen. This in turn reduces their levels, leaving fewer resources available to perform subsequent executive control tasks (Gailliot, 2008; Gailliot & Baumeister, 2007; Gailliot, et al., 2007). In support of this conclusion, high blood glucose levels are linked to better performance on tasks that require executive control, such as a working memory task (Kennedy & Scholey, 2000) or a Stroop task (Benton, Owens, & Parker, 1994). Furthermore, the extent to which completing an executive control task lowers blood glucose levels is predictive of performance on a subsequent task that requires executive control (Gailliot, et al., 2007).

Of interest to the current studies, previous research has shown that both working memory (e.g. Schmeichel, 2007) and the ability to conduct a maintained search through memory (e.g. Neshat-Doost, Dalgleish, & Golden, 2009) 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 (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., 2009). 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).

Social situations can deplete executive resources.

Executive control's role on retrieval disruption may be especially important when recalling in a collaborative setting. Recalling information in a social setting often comes with both cognitive and social demands. From the cognitive perspective, individuals must work to overcome retrieval disruption (by maintaining their own organizational strategy in the face of distraction). As discussed earlier, executive depletion likely increases retrieval disruption and leads to lower recall. From the social perspective, individuals must (amongst other things) coordinate their retrieval efforts with those of the group. Previous research has shown that successful social interactions require executive resources and that executive depletion decreases some prosocial behaviors (for a review, see Vohs & Ciarocco, 2004). In particular, compared to non-depleted individuals, depleted individuals are less accommodating in relationships (Finkel & Campbell, 2001), less charitable (Fennis, Janssen, & Vohs, 2009), and less helpful (DeWall, Baumeister, Gailliot, & Maner, 2008). They engage in more socially inappropriate behavior (von Hippel & Gonsalkorale, 2005), are more likely to be dishonest (Mead, Baumeister, Gino, Schweitzer, & Ariely, 2009), and show higher levels of aggressive responding (DeWall, Baumeister, Stillman, & Gailliot, 2007; Finkel, DeWall, Slotter, Oaten, & Foshee, 2009;

Stucke & Baumeister, 2006). These negative interpersonal activities likely decrease the coordination of retrieval efforts. Problematically, this may serve to further deplete the participants since difficult, or uncoordinated, social coordination depletes executive resources (e.g. Ciarocco, Sommer, & Baumeister, 2001; Dalton, Chartrand, & Finkel, in press; Finkel, et al., 2006; Fitzsimons & Finkel, in press; Gailliot, et al., 2007; Inzlicht, McKay, & Aronson, 2007). As a result depleted participants should have fewer executive resources available during a collaborative memory task than during an individual memory task. It is therefore possible that depletion may have a greater negative effect on recall in a collaborative memory paradigm than in a part-set cuing paradigm.

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 in young adults for 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 encoding is equated for attention and executive control. 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 organization 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 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. Thus, the executive capacity of participants at encoding was held constant across all conditions.

In brief, 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 cuing paradigm (Experiment 1) and in a collaborative memory paradigm (Experiment 2). Thus, this manipulation allowed direct examination of how executive depletion affects retrieval disruption while controlling the executive control processes during encoding in both a part-set cuing 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) relate to subsequent retrieval disruption (as in Cokely, et al., 2006).

II. Experiment 1: The role of executive control in modulating the part-set cuing deficit

Method

Participants.

A sample of 152 undergraduate students (38 per condition) was recruited from Stony Brook University to participate in this experiment. The sample was predominately women (70%) and the mean age was 19.97 (SD = 3.94). Participants received partial course credit in exchange for their participation.

Materials.

Study items consisted of 6 categorized lists of 7 low frequency exemplars and 7 high frequency exemplars each drawn from the Van Overschelde, Rawson, & Dulosky (2006; which is an update of Battig & Montague, 1969) norms. Exemplar frequency was matched across the six lists. Within each list, the 7 exemplars with the higher category frequency (range of 17-73) were designated as the ‘target’ words, and the 7 exemplars with the lower frequency (range of 5-10) 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; see also Pei & Tuttle, 1999). Stimuli are presented in Appendix A.

It should be noted that the choice of these materials was made to ensure that the present experiment tests the retrieval disruption mechanism. In some cases, the part-list

cuing phenomenon can also arise from *retrieval inhibition* (e.g. Bäuml & Aslan, 2004).¹ Together, a *two-mechanism explanation* (Bäuml & Aslan, 2006) accounts for the extant evidence where the part-set cuing deficit is caused by retrieval disruption when the encoded items have a high degree of inter-item associations and by retrieval inhibition when the encoded items have a low degree of inter-item associations. By using categorized word lists that possess a high degree of inter-item associations, the current experiment focused specifically on the operation of the retrieval disruption mechanism as this mechanism is proposed to be common to both the part-set cuing deficit and the collaborative inhibition effect that are of present interest (Basden, et al., 1997).

Design.

This experiment had a 2-factor design with executive depletion (depleted or not depleted) and test format (part-set cued or free recall) both manipulated as between-subjects factors. Thirty-eight participants were assigned to each of the four between-subject conditions.

Procedure

Study Phase.

¹ The retrieval inhibition account of the part-set cuing deficit (e.g. Bäuml & Aslan, 2004) centers on the assumption that participants covertly retrieve the part-set cues as they are presented. This in turn leads to inhibition of the 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 studied 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, this retrieval inhibition account posits that the memory representations of the non-cued target items are themselves damaged by covert retrieval of the cue items. This in turn leads to lasting memory impairment of the non-cued target items (Bäuml, 2008). While the retrieval disruption account and the retrieval inhibition account of the part-set cuing deficit make opposite predictions, both are supported by empirical evidence. A recent two-mechanism account seems to resolve these discrepant findings. Proposed by Bäuml and Aslan (2006), the part-set cuing deficit is thought to be caused by retrieval inhibition when the encoded items have a low degree of inter-item associations and by retrieval disruption when the encoded items have a high degree of inter-item associations. Thus, the mechanism mediating the part-set cuing deficit appears to depend on the encoding conditions. The current experiments focused specifically on the retrieval disruption mechanism.

Participants were first shown the exemplars from all six lists in one of three random orders. That is, during encoding the 6 categorized lists (each with 14 exemplars) were presented to participants as a single study list (with 84 items). Within each study list no more than three items from any category appeared successively. Each item was displayed for three seconds in lower-cased letters and centered 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 memory test.

Depletion Manipulation (or Control Distractor Task).

After completing the study phase, half of the participants completed an activity (adapted from Schmeichel, 2007, Experiment 2; see also Mead, Baumeister, Gino, Schweitzer, & Ariely, 2009; Pocheptsova, Amir, Dhar, & Baumeister, 2009; Schmeichel & Vohs, 2009) designed to deplete their executive resources and half of the participants completed a control activity. Participants in the depletion group spent five 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. This manipulation has previously been shown to reduce subsequent executive control, as measured by the operation span and reverse digit span tasks (Schmeichel, 2007). In contrast, participants in the no-depletion condition spent five 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 ‘control’ task does not have an effect on executive processes (Schmeichel, 2007).²

Test Phase #1: The Part-Set Cuing Deficit.

Half of the participants were tested using a part-set cued recall test. In particular, participants received a sheet of paper listing each of the six category names along with the seven non-target cue items from each category. Cues were presented in a different order from study (e.g. Luek, McLaughlin, & Cicala, 1971; Sloman, Bower, & Rohrer, 1991) and were blocked by category (Basden, Basden, & Stephens, 2002) in order to maximize the part-set cuing 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, et al, 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 conditions, participants worked on this task alone for ten minutes. Thus, four groups completed this test phase: (1) Depleted participants tested using part-set cued recall, (2) Depleted

² Some research by Persson, Welsh, Jonides, and Reuter-Lorenz (2007) has suggested that performing a cognitively demanding executive control task will only have a negative effect on subsequent tasks that also rely on the same sub-component of executive control (for alternate views see Gailliot, et al., 2007; Inzlicht & Gutsell, 2007; Muraven & Baumeister, 2000). For example, performing a cognitively demanding interference resolution task reduces performance on a subsequent interference resolution task but not on a subsequent response inhibition task (Persson, Welsh, Jonides, & Reuter-Lorenz, 2007). Thus, the depletion task used in the present studies (i.e. writing without the letters ‘a’ or ‘n’) was chosen because it seems to share feature similarities to a part-set cued recall or collaborative memory task. In particular, during all of these tasks participants must selectively search memory for non-dominant responses while suppressing other responses.

participants tested using free recall, (3) Control participants tested using part-set cued recall, and (4) Control participants tested using free recall.

Test Phase #2: Free Recall Test.

Immediately following the previous 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).

Assessments of Executive Control.

Attentional Control Scale. Participants first completed a self-report measure of executive attentional control, the Attentional Control Scale (Derryberry & Reed, 2001; cited in Derryberry & Reed, 2002). This 20-item scale contains items about one’s ability to focus attention (e.g. ‘*When I need to concentrate and solve a problem, I have trouble focusing my attention*’), to shift attention between tasks (e.g. ‘*I can quickly switch from one task to another*’), and to flexibly control thought (e.g. ‘*I can become interested in a new topic really quickly when I need to*’). Participants responded to each item on a 1-4 Likert Scale (1 = *almost never*, 2 = *sometimes*, 3 = *often*, 4 = *always*). Eleven of the questions are worded negatively and these were reverse-scored prior to analyses. This measure has been shown to be internally consistent ($\alpha = .88$; Derryberry & Reed, 2001; cited in Derryberry & Reed, 2002).

Operation Span Task. Following completion of the Attentional Control Scale, 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 3 and 7 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, Kane, Bunting, Hambrick, Wilhelm, and Engle (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 as it was the measure used by Cokely and colleagues (2006) to demonstrate differences in the part-set cuing 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 more than 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 consisting of three sections (see Appendix B). The first section of this questionnaire asked them to provide basic demographic information. The second section assessed potential depletion mediators. In particular, participants were asked to indicate (a) when they had last eaten (as this will impact the amount of blood glucose available to the participant), (b) how many hours they had slept the previous night (since fasting blood glucose levels are higher both for people who sleep less than 7 hours or for people who sleep more than 8 hours per night than for people who sleep 7 to 8 hours; Hall, Muldoon, Jennings, Buysse, Flory, & Munuck, 2008), and (c) the time of the experiment (since blood glucose can fluctuate over the course of the day; Jarrett, Murrells, Shipley, & Hall, 1984). Finally, in the third section participants were asked to rate 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 upon 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 C for two 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 Cuing Deficit.

A part-set cuing 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 cuing 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).

A one-factor (Test format: Part-set cued recall vs. Uncued free recall) between-subjects 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, cuing impaired recall. Participants recalled a greater proportion of the noncued, 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, $t(147) = 2.98$, $SE = .03$.

The direct effect of executive depletion on retrieval disruption at the retrieval stage.

I next examined the role of executive depletion in modulating the observed part-set cuing deficits. If low executive control increases susceptibility to interference (e.g. Hasher & Zacks, 1988) and, therefore, increases retrieval disruption, then depleted participants should display a larger part-set cuing 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 cuing 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 are equated 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 control does not seem to exert a direct influence on susceptibility to retrieval disruption at the retrieval stage.

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 cuing 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 cuing 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; Experiments 1,3, 4, 5; Basden, Basden, & Galloway, 1977; Bäuml & Aslan, 2006), continued inhibition has also been observed under conditions where retrieval disruption is theorized to occur (e.g. Basden & Basden, 1995; Experiment 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 cuing 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 cuing 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 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 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 cuing deficit on the second, always free-recall, memory test for participants in the depletion condition.

Potential Executive Depletion Mediators.

At the end of the experiment, participants provided self-report ratings on three factors that could have had an impact on their resting blood glucose levels. In particular, participants indicated when they had last eaten, how many hours they had slept the previous night, and what time of day the experiment took place. To test the role of these variables, all previous analyses were repeated using these variables, and their interaction terms, as covariates. The interaction terms were included since these factors can interact to predict blood glucose levels. For instance, the impact of food deprivation on blood glucose depends upon the time of day that the deprivation is instantiated and terminated

(Sommerville, Perez, Elias, & Smith, 1988). None of the previous patterns of results was changed through inclusion of these covariates. Furthermore, none of these variables (or their interaction terms) significantly correlated with memory performance (on either the first or second memory test) in any of the conditions.

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, $F(3, 147) = 1.45$, $MSE < .01$, $p = .23$. Furthermore, while errors consistently increased from the first to the second memory test, $F(1, 147) = 23.34$, $MSE < .01$, this increase did not vary as a function of condition, $F(3, 147) = .02$, $MSE < .01$, $p = .998$.

Subjective Evaluation of the Memory Tests.

At the end of the experiment, all participants rated how difficult each of the memory tests had been to complete. Overall, participants rated the first memory test (which was either free or cued recall depending upon condition) as being of medium difficulty ($M = 4.44$; scale of 1-7). However, they did not differ in their ratings of this task as a function of condition, $F(3, 147) = 1.03$, $MSE = 1.53$, $p = .38$. Similarly, participants rated the second memory test (which was always free recall regardless of condition) as being of medium difficulty ($M = 4.15$, $SD = 1.37$; scale of 1-7), and again

did not differ in their ratings of this task as a function of condition, $F(3, 147) = 0.25$, $MSE = 1.89$, $p = .86$. Finally, while the second memory test was consistently rated as easier to complete than the first memory test, $F(1, 147) = 8.93$, $MSE = .71$, this perception again did not differ as a function of condition, $F(3, 147) = .46$, $MSE = .712$, $p = .71$.

Individual Differences in Executive Control.

At the end of the experiment, all participants completed two measures of executive control: the Attentional Control Scale (Derryberry & Reed, 2002) and the automated operation span test (Unsworth, Heitz, Schrock, & Engle, 2005). Five participants (3% of participants) were not included in the following analyses due to high error rates on the operation span test that rendered their scores uninterpretable (i.e. their error rates were more than three standard deviations greater than the mean).

Surprisingly, scores on the Attentional Control Scale and on the operation span test were not significantly correlated with one another, $r = .04$, $p = .61$. However, this is in line with some recent research showing limitations in the ability of the Attentional Control Scale to predict behavior in people without anxiety (Derryberry & Reed, 2002; Tipples, 2008). Rather, in the present study a participant's Attentional Control Scale score was significantly related to how difficult they perceived the operation span test to have been, $r = -.19$. Thus, the Attentional Control Scale may correlate with meta-cognitions but not with actual behavior in people without anxiety. Given the Attentional Control Scale's lack of predictive ability it is not considered in any subsequent Experiment 1 analyses.

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, $F(1, 144) = 0.36$, $MSE = 118.06$, $p = .55$ (see Table 2). Likely this was due to the delay between the depletion manipulation and assessment of operation span score in the current experiment. In contrast to Schmeichel (2007), where the operation span test immediately followed the depletion manipulation, in the current experiment the operation span test occurred more than 20 minutes after the depletion manipulation (during which time participants completed the two memory tests and the Attentional Control Scale). This is in line with some recent research suggesting that the time course of executive depletion is limited. In particular, Converse and DeShon (2009) demonstrated negative effects of depletion only on an immediate test and not on a subsequent test.

The indirect effect of executive control on retrieval disruption through the encoding stage. I next examined the relationship between performance on the operation span test and memory performance. Previous research by Cokely, Kelley, and Gilchrist (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 cuing 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).³ 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 cuing 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, $F(1, 26) = 0.43$, $MSE = .02$, $p = .52$.

Discussion

Experiment 1 demonstrated no direct relationship at the retrieval stage between executive depletion and retrieval disruption in a part-set cuing paradigm. That is, holding

³ It should be noted that the measurement of operation span used in the current experiment differs from that used by Cokely and colleagues (2006). Specifically, in the current experiment operation span was defined as the number of items correctly recalled regardless of whether the entire set of items was recalled (a partial-credit scoring procedure). In contrast, Cokely et al. (2006) defined operation span as the number of items recalled only from sets where all the items were recalled (an all-or-nothing scoring procedure). The following example illustrates the difference between these two measures. Assume that a participant encountered three sets of letters. The first set was 4 letters long, the second was 5, and the third was 6. Further assume that the participant's correct serial recall of these sets was 4 (out of 4) items, 5 (out of 5) items, and 4 (out of 6) items. Using the partial-credit scoring procedure this participant's operation span score would be calculated as 13 (4 + 5 + 4). Using the all-or-nothing scoring procedure this participant's operation span score would be calculated as 9 (4 + 5 + 0).

In the current experiment, while the relationship reported between operation span and the part-set cuing deficit is completely replicated using the partial-credit scoring procedure, it is only partially replicated using the all-or-nothing scoring procedure. When using the all-or-nothing scoring procedure, individuals with high operation span scores (defined as operation span scores in the upper quartile with a score above 55) demonstrated a significant part-set cuing deficit, $F(1, 33) = 6.38$, $MSE = .02$, consistent with the findings from Cokely et al. (2006). This pattern is smaller in magnitude but numerically present and marginally significant, for individuals with low operation span scores (defined as operation span scores in the bottom quartile with a score below 36), $F(1, 30) = 3.69$, $MSE = .01$, $p = .06$. Thus, as in Cokely et al. (2006) the part-set cuing deficit in the present study was statistically present for high operation span individuals, but less robust for low operation spans individuals. However, in contrast to Cokely et al. (2006), no significant interaction emerged between operation span grouping and test type (free versus cued recall), $F(1, 63) = .30$, $MSE = .01$, $p = .58$, in predicting memory performance. Thus, using the all-or-nothing scoring procedure there is only a partial replication of the findings reported by Cokely and colleagues (2006).

Two potential explanations emerge for this discrepancy. First, the the automated operation span measure (Unsworth et al., 2005) used in the current experiment is not identical to the traditional operation span test (Turner & Engle, 1989) used by Cokely, et al. (2006). For example, the automated operation span test is computer-paced and asks participants to recall strings of letters. In contrast, the operation span test is experimenter-paced and asks participants to recall strings of words. While these measures are well correlated, $r = .45$ (Unsworth, et al., 2005, p. 501), they are not identical. Perhaps more importantly, the partial-credit scoring procedure used in the current experiment is known to produce more reliable results than the all-or-nothing scoring procedure (Conway, et al., 2005). Thus, the discrepant results obtained from the two scoring procedures likely reflect the reduced reliability of the all-or-nothing scoring procedure compared to the partial-credit scoring procedure. Regardless, even the discrepancy in the all-or-nothing scores is in the predicted direction and consistent with the conclusion arrived at with the partial-credit score.

encoding constant, changes in executive control at retrieval (instantiated through an executive depletion manipulation) did not affect the part-set cuing deficit. However, this finding occurred in the context of simultaneously replicating the results of Cokely and colleagues (2006) that increases in executive control at encoding (measured through existing individual differences) correspond to increases in the part-set cuing deficit. 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. Thus, in replication of previous results (Cokely, et al., 2006), in the current experiment executive control was shown to exert an indirect influence on retrieval disruption.

III. Experiment 2: The role of executive control in modulating the collaborative inhibition effect

Overview of 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 cuing deficit. Experiment 2 further addressed this question by examining the effects of executive control on collaborative inhibition. Given that both the part-set cuing deficit and the collaborative inhibition effect are considered to occur due to retrieval disruption, together these experiments provide a strong test of the direct role of executive control on 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. As discussed earlier, there are several reasons to hypothesize that this is the case. First, executive depletion can decrease various forms of prosocial behavior 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 unsynchronized, social interactions can themselves deplete executive resources (Dalton, Chartrand, & Finkel, in press; 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 in 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 (Meade & Roediger, 2002; Gabbert & Memon, 2004). 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 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 cuing 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, Blair, & Huebsch, 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 cuing deficit in Experiment 1.

Method

Participants.

A new sample of 192 undergraduate students (16 triads per condition) was recruited from Stony Brook University. The sample was approximately balanced between men and women (47.92% women) and the mean age of participants was 19.95 (SD = 3.217). Participants completed the experiment in triads of strangers.

Materials.

The same study items from Experiment 1 were used.

Design.

Collaborative inhibition was assessed between participants using an adaptation of Basden, et al.'s (1997) and Weldon & Bellinger's (1997) methodologies. The study materials and procedure chosen have been shown by previous experiments to be sensitive to manipulations that would increase (or decrease) retrieval disruption (e.g. Basden, et al., 1997; Finlay, et al., 2000). This experiment had a two factor, executive depletion (depleted or not depleted) and group format (collaborative or nominal groups), between-subjects design.

Procedure

Study Phase.

Each participant was individually shown the exemplars from all six categorized 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 three exemplars from any list appear successively). Within each group, each group member 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 lower-case letters, centered on the computer screen.

Category names were not provided. Intentional study instructions were used such that participants were told about the upcoming memory test.

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'). For a more detailed description, please see 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. 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 ten 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 ten 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, Experiment 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. For example, imagine that during this recall session Participant 1 remembered items A, B, and C, Participant 2 remembered items C, D, and F, and Participant 3 remembered items B, C, E, and F but also intruded the non-studied item X. The nominal recall score for this group would be 6 (items A-F), while the nominal error rate for this group would be 1 (item X). Repeated items were counted only once. As in most published collaborative memory experiments, nominal groups were created based upon 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.

Assessments of Executive Control.

Immediately following the second memory test, all participants completed the Attentional Control Scale (Derryberry & Reed, 2002) and the automated operation span task (Turner & Engle, 1989; Unsworth, Heitz, Schrock, & Engle, 2005). For a more detailed description, please see Experiment 1.

Final Questionnaire.

Participants completed the same final questionnaire that was used in Experiment 1. This questionnaire assessed: (a) demographic information, (b) information about when

the participant last ate and how many hours they slept, and (c) subjective ratings about the difficulty of each task during the experiment.

Results

Manipulation Check.

Participants across the four conditions 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 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 3). 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.

The direct effect of executive depletion on retrieval disruption at the retrieval stage.

I 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, I conducted a 2 (Executive Depletion: Depleted vs. Not depleted) X 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 increase 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 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 3). 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, $F(3, 60) = 4.78$, $MSE < .01$. As in previous experiments (e.g. Basden, Basden, & Henry, 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, taking these error rates into consideration did not affect the prior conclusions about collaborative inhibition. Corrected group recall

(hits minus false alarms) was higher in the current experiment for nominal groups ($M = .60$) compared to collaborative groups ($M = .54$), $F(1, 62) = 5.26$, $MSE = .01$.

As in Experiment 1, error rates did not vary as a function of condition on the second, always individual free recall, memory test, $F(3, 188) = 0.61$, $MSE < .01$, $p = .61$. Participants who had previously been part of a nominal group produced no more intrusions ($M = .01$) than participants who had previously been part of a collaborative group ($M = .01$), $t(188) = .61$, $SE = .01$, $p = .55$. Error rates did not vary as a function of depletion condition, $t(188) = 1.13$, $SE = .01$, $p = .26$.

Subjective Evaluation of the Memory Tests.

At the end of the experiment, participants provided subjective evaluations of how difficult each memory test was to complete. Participants varied in their ratings of the first memory test (which was either collaborative or nominal recall depending upon condition) as a function of condition, $F(3, 188) = 5.22$, $MSE = 1.43$. Participants from the nominal groups rated this task as significantly harder to complete ($M = 4.19$; scale of 1-7) than participants from the collaborative groups ($M = 3.59$), $t(188) = 3.44$, $SE = .34$. While this pattern was numerically present for all participants, it reached statistical significance for participants in the control conditions, $t(188) = 3.76$, $SE = .24$, but not for participants in the depletion conditions, $t(188) = 1.11$, $SE = .24$, $p = .27$. Participants also marginally varied as a function of condition in their ratings of the second memory test (which was always individual free recall regardless of condition), $F(3, 188) = 2.38$, $MSE = 2.07$, $p = .07$, however, no differences emerged as a function of either previous test status, $t(188) = -.90$, $SE = .41$, $p = .37$, or of depletion status, $t(188) = 1.21$, $SE = .41$, $p = .23$. Finally, differences emerged in how participants rated each of the two memory tests as a function

of condition, $F(1, 188) = 4.01$, $MSE = .80$. Participants from the collaborative groups perceived the collaborative memory test as being easier ($M = 3.59$) than the final individual memory test ($M = 4.17$), $F(1, 95) = 14.71$, $MSE = 1.07$. In contrast, participants from the nominal groups perceived the first memory test as being more difficult ($M = 4.19$) than the second memory test ($M = 3.98$), $F(1, 95) = 4.05$, $MSE = .52$. There were no significant effects of depletion in these analyses.

Individual Differences in Executive Control.

Participants completed both the Attentional Control Scale (Derryberry & Reed, 2002) and the automated operation span test (Unsworth, Heitz, Schrock, & Engle, 2005) as measures of executive control. Seven participants (4% of participants) 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). As in Experiment 1, while scores on the Attentional Control Scale did not significantly correlate with performance on the operation span test, $r = .04$, $p = .57$, they did significantly correlate with ratings of how difficult participants perceived the operation span test to have been, $r = -.19$ (see Table 2). Participants who rated themselves as having better attentional control perceived the operation span task to be easier than participants who rated themselves as having lower attentional control. However, this did not translate into actual differences in performance.

As in Experiment 1, and in contrast to Schmeichel (2007), depletion did not affect performance on the operation span test, $F(1, 183) = 0.86$, $MSE = 95.69$, $p = .36$ (see Table 2). That is, depleted participants ($M = 61.90$) performed equivalently to non-depleted control participants ($M = 60.57$) in terms of their operation span scores. As

noted earlier, in the current experiment operation span scores were assessed more than twenty minutes after the depletion manipulation. In contrast, in Schmeichel (2007) they were assessed immediately after the depletion manipulation. This is in line with research suggesting that depletion is a transient phenomenon whose negative effects dissipate over time (Converse & DeShon, 2009).

The relationship between group members' operation span scores and group memory performance could not be directly assessed. In particular, this data is 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 Modeling (HLM). Problematically, HLM analyses require the dependent variable to be operationalized 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 (see Beaubien, Hamman, Holt, & Boehm-Davis, 2001; Castro, 2002 for discussions of this issue). Similarly, the potential depletion mediators that were assessed in Experiment 1 (e.g. when an individual last ate) could not be used to predict group memory scores in this experiment.

I next assessed the relationship between operation span scores and final memory 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 upon the attentional resources available during the previous memory test (i.e. the collaborative or nominal 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 upon an individual's level of executive control because collaboration demands more attentional resources. 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 executive control.

IV. General Discussion

Competing predictions about the relationship between executive control and retrieval disruption were tested in two theoretically-related memory paradigms - a part-set cuing paradigm that involves individual recall and a collaborative memory paradigm that involves group recall. These studies were motivated by conflicting findings in the literature about the relationship between these variables. On the one hand, some previous research has suggested that executive control does not exert a direct role on retrieval disruption at the retrieval stage (e.g. Cokely, Kelley, & Gilchrist, 2006). On the other hand, other research has suggested that increases in executive control correspond to decreases in distractibility (e.g. Connelly, Hasher, & Zacks, 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 predict 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.

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 (e.g. participants with low vs. high executive control, older vs. younger adults) approach. 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 while holding encoding constant and examined the effects in individual recall settings (the part-set cuing 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 both executive depletion and test type were manipulated. Participants performed either an executive depletion task (i.e. story-writing without the letters 'a' or 'n') or a matched control task (i.e. story-writing without the letters 'q' or 'z') prior to completing either a free recall test or a part-set cued recall test. If executive depletion minimizes retrieval disruption, then depletion should lower part-set cued recall but not free recall performance. The study results showed no evidence for this outcome. While participants performed better in the free recall conditions than in the part-set cued recall conditions (i.e. the standard part-set cuing deficit), depletion exerted no influence. Thus, manipulations of executive control via a depletion manipulation at retrieval do not seem to exert a direct influence on retrieval disruption in a part-set cuing 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. 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, Experiment 1 demonstrates 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, as manipulated through a depletion procedure, do not affect retrieval disruption directly.

Given that the executive depletion task did not affect retrieval disruption in Experiment 1, it is important to note that manipulation checks confirmed the executive depletion task was in fact depleting. In both experiments, participants who completed the depletion task rated it as more difficult and had qualitatively worse performance than participants who completed the control task. These results mirror the manipulation check ratings of Schmeichel's (2007) experiments in which depleted participants also exhibited subsequent deficits on measures of executive control abilities. It should also be noted that while depletion did not affect measures of executive control abilities (i.e. operation span) in the current studies, this does not reflect a manipulation failure. Previous research has shown that the negative effects of executive depletion are temporally constrained (Converse & DeShon, 2009). Thus, in the current studies executive control abilities were measured more than 20 minutes after the depletion manipulation in order to ensure that the measurement reflected individual differences in abilities and not executive depletion. This allowed for disambiguation between the role of executive control on retrieval disruption at both the encoding and retrieval stages.

Experiment 2 was designed to examine the effects of executive depletion on retrieval disruption in the collaborative memory paradigm rather than in the part-set cued recall paradigm. The procedure in Experiment 2 was very similar to that of Experiment 1

except the use of a comparison between collaborative group recall and nominal group recall. Participants performed either the executive depletion task or a matched control task prior to completing either an individual free recall test or a collaborative free recall test. Nominal groups were created by combining the non-overlapping responses provided by three participants completing the individual free recall test. If executive depletion minimizes retrieval disruption, then depletion should lower collaborative group recall but not nominal group recall performance. While this relationship was not observed in a part-set cuing paradigm (Experiment 1) some previous research suggests that depletion may exert stronger influences in a social setting than in an individual setting. In particular, executive depletion has negative effects on both cognitive (e.g. Schmeichel, 2007) and social (e.g. Finkel & Campbell, 2001) measures. For example, after completing an executive depletion task people are less pro-social and helpful (e.g. DeWall, Baumeister, Gailliot, & Maner, 2008). This may be especially problematic as unsynchronized behavior, even when not consciously noticed by people, can itself lead to depletion (Dalton, Chartrand, & Finkel, in press; Finkel, et al., 2006). Thus, it was hypothesized that depletion could exert effects in a collaborative memory paradigm even though no effects were observed in the part-set cuing paradigm. On the other hand, other research suggests that collaborative inhibition is relatively impervious to manipulations of various social factors (Weldon, Blair, & Huebsch, 2000). Thus, the competing hypothesis was also generated that the relationship between executive depletion and retrieval disruption should remain constant across individual and group memory paradigms. Results confirmed this competing hypothesis. While a standard collaborative inhibition effect was observed such that participants performed better in the nominal

groups than in the collaborative groups, this was not affected by executive depletion. Thus, executive depletion does not affect retrieval disruption in a collaborative memory paradigm.

Taken together, these results are consistent with research showing differential effects of divided attention at retrieval and at encoding. Looking first at the retrieval stage, previous research has shown that retrieval is minimally affected by manipulations of attention (e.g. Craik, 2001). For instance, participants who simultaneously performed a digit-monitoring task and a free recall task (a divided attention condition) performed equivalently to participants who only performed the free recall task (a full attention condition; Baddeley, Lewis, Eldridge, & Thomson, 1984). Based on these results it has been argued that retrieval is a relatively automatic (e.g. Baddeley, et al., 1984), or obligatory (e.g. Craik, et al., 1996), process and one that does not require executive control to complete. Given that executive control is an attentional construct, it therefore follows that manipulations of executive control at the retrieval stage do not influence performance.

While retrieval is often relatively automatic and not reliant upon attentional resources, this is not always true. In fact, under certain circumstances divided attention can have detrimental effects on memory retrieval (e.g. a source memory test; Dywan & Jacoby, 1990). A neuropsychological account (i.e. the component-process model of memory) has been proposed to explain these discrepant findings. More specifically, it has been proposed that retrieval based predominately on medial temporal lobe / hippocampal activity is relatively automatic and unaffected by divided attention. In contrast, retrieval that involves prefrontal cortex activity is relatively controlled and

affected by divided attention (e.g. Fernandes & Moscovitch, 2000; Moscovitch, 1992, 1994; Moscovitch & Umiltà, 1990). Some evidence suggests that participants in the current experiment may not have engaged prefrontal regions during the part-set cued recall and collaborative memory tasks. In particular, performing a part-set cued memory test (under circumstances in which retrieval disruption should operate) does not activate prefrontal cortical regions any more strongly than performing a free recall test (Crescentini, Shallice, Missier, & Macaluso, 2010). This should mean that participants in the current experiment did not preferentially activate prefrontal cortical regions during the retrieval disruption tasks and were therefore unaffected by the manipulations of attentional resources (as in executive depletion).

However, the findings of Crescentini and colleagues (2010) that prefrontal cortical regions are not preferentially involved in a part-set cued task should be interpreted with caution. In particular, while they failed to find differences in prefrontal cortex activation during a part-set cued memory test and a free recall memory test (under circumstances in which retrieval disruption is thought to operate) they also failed to find behavioral differences. That is, there was no significance difference in recall between the part-set cued and free recall conditions. The conclusions about brain activation differences during completion of these two tasks should therefore be viewed cautiously until they are substantiated by future research. Finally, one additional point should be noted about the findings of Crescentini and colleagues (2010). That is, while no differences in recall or prefrontal cortex activation were observed under conditions thought to rely on retrieval disruption; both were observed under conditions thought to rely on retrieval inhibition. That is, after encoding items with a low degree of inter-item associations participants

recalled more items, but showed less prefrontal cortex activation, during a free recall test than during a part-set cued recall test. Thus, one direction for future research may be to examine whether executive control modulates the part-set cuing deficit when items have a low degree of inter-item associations, but not when items have a high degree of inter-item associations. In other words, executive depletion may exert an effect on retrieval inhibition rather than retrieval disruption.

In contrast to the previous results examining the role of divided attention at retrieval, divided attention at encoding almost always exerts a negative impact on memory. That is, dividing attention at encoding lowers performance on subsequent free recall, cued recall, recognition, and source memory tests compared to full attention conditions (e.g. Baddeley, et al., 1984; Craik, et al., 1996; Fernandes & Moscovitch, 2000, 2002; Murdock, 1965; Naveh-Benjamin, 1987; Naveh-Benjamin, Craik, Gavrilesco, & Anderson, 2000; Naveh-Benjamin, et al., 1998; Naveh-Benjamin, Guez, & Sorek, 2007; Reinitz, Morrissey, & Demb, 1994). For example, in Baddeley, et al. (1984; Experiment 2), participants were asked to complete a distracting digit monitoring task either while encoding a word list or while recalling a word list. Results showed uniformly negative effects of divided attention at encoding. In contrast, few negative effects of divided attention at retrieval were obtained. Given that executive control is related to attentional resources (e.g. McCabe, et al., 2010), then it follows that executive control may be related to the way participants encode information. Evidence in support of this conclusion was found in Experiment 1. As in Cokely, et al. (2006), in the present Experiment 1 individuals with high executive control encoded information in a manner that left them susceptible to retrieval disruption (likely due to a higher degree of inter-

item associations created at encoding). In contrast, individuals with low executive control were not affected by retrieval disruption. Thus, in the current experiments executive control was shown to have an effect at encoding (as assessed through individual differences) but not at retrieval (as assessed through the experimental manipulation of executive depletion). Future research is needed to further this finding and examine the role of executive depletion at encoding. Given that higher executive control is related to the tendency to encode information in a manner that leaves one susceptible to retrieval disruption, then depletion prior to encoding should reduce subsequent retrieval disruption effects. That is, if participants are depleted prior to encoding they should later exhibit a smaller part-set cuing deficit and collaborative inhibition effect than participants that are not depleted prior to encoding. These results will help further elucidate the role of executive control in modulating retrieval disruption effects.

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 does not seem to directly influence retrieval disruption through its role at retrieval.

Table 1

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.

		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)

Table 2

Operation span scores as a function of depletion condition in both the first and second experiment. Note that the math errors consist of two types: speed and accuracy errors. Thus, the math errors column is the sum of the speed errors and accuracy errors columns in this table. Numbers in parentheses are standard deviations.

		Automated Operation Span Measures				
		Partial-Credit Scoring	All-or-Nothing Scoring	Math Errors	Speed Errors	Accuracy Errors
Exp 1	Control, Q/Z story, condition (n = 73)	60.59 (9.89)	45.55 (13.96)	6.47 (3.59)	1.18 (1.40)	5.29 (3.03)
	Depletion, A/N story, condition (n = 73)	59.51 (11.76)	44.62 (15.20)	6.47 (3.53)	1.00 (1.12)	5.42 (3.14)
Exp 2	Control, Q/Z story, condition (n = 93)	60.57 (10.15)	44.48 (16.07)	6.42 (3.39)	1.18 (1.18)	5.24 (3.13)
	Depletion, A/N story, condition (n = 92)	61.90 (9.40)	47.16 (15.86)	6.75 (3.39)	1.28 (1.29)	5.47 (2.99)

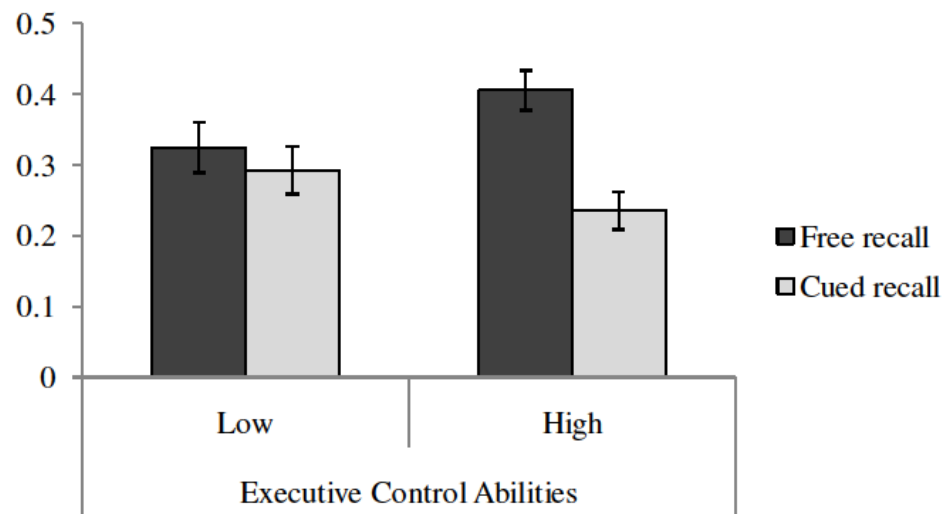
Table 3

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.

		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)

Figure 1.

Mean proportion of critical items correctly recalled on the first memory test of Experiment 1 as a function of 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 cuing deficit, low executive control individuals do not.



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Appendix A

Study items used in both Experiment 1 and Experiment 2

Category	Critical Target Words	Non-Critical Cue Words
Instruments	guitar flute piano clarinet trombone violin cello	harp horn banjo harmonica cymbals keyboard tambourine
Birds	eagle blue jay cardinal hawk crow sparrow pigeon	ostrich penguin flamingo raven duck chicken vulture
Sports	baseball tennis swimming hockey golf volleyball lacrosse	cheerleading racquetball polo wrestling bowling badminton cricket
Fabrics	silk polyester wool nylon rayon satin spandex	velvet jean suede cashmere flannel lace lycra
Fish	salmon trout bass catfish tuna shark flounder	dolphin angelfish blowfish minnow piranha snapper whale
Vegetables	lettuce broccoli tomato cucumber corn celery onion	cabbage radish asparagus pepper beet turnip zucchini

Appendix B

Final Questionnaire given to all participants in both Experiment 1 and Experiment 2

Sex: _____

Age: _____

Ethnicity: _____ (or check here [] if you'd prefer not to specify)

What time did this experiment start today? _____

Including snacks, what time that you last eat something?

Please list (to the best of your ability) everything that you have had to eat or drink in the three hours prior to the experiment. For each item, please estimate what time you ate or drank it.

Item

Time that I ate or drank it

What time did you wake up this morning? _____

How many hours did you sleep last night? _____

Do you consider yourself to be a morning or night person? _____

How easy or difficult was the story writing exercise? (i.e. when you had to write about a vacation or trip without using certain letters).

1	2	3	4	5	6	7
very easy			neither			very difficult

How easy or difficult was the FIRST memory test you completed? (i.e. the first time you had to remember the words from the beginning of the experiment)

1	2	3	4	5	6	7
very easy			neither			very difficult

Appendix C

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.”