Attentional Selection and Reduced Interference Improve Visual Short-Term Memory in Mild Cognitive Impairment

by

Rachel Newsome

A thesis submitted in conformity with the requirements
for the degree of Master of Arts

Psychology Department
University of Toronto

Library and Archives
Canada

Published Heritage
Branch

395 Wellington Street
Ottawa ON K1A 0N4
Canada

Bibliothèque et
Archives Canada

Direction du
Patrimoine de l'édition

395, rue Wellington
Ottawa ON K1A 0N4
Canada

Canada

Attentional Selection and Reduced Interference Improve Visual Short-Term Memory in Mild Cognitive Impairment

Rachel Newsome

Master of Arts

Psychology Department
University of Toronto

2011

Abstract

Visual short-term memory (VSTM) is a vital cognitive ability, allowing us to hold online the contents of visual awareness. Healthy older adults have reduced VSTM capacity compared to young adults; however recent evidence suggests that their performance may be improved by the use of a retroactive cue ("retro-cue"). The retro-cue reduces interference from irrelevant items within VSTM. Mild cognitive impairment (MCI) patients have reduced VSTM performance, compared to healthy older adults. Here, we examined whether the use of a retro-cue would increase VSTM capacity in MCI patients. By presenting a retro-cue after a to-be remembered array, we direct attention to the to-be probed location, which reduces interference from other items that are no longer relevant. The present findings suggest that VSTM capacity per se is not compromised in MCI patients, but these patients may be more susceptible to the effects of interference.

Acknowledgments

Table of Contents

List of Tables

List of Figures

1   Introduction

1.1   General Introduction

How do we keep track of our surroundings as we move through daily life? How do we maintain a visual representation of our environment as we navigate through a crowded street? Visual short-term memory (VSTM) is the ability to maintain visual information in mind for a brief period of time after that information is no longer available in the environment. It is thought to be the visual storage element of working memory. To successfully perform many every-day tasks, both simple and complex, requires mental representation of one's surroundings. We then use these representations to make decisions about the environment and act on those decisions.

VSTM is different from iconic memory, which is sensory memory in the visual domain. Iconic memory is very brief, less than 1000 ms, but has a high capacity. In contrast, VSTM representations last longer and can persist through distractions, such as eye movements or eye blinks. The amount of information available to the visual system is practically infinite; yet the amount of information that visual working memory can process is limited, both in processing capacity and storage capacity. Additionally, VSTM is different from long-term memory (LTM). The storage capacity of LTM is more or less unlimited, and is very long-lasting, sometimes enduring for decades. In contrast, information stored in VSTM lasts for a few seconds.

A paradigm called a change detection task assesses VSTM by requiring subjects to visually encode both location and features of the stimuli. In a typical change detection task, a number of objects are displayed (*memory array*), after a short delay, another display of stimuli is displayed (*test array*), and the participant is asked whether the sample and test arrays are the same or different. See **Figure 1** for an example of a

change detection task. Using a formula proposed by Pashler and modified by Cowan to account for guessing, capacity estimates are calculated as *K* estimates (Pashler, 1988, Cowan, 2001). Most people accurately detect a change in an array with three or four different stimuli, but performance declines when there are more stimuli in the array (Cowan, 2001, Todd and Marois, 2004). However, this capacity limit differs for certain populations; specifically, older adults and memory impaired populations have reduced VSTM performance relative to healthy young adults (Hamm and Hasher, 1992, Alescio-Lautier et al., 2007, Lustig et al., 2007, Adamo et al., 2009, Bublak et al., 2011)
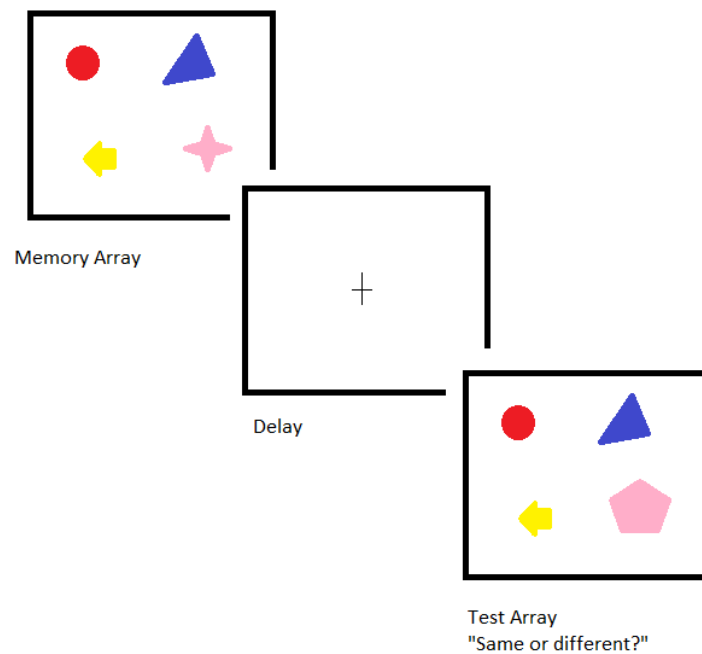
Figure 1. An example of a change detection task. An array of objects are displayed in the memory array, after a short delay, a test array is displayed. One must determine whether the test array is the same or different from the memory array. Here the arrays are different because the pink object in the lower right visual field changes to a different pink object.

1.2   Theories of Memory

1.2.1   Embedded Process Model

Cowan's embedded process model theory proposes that working memory is the activated content, or an embedded process of LTM (**Figure 2**). This theory proposes that working memory is not separate from LTM, but is in fact a part of LTM. An important division of this activated content of working memory is the "focus of attention" (Cowan, 1999). According to this model, the focus of attention involves the enhanced processing of some information in working memory, while other simultaneously available information is absent from the focus of attention. Information contained in the focus of attention can be stored in LTM, and information that does not enter the focus of attention is less likely to be encoded into LTM. For example, the day after a party, one might remember a conversation he was actively involved in, but not the song that was playing at the same time.
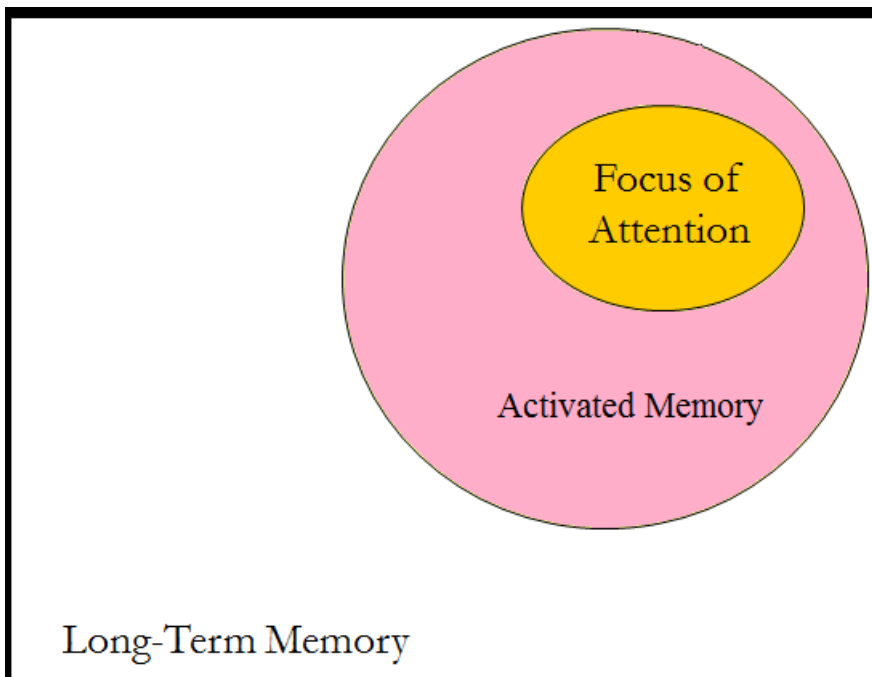
Figure 2. Cowan's Embedded Process Model proposes that working memory is the activated content of LTM. The focus of attention involves the enhanced processing of WM.

Saliency of information is vital to the focus of attention. When salient information becomes available while awareness is directed elsewhere, that information automatically activates memory representations. An example of this is the Cocktail Party Phenomenon: in a party environment, when a person hears his name from across the room, he automatically attends to that information (Wood and Cowan, 1995, Conway et al., 2001). A critical component of this theory is that the focus of attention is habituation of orientation. This occurs when stimuli with features not particularly important to the individual remain relatively unchanged over time, activate features in memory, but do not elicit awareness. Thus, people become habituated to stable stimuli in the environment. Using the same cocktail party example, after a time, people may not notice the loud music in the background, but when someone turns the music off, this environmental change becomes activated in attention. Thus, while people habituate to stimuli, we orient our focus of attention to changes in the environment (Cowan, 1999, in press).

Cowan's model suggests that there are two types of central capacity limits: processing-related and storage-specific (Cowan, in press). The processing-related limit refers to whether or not individuals can adopt processing strategies to enhance performance. This concept is variable on different tasks, and includes strategies to maximize performance, such as chunking information (e.g., to remember the numbers "7-4-2", remember "742") or distracting tasks which decrease performance (e.g., solving algebraic problems while encoding a list of words). On the other hand, storage-specific capacity is a stable, measurable concept, referring to the general capacity of storage for an individual. Furthermore, storage-capacity limits are affected by processing-related limits. Additionally, both capacity limits differ across individuals (Cowan, in press).

1.2.1.1 Storage-Capacity and Processing-Related Limits of VSTM

Capacity limits of working memory are closely related to those in the visual domain. It is largely agreed that VSTM is capacity limited, yet there is debate about whether VSTM is limited to a small number of "slots," or whether the limit is due to the amount and type of information in the visual environment. The first view of visual working memory proposes that VSTM contains a small amount of fixed-resolution slots (Luck and Vogel, 1997). This view suggests that objects are the main storage unit of VSTM, and that individuals can maintain three to four objects. A recent study examined the slot view by displaying parts of objects in a change detection task (Xu, 2002). The results indicated that features were stored more efficiently when they made an object (e.g., a coloured circle with a black bar through it makes a "Saturn"-like object) than when the features were spatially separated objects (e.g., a coloured circle or a black bar displayed separately). Thus, when the features are singular objects (a circle or bar), each of the features takes up a slot in VSTM; however when the features combine into a single object, those same features only take up one slot in VSTM. This primary slot view provides evidence for the storage-capacity limit of working memory.

In contrast, the second viewpoint proposes that capacity limits are due to the amount of information in the environment. This approach, called the "resources" view indicates that a fixed number of resources are distributed among items in the environment, and with increasing items, resolution of the representation decreases. Thus, all objects can be stored, but with varying resolution, depending on the number of objects (Vogel et al., 2001). Research from Alvarez and Cavanagh has shown that capacity estimates decreased with increasingly difficult items, suggesting that VSTM

capacity is a function of information load (Alvarez and Cavanagh, 2004). The resources view supports the processing-related limit suggested by Cowan.

Thus, the question arises, is VSTM distinctly limited by either storage-capacity or processing resources, or does it require both?

1.2.2   Inhibitory Control Theory

One theory of working memory relates to the processing resources viewpoint. Hasher and Zacks proposed a theory of inhibitory control to explain working memory capacity (Hasher and Zacks, 1988). This theory stresses the importance of efficiency of resources in memory, suggesting that inhibition requires the ability to limit information from activating working memory. This ability is reduced in older adults, young children, those at a high level of stress, or individuals tested at a non-optimal time of day (for review see Lustig et al., 2007). This inhibition has two component functions: 1. to prevent irrelevant information from entering the focus of attention, and 2. to delete irrelevant information from the focus of attention.

These functions both refer to keeping irrelevant information from current awareness. Older adults have a reduced ability to filter this irrelevant information, which leads to their reduced storage capacity. Additionally, this "leaky filter" that is letting in too much information means that older adults are more susceptible to the effects of interference from irrelevant stimuli (Hasher and Zacks, 1988). A recent study by Rowe and colleagues found that older adults had better memory for distractors than did young adults, suggesting that older adults' increased susceptibility to interference prevented them from filtering out the distracting information in working memory, and they actually encoded this irrelevant information into long term memory (Rowe et al., 2006) (for similar results, see Kim et al., 2007, Gopie et al., 2011).

1.2.3   Interference

Generally, interference refers to the effects of irrelevant information (Lustig and Hasher, 2001). It can include distractors, memories that are irrelevant to the current situation, and the desire to make responses that are inappropriate to the situation. Interference in memory tasks can refer to *proactive* or *retroactive* interference. Proactive interference refers to irrelevant information that is learned before the target information; for example, when one has the same phone number for several years and then has to change their number, knowledge of the previous number interferes with learning the new number. In contrast, retroactive interference refers to irrelevant information that is learned after the target information. Using the same phone number example, it is hard to remember the previous number once the new number has been learned.

A recent study examined the effects of retroactive interference on a story recall task with amnesic patients (Cowan et al., 2004). After hearing a story, patients were either given standard psychometric tests (*high interference* condition), or allowed to sit in a dark, quiet room (*low interference* condition). Amnesic patients recalled more of the story when the delay was spent in the low interference condition, suggesting that the patients were more susceptible to interference from the psychometric test and that this interference prevented relevant information from being stored in long-term memory. A follow-up study examined the same task in mild cognitive impairment patients (MCI, see **Section 1.3** for a description of mild cognitive impairment) and found similar results: MCI patients remembered up to 35% more of the story in the low interference condition than in the high interference condition (Della Sala et al., 2005). MCI patients are also susceptible to this type of retroactive interference. Additionally, Newsome et al. examined this effect in an object discrimination task, in which MCI patients were asked

to indicate whether two visually similar objects were identical or slightly different (i.e., one of the three features was subtly different, Newsome et al., 2011). In the high interference condition, all objects were semantically negligible blob-like objects that shared similar features. In the low interference condition, the blob objects were temporally separated by colourful photographs of everyday objects, whose features did not overlap with the blobs (see **Figure 3**). Again, MCI patients were impaired in the high interference condition, suggesting that their susceptibility to interference may also extend to visual perception.
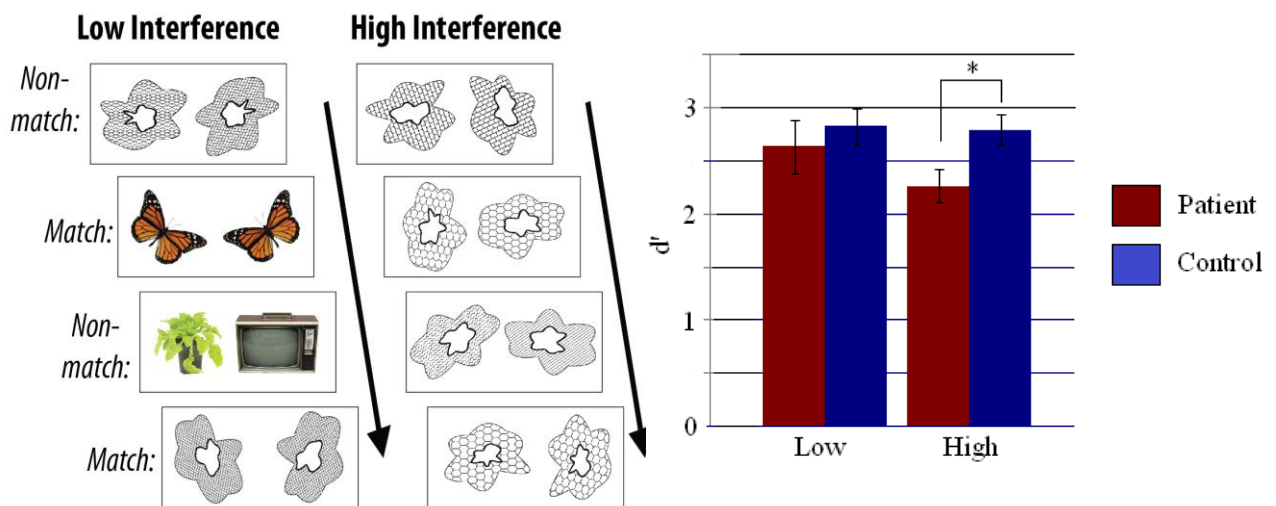
Figure 3. Task and results from Newsome et al., 2011. Task: Are the two objects a match or a non-match? For non-match blob trials, only one feature differed, all objects are trial-unique. MCI patients were impaired on high interference condition, but intact on low interference condition, suggesting that MCI patients may be more susceptible to perceptual interference.

1.2.4   Attention

Visual attention is the means by which all organisms select relevant information from the environment, and it is an important component of working memory. It acts as a filter, focusing on salient, important information from the attended environment and suppressing irrelevant information from unattended stimuli. One can voluntarily direct attention to a specific object, location, or feature, and this is called voluntary attentional control (Serences et al., 2005).

Kane and colleagues examined attentional control in low and high span working memory individuals (Kane et al., 2001). They used a measure of attentional control, the anti-saccade task, to measure inhibitory functions in these individuals. In this task, participants must suppress the natural reflex to look at a visual target when it appears in the visual field and instead, look in the opposite direction of the target. In contrast, a pro-saccade task involves looking towards the target when it appears and is thus aligned with an individual's natural reflex. The authors found that low-span individuals were slower and made more errors on the anti-saccade task, and that these same individuals performance was low when task switching from an anti-saccade task to a pro-saccade task. Conversely, high capacity individuals scored well on both attentional control tasks. These findings suggest that attentional control and working memory capacity are correlated, fitting with both Cowan's Embedded Process Model, and Hasher's Inhibitory Control Theory. Cowan's model predicts that low-capacity individuals have a smaller storage capacity and a reduced processing capacity; thus, in the anti-saccade task, low span individuals' processing resources are taken up by attending to the non-target direction. Additionally, according to Hasher's model, the low

capacity individuals are more susceptible to interference, and thus, these individuals could not inhibit the irrelevant target information in the antisaccade task.

1.3   Mild Cognitive Impairment and VSTM

Mild cognitive impairment (MCI) is a memory impairment condition associated with an increased risk for developing Alzheimer's disease (AD); an estimated 70% of MCI patients will convert to AD or a related dementia (Petersen and Negash, 2008). It is thought that MCI patients are likely to have an underlying neuropathology, but do not yet meet criteria for diagnosis of dementia (Petersen et al., 2001). Unlike dementia patients, MCI patients may have slight impairments in other general cognitive domains, but these impairments are not enough to impact everyday function (e.g., hygiene, communication) (Petersen, 2004a).

MCI patients have greater impairments in VSTM than healthy older adults (Alescio-Lautier et al., 2007, Bublak et al., 2011). Alescio-Lautier and colleagues examined VSTM in MCI and AD patients using a variation of a change detection task. To control for difficulty, the authors administered a span control task prior to the experimental task, to assess individual memory capacity. Using this estimate, they ensured that the change detection task did not exceed each person's individual memory capacity. Even though the task did not exceed their VSTM capacity, both MCI and AD patients were impaired at detecting change. Additionally, this memory impairment was greater when there was a distractor present in the one second delay between the studied image and the probe image. With a distractor, participants were forced to shift their attention from the previous task (the memory array) to the present task (the distractor). These results suggest that there may be a dysfunction in attentional

processes in these patients, and that reducing interference (i.e., the distractor), may be one way to ameliorate this difference.

Interestingly, another study assessing VSTM in MCI patients found that MCI patients storage capacity estimate (*K* estimate, Pashler, 1988, Cowan, 2001) was *not* impaired, compared to healthy controls, but patients did have an elevated estimated threshold viewing-time value compared to controls (Bublak et al., 2011). That is, MCI patients required a longer viewing duration at encoding to report seeing any stimuli. The authors interpreted these results as owing to the fact that MCI patients may have deficits in *pre*-attentive processing (i.e., when objects in the visual field are first coded into neural representations). These results are consistent with Hasher's Inhibitory Control Theory, suggesting that MCI patients may be more vulnerable to proactive interference. Taken together, these results suggest that MCI patients' VSTM capacity is not reduced, per se, but that the attentional processing involved in VSTM tasks may be impaired, perhaps due to more susceptibility to interference.

1.4   Retro-cue

VSTM performance can be modified by experimental design. The use of a retroactive cue ("retro-cue") enhances performance in VSTM tasks (Lepsien et al., 2005). A retro-cue involves giving a cue after a to-be remembered display has appeared, but before the appearance of a probe. As such, the cue appears retroactively and directs attention to the to-be probed location, thus reducing interference from other locations which are no longer relevant. Retro-cueing increases VSTM capacity estimates in healthy young adults by as much as 30% (Landman et al., 2003, Lepsien et al., 2005, Vogel et al., 2006, Lepsien and Nobre, 2007, Makovski and Jiang, 2007, Matsukura et al., 2007). Once the retro-cue appears, all irrelevant items can be

eliminated from memory, eliminating any inter-item interference that may be occurring. Thus, a retro-cue should scale with set-size; that is for a set size of one, attention is singularly directed to one item, and there would be no benefit of the retro-cue. For a set-size of 3, a retro-cue eliminates 2/3 items, which would be a large benefit, and this benefit would theoretically increase with each set size.

To our knowledge, no one has examined the use of a retro-cue in MCI patients. Thus, it is unclear whether the deficits MCI patients show in VSTM tasks (Alescio-Lautier et al., 2007, Bublak et al., 2011) would be attenuated, or even ameliorated, by a retro-cue. Recently, Adamo and colleagues found that the use of a retro-cue could bring the VSTM performance of older adults up to the level of young adults, reflecting a VSTM increase of 30% (Adamo et al., 2009). The retro-cue directed attention to a single item to be held in memory, making VSTM more resistant to interference in the older adults.

1.5   Predictions

In the present study, we sought to investigate whether the use of a retro-cue would improve VSTM capacity in MCI patients. Using the same design as Adamo and colleagues, we presented a retro-cue after the memory array was removed, in order to direct attention to the to-be probed location. Additionally we included a simu-cue condition, in which the cue was presented at the same time as the probe display. This served as a control task to get an estimate of baseline performance. In this condition, the cue also directed attention to the probe location but it appeared simultaneously with the probe and thus was not a useful cue to participants. We compared performance on a change detection task using either a retro-cue, where an arrow appeared after the memory array, pointing to the to-be remembered item, or a simu-cue, where the arrow was shown at the same time as the probe display (**Figure 4).**

We predicted that:

1. Both patients and controls would show increased capacity in terms of *K* for retro-cue trials, relative to simu-cue trials. Similarly, both patients and controls would have faster reaction times for retro-cue trails, relative to simu-cue trials.

2. Both patients and controls would show a greater retro-cue benefit after capacity limit had been reached. Additionally, given their increased deficits, we expected that patients would show a larger retro-cue benefit than controls, after capacity limit had been reached.

2 Methods

2.1 Participants

Ten patients with clinically diagnosed MCI participated in this study. These patients were recruited through the Emory Alzheimer's Disease Research Center, Atlanta, GA. All patients had a full neuropsychological work-up and consensus diagnosis from a group of neuropsychologists (see **Section 2.2** for details of neuropsychological battery). Of these ten patients, one was excluded from data analysis for having both a perfect score on the Montreal Cognitive Assessment (Nasreddine et al., 2005), and a score well within the normal range on the Mini Mental Status Exam (Folstein et al., 1975), leading us to believe that he was "worried well" (Ahmed et al., 2008). Additionally, one was excluded for a non-amnestic MCI diagnosis. Some evidence suggests that non-amnestic MCI patients have a different disease progression than those with the amnestic subtype. Additionally, they may be less likely to develop Alzheimer's disease than amnestic patients, but more likely to develop semantic dementia or Lewy body dementia (Petersen, 2004b). On the basis of these criteria, we excluded this patient. Of the remaining eight patients, (four female, mean age= 66.07

(standard deviation = 5.28), mean education = 15.61 (standard deviation = 1.85)), all presented with an amnestic MCI diagnosis, three presented with an additional language impairment, one with amnestic, executive function, and visuospatial impairments, and one with additional executive function and language impairments.

All patients undertook the present study in Dr. Audrey Duarte's laboratory at Georgia Institute of Technology, signed an informed consent form approved by the Georgia Tech Institutional Review Board, and were compensated for their time and travel expenses.

Nineteen neurologically normal volunteers participated as controls for this task (11 female, mean age = 66.07 (standard deviation = 5.28), mean education = 15.61 (standard deviation = 1.85)). Mean age and education did not differ from patients [$t(25)$'s < 0.51, $p's$ > 0.62]. Control participants were recruited through the Adult Volunteer Pool at the University of Toronto and performed the experiment in the Department of Psychology at the University of Toronto. All control participants signed informed consent forms approved by the University of Toronto's Ethics Review Office.

2.2 Neuropsychological Battery

The MCI patients received an annual neuropsychological battery, consisting of the following tests: the Mini-Mental Status Exam (MMSE, Folstein et al., 1975), the Wechsler Memory Scales - Revised I and II (WMS I, WMS II, Wechsler, 1945), the Clinical Dementia Rating (CDR, Morris, 1993), the Wechsler Adult Intelligence Scale - Revised (WAIS-R, Wechsler, 1981), Trail making tests A and B (Reitan and Wolfson, 1985), Judgment of Line Orientation Tasks (JOLO, Benton et al., 1978), Category Fluency: Animals and Vegetables (Drachman and Leavitt, 1972), Digit Symbol, the Boston Naming Test (BNT, Kaplan et al., 1983), Digits Forward, Digits Backward, Clock

Drawing Test (CDT), Global Deterioration Scale (GDS, Reisberg et al., 1982), the Beck

Depression Inventory (BDI, Beck et al., 1961), and a Word List Delayed Recall. **Table 1**

shows these scores for each patient. A group of clinicians from Emory Alzheimer's

Disease Center assessed these scores and reached a consensus diagnosis for the

patients. All patients completed this battery within five months of experimental testing.

Additionally, six patients (MCI 3 – MCI 8, see **Table 1**) were administered the brief

Montreal Cognitive Assessment (MoCA, Nasreddine et al., 2005) immediately after

experimental testing.

2.3   Stimuli and Procedure

Participants were asked to indicate whether a stimulus was the same colour as

the stimulus in the same location displayed previously. As can be seen in **Figure 4**, in

both retro-cue and simu-cue trials, a memory array appeared on screen for 1000 ms.

This memory array contained between one and six coloured circles that were 1.31° in

diameter, and either brown, red, orange, yellow, green, light blue, dark blue, purple, or

pale grey. These stimuli were displayed evenly within an imaginary circle with a

diameter of 5°. Next, a blank delay screen appeared for 1000 ms. In retro-cue trails only

a white arrow appeared in the center of the screen, which directed attention to the to-be

probed location. This arrow was 100% accurate in pointing to the location that would

later be probed. After a 400 ms delay, a probe screen containing only one coloured

circle was displayed. Participants were instructed to report whether the circle was the

same colour as the circle in that exact location in the memory array seen previously.

Thus, for the trial in the left side of **Figure 4,** participants saw a memory array

containing two coloured circles, a delay, a retro-cue pointing to the location which was

previously a yellow circle, a delay, and finally a probe with a green circle. This is an

example of a "different" trial, where the probe colour is different from the memory array

colour. In contrast, for simu-cue trials, immediately after a memory array and delay

period, participants saw a probe trial with both a coloured circle, and a white arrow

pointing to that circle. This is shown on the right side of **Figure 4**. This is also an

example of a "different" trial, as the probe colour is not yellow. For "same" trials, the

probe circle would be the same colour as the circle in that location in the memory array.
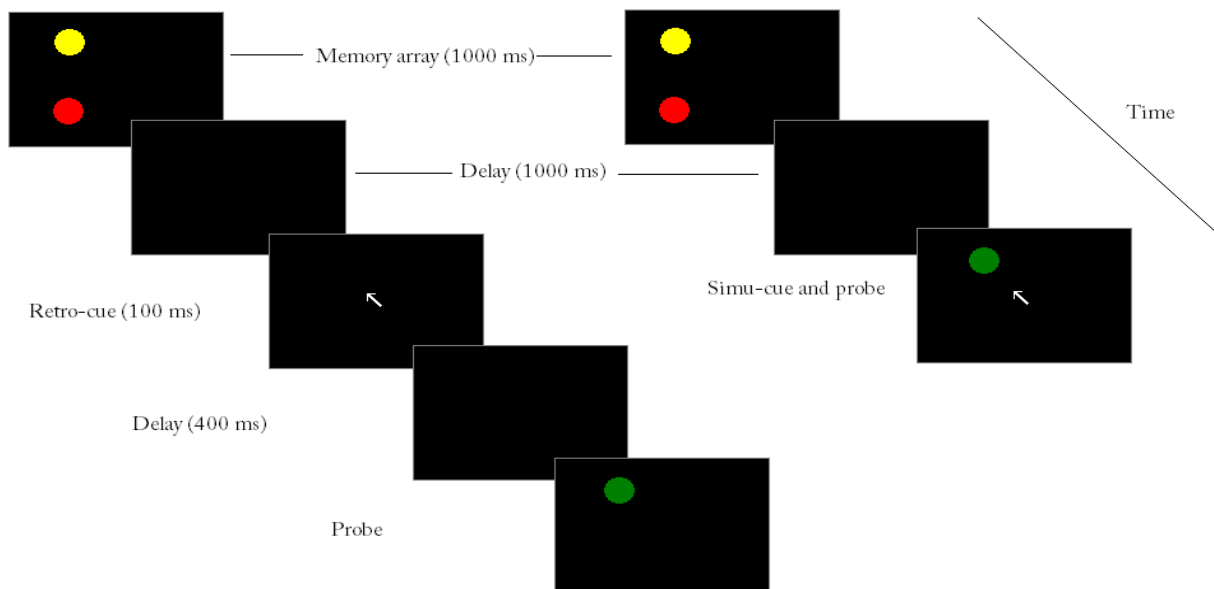
Figure 4. A memory array of 1-6 coloured circles was displayed for 1000 ms,
followed by a blank screen for 1000 ms. In retro-cue trials, an arrow pointing to the
to-be probed location was displayed for 100 ms. Here, the arrow is directing
attention to the location which previously contained a yellow circle. After a 400 ms
delay, the probe was displayed. This trial is an example of a "different" trial,
because the circle in the probed location is green, not yellow. In contrast, in simu-
cue trials, the probe appeared immediately after the first delay period, with an
arrow pointing to the to-be probed location. This trial is also an example of a
different trial, since the circle in the probed location is green, not yellow. In "same"
trials, the probed circle would be the same colour as the location in the memory
array.

The simu-cue trial allowed for an individual baseline performance measure. We examined the differences between this baseline simu-cue measure and the retro-cue. Equal numbers of simu-cue and retro-cue trials were presented for each set size (i.e., 1 through 6), with 50% of the probe circles matching the cued circles (i.e., "same" trials). There were 25 trials for each combination of cue type (i.e., retro-cue or simu-cue), set size (i.e., 1, 2, 3, 4, 5, 6), and response type (i.e., "same" or "different" trials), for a total of 600 trials. These trials were randomly distributed throughout the task. The experiment was divided into 10 blocks of 60 trials each, and participants could take a break between each block of trials.

At the beginning of the experiment, participants were shown a display of all of the possible colours of stimuli to verify that stimuli were perceptually discriminable from one another. No participants reported difficulty in discriminating the colour of the stimuli. Participants were instructed to remember all of the items presented in the memory array, and that the cue would indicate which item would be tested. They were also told that the cue would help them when it appeared before the probe (i.e., for *retro-cue* trials only). Participants were encouraged to respond fairly quickly, but that speed was not as important as accuracy.

2.4 Planned Analyses

To examine our hypotheses presented at the outset, we planned the following analyses. Given our directional predictions, all planned comparisons are one-tailed.

2.4.1 Prediction 1: Retro-cue will improve behavioral performance for both groups in terms of both *K* estimates and reaction times

2.4.1.1 Capacity Benefit for Retro-cue

Our first prediction was that behavioral performance for both groups would be improved by the retro-cue. To examine this we first looked at capacity. Capacity performance was measured with *K* estimates, where *K* = (correct responses for match trials – incorrect responses for non-match trials)$^{set\ size}$ (Pashler, 1988, Cowan, 2001). Separate *K* estimates were computed for each participant, cue type (i.e., retro-cue or simu-cue) and set size (i.e., 1, 2, 3, 4, 5, 6). We hypothesized that both patients and controls would show an increased capacity in retro-cue trails, relative to simu-cue trails. To examine this, we planned to perform a 2 (Patient, Control) x 2 (Retro-cue, Simu-cue) x 6 (Set Size of 1, 2, 3, 4, 5, 6) Repeated Measures ANOVA with a dependent variable of *K*. In this analysis, we predicted a main effect of Cue driven by greater *K* for the retro-cue condition, thus suggesting that the use of a retro-cue can improve capacity for both groups. For completeness, we also report results of all interactions and other main effects.

2.4.1.2 Faster reaction times with Retro-cue Trials

We examined reaction times (RTs) averaged over all correct trials (i.e., hits and correct rejections) for each condition (i.e., retro-cue, simu-cue), and set size separately. Previous studies using the retro-cue paradigm have shown faster RTs for retro-cue conditions (e.g., Lepsien et al., 2005, Makovski and Jiang, 2007, Makovski et al., 2008) and we hypothesized that both patients and controls would also show this effect. To examine this hypothesis, we planned a 2 (Patient, Control) x 2 (Retro-cue, Simu-cue) x 6 (Set Size of 1, 2, 3, 4, 5, 6) Repeated Measures ANOVA with a dependent variable of

RT. As for the analysis above, we predicted a main effect of Cue, indicating a faster retro-cue RT.

2.4.2 Prediction 2: Retro-cue capacity benefit will be larger when capacity has been reached

To measure retro-cue benefit, we calculated a percentage for each participant and set-size, using the following formula: *Percent Benefit* = ((retro-cue – simu-cue)/ (retro-cue + simu-cue) x 100). We predicted that both groups would show a larger retro-cue benefit after VSTM capacity had been reached. Thus we performed a 2 (Patient, Control) x 6 (Set Size of 1, 2, 3, 4, 5, 6) Repeated Measures ANOVA, with a dependent variable of percent benefit. We predicted a main effect of set size, driven by improved performance after capacity had been reached.

Additionally, given their susceptibility to interference, we hypothesized that patients would show a greater benefit from retro-cue trials than healthy controls (Della Sala et al., 2005, Newsome et al., 2011). Thus, we predicted a Set Size x Group interaction, indicating that patients show a greater benefit for retro-cue trials than simu-cue trials. We performed independent t-tests, between groups, using percent benefit at each set size as the dependent variable to follow-up this interaction

3 Results

3.1 Prediction 1: Retro-cue will improve behavioral performance for both groups in terms of both *K* estimates and reaction times

3.1.1.1 Capacity Benefit for Retro-cue

Following our first prediction, we wanted to investigate whether the retro-cue would improve capacity in both patients and controls. **Figure 5** shows mean performance for each trial type and group. As described in **Section 2.4.1**, we performed a 2 (Patient, Control), x 2 (Retro-cue, Simu-cue) x 6 (Set Size, 1, 2, 3, 4, 5, 6) ANOVA

to examine the capacity benefit for both groups. There was also a main effect of Cue [F (1,25) = 39.94, p < 0.001], suggesting that, as predicted, performance was higher for retro-cue trials than simu-cue trials. A main effect of Set Size [F (5,130) = 45.54, p < 0.001] indicated that performance was better for smaller set sizes than higher set sizes. Additionally, there was a trend towards main effect of Group [F (1,26) = 3.16, p = 0.10], with MCI patients performing worse than control participants. There were no interactions with group [F's < 1.32, p's > 0.26]. The ANOVA revealed a Cue x Set Size interaction [F (5,125) = 10.23, p < 0.001] indicating that the benefit of the retro-cue increased as set size increased. Follow-up paired t-tests confirmed that retro-cue performance was higher than simu-cue performance at set sizes 3, 4, 5, and 6 [$t(26)$'s > 4.26, p's < 0.001].
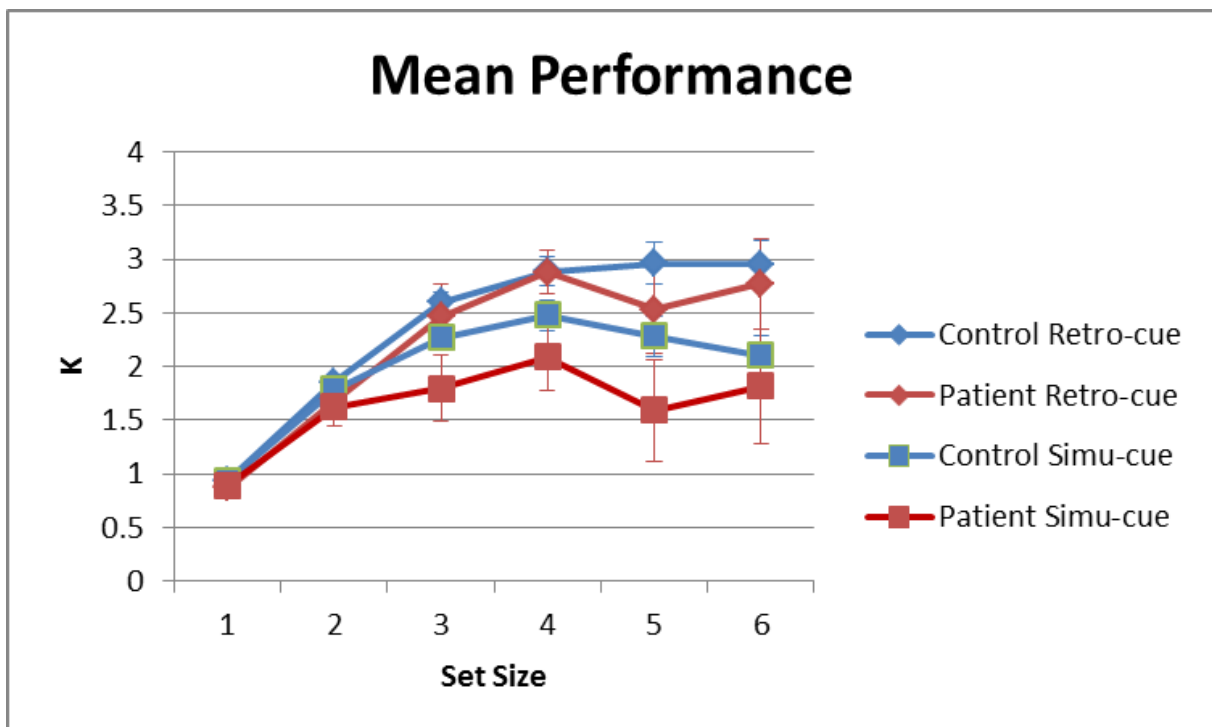
Figure 5. Mean K estimates for retro-cue and simu-cue trials for each set size. Performance increases as a function of set size. Additionally, K is larger for retro-cue than simu-cue trials for both groups.

3.1.1.2   Faster reaction times with Retro-cue Trials

We predicted that both groups would have faster RTs for retro-cue trials (**Figure 6**). To test this prediction, we performed a 2 (Group) x 2 (Cue) x 6 (Set Size) ANOVA, as is described in **Section 2.4.1.** The ANOVA revealed a main effect of Cue [$F(1,25)$ = 141.69, $p < 0.001$], indicating that both groups were faster to respond to retro-cue trials than simu-cue trials. There was an additional main effect of Set Size [$F(5, 125)$ = 41.99, $p < 0.001$], indicating that as set size increased, participants were slower to respond. The ANOVA revealed a Cue x Set Size x Group interaction [$F(5,125)$ = 2.31, $p = 0.03$], and Set Size x Group interactions [$F(5,125)$ = 1.99, $p = 0.05$], suggesting that controls actually show a greater retro-cue RT benefit for higher set sizes. The main effect of Group was not significant [$F(1, 25)$ = 1.41, $p = 0.12$], suggesting that there was no overall difference between patients and controls in terms of reaction time.
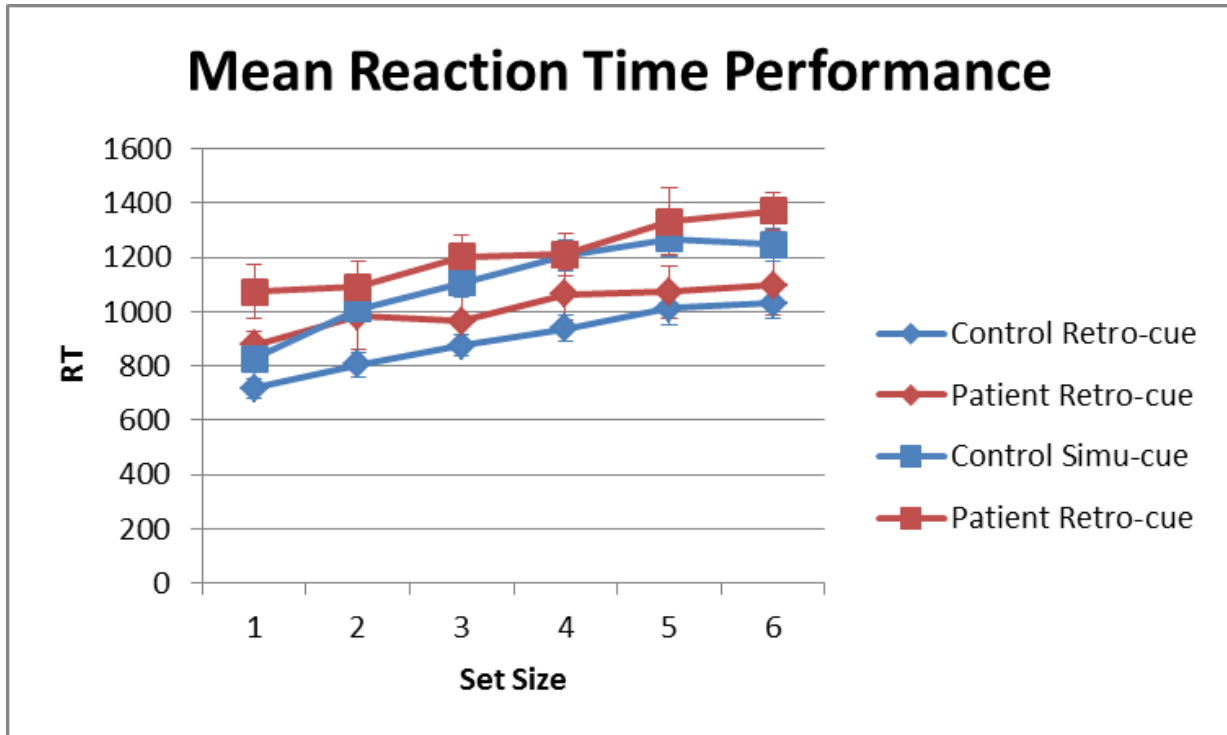
Figure 6. Mean RT for each trial type and set size. Reaction time is faster for retro-cue trials than simu-cue trials. RT increases as a function of set size.

3.1.2 Prediction 2: Retro-cue capacity benefit will be larger when capacity has been reached

We predicted that both groups would show a larger retro-cue benefit after VSTM capacity had been reached. **Figure 7** shows percent benefit performance at each set size. To test this prediction, we performed a 2 (Group) x 6 (Set Size) ANOVA, using percent benefit as the dependent variable, as is described in **Section 2.4.2.1**. The ANOVA revealed a main effect of Set Size [$F(5,125) = 10.85$, $p < 0.001$], indicating that the retro-cue benefit was larger at higher set sizes. There was a main effect of Group [$F(1,25) = 4.60$, $p = 0.04$], suggesting that patients showed a greater retro-cue benefit than controls.

Furthermore, the ANOVA revealed a Set Size x Group interaction [$F(5,125) = 2.19$, $p = 0.05$], suggesting that as set size increased, patients showed a greater benefit for the retro-cue than controls.This independent t-test (described in **Section 2.4.2**) was significant at set sizes 3, 4, and 5 [$t(25)$'s > 2.00, p's < 0.05], and trending towards significance at set size 6 [$t(25) = 1.57$, $p = 0.06$], indicating that the retro-cue benefitted patients more than controls when capacity limit had been reached.
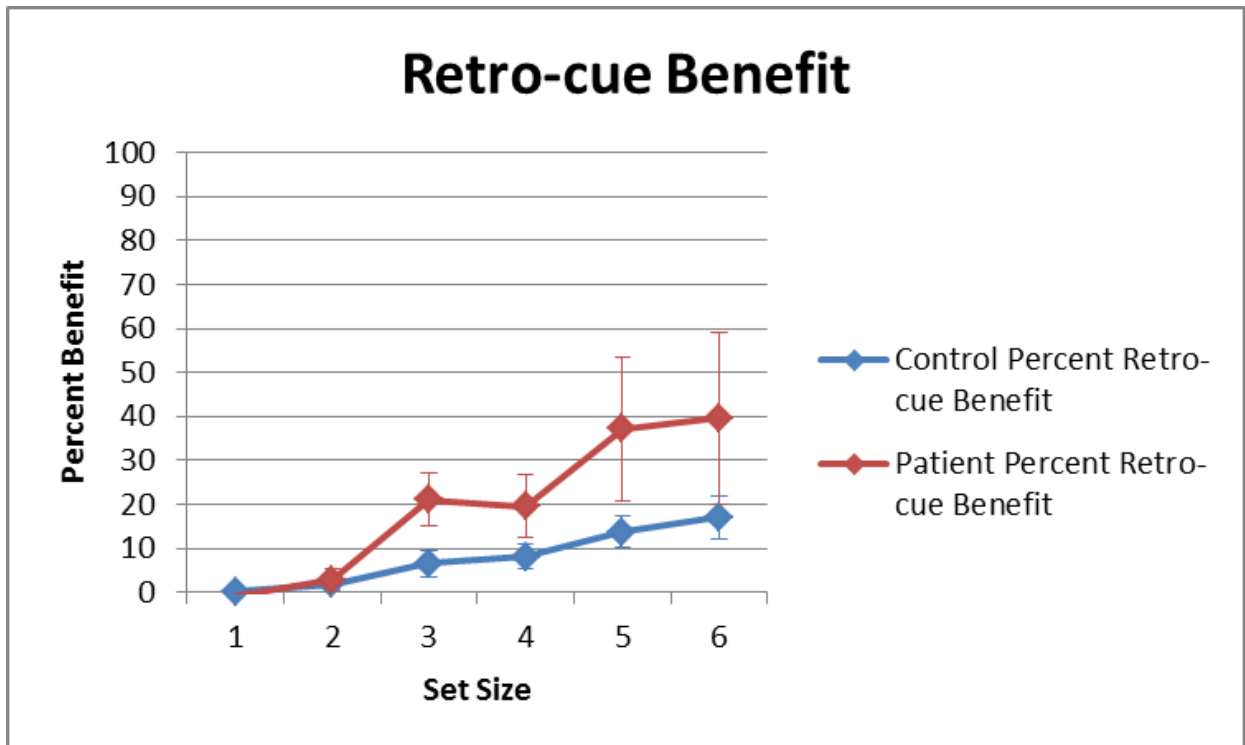
Figure 7. Percent benefit of retro-cue for each set size. Benefit of retro-cue increases with set-size. This benefit was larger for patients than controls at Set Sizes 3, 4, 5 and 6, suggesting that the retro-cue benefitted patients more than controls when capacity limits had been exceeded.

4 Discussion

The ability to mentally represent our visual environment is vital to our everyday lives and VSTM provides us with the cognitive processes to form mental representations of our surroundings. The overall efficiency of this system decreases with age and cognitive impairment. It is important to understand how this process works, and ways in which we can improve the efficiency of VSTM, so that we can find real-world ways to help those with decreased VSTM.

In the present study, we investigated how a retro-cue could enhance VSTM performance in a change-detection task. At the outset, we presented two predictions: 1.

That the retro-cue would increase capacity and decrease reaction times for both patients and controls, and 2. Both groups would show a larger retro-cue capacity benefit when capacity limit had been reached, but this benefit would be larger in patients. Our results supported these two predictions.

Addressing the first prediction, we found that *K* estimates increased for the retro-cue condition, relative to the simu-cue condition, for both groups. Additionally, reaction time data support this claim – both patients and controls were faster to respond accurately to retro-cue trials than simu-cue trials. We examined our second prediction by looking at the percentage of benefit for the retro-cue trials. The results indicated that both groups showed a larger benefit at higher set sizes, when capacity limits had been reached. Moreover, this benefit was much larger for patients at set sizes 3, 4, and 5, indicating that patients had a much larger retro-cue benefit than controls.

4.1 Relationship of Current Results to Theories of Memory

In the introduction, I present two different views of VSTM: the slots view and the resources view. The slots view purports that VSTM contains a small number of fixed-resolution slots, and that objects fill up these slots (e.g., Luck and Vogel, 1997). The resources view proposes that individuals have a fixed number of resources distributed among items in the environment, and that with increasing items, resolution of the mental representation of those items decreases (e.g. Vogel et al., 2001). These theories roughly correspond to two more general theories in working memory, Cowan's Embedded Process Model, and Hasher and Zack's Inhibitory Control Theory. Cowan's model proposes that there are both capacity limits and processing-related limits (Cowan, in press). On the other hand, Hasher and Zack's theory stresses that efficiency

of resources, in particular, the ability to inhibit irrelevant information, is vital to working memory capacity (Hasher and Zacks, 1988).

The slot model of working memory would predict the retro-cue would have no effect on capacity, because regardless of the process used, the number of objects held in VSTM is the same for both retro-cue and simu-cue trials. In contrast, the resources view would predict a retro-cue benefit, as the retro-cue allows the number of resources used to be minimized, such that an individual only has to hold in mind the single item to-be probed. The resources view fits with the Hasher and Zack's theory, that maximizing efficiency of resources benefits capacity.

The current study provides evidence for the resources view of VSTM. This view purports that a fixed number of resources are available to be divided among a number of items. Additionally, this view states that all objects can be stored, but with decreased resolution as the amount of information to be stored increases (Vogel et al., 2001, Alvarez and Cavanagh, 2004). Use of a retro-cue allows storage capacity to increase for both patients and controls, relative to the simu-cue. The retro-cue does not increase the number of "slots" that these individuals has, but allows resources to focus only on relevant information, and to eliminate inter-item interference from stimuli that are no longer relevant. Furthermore, this provides evidence for Cowan's processing-related capacity limits. The VSTM deficits seen in MCI patients can be ameliorated by the retro-cue. The retro-cue provides a processing strategy by which performance can be maximized (Cowan, in press).

This study also provides evidence for the Hasher and Zacks Inhibitory Control View, suggesting that the working memory deficits seen in aging and memory impaired populations may stem from the inability to inhibit irrelevant information. The retro-cue

provides an attentional cue to reduce this interference. Taken together, these results provide evidence that the retro-cue improves VSTM performance by reducing interference. Additionally, it suggests that the deficits seen in MCI patients may not be due to capacity, per se, but that MCI patients may be more susceptible to interference.

4.2   Future Directions

In the present study we investigated the effects of reducing inter-item interference with the use of a retro-cue. Our results provide an example of MCI patients benefitting from a reduction of retroactive interference during a very short delay period, and suggest that VSTM capacity in MCI is affected by interference. However these results do not address how other types of interference common in everyday life (e.g., processing many similar looking faces, juggling multiple task demands, etc.) may augment memory performance in this population. For example, manipulating the kinds of interference during a delay between study and test, or reducing proactive interference may increase performance in MCI patients.

Reducing cognitive interference led to improved recall of a story in MCI patients (Della Sala et al., 2005). In the study, participants either sat in a dark quiet room during the delay between a story and the recall of that story (low interference condition), or performed standard psychometric tests (high interference condition). Additionally, MCI patients benefitted from reduction of perceptual interference in a complex object discrimination task (Newsome et al., 2011). We plan to further examine retroactive cognitive interference by using the same interference delay tasks used by Della Sala et al. in a memory task involving very perceptually similar objects. At study, a list of objects will be shown, and at test, participants will decide whether the studied object (target) or a very similar object (foil) was seen previously (**Figure 8**). Critically, the delay between

study and test will be either ten minutes of standard psychometric tests (*retroactive high interference* condition), or ten minutes sitting in a dark, quiet room (*retroactive low interference* condition). We predict that MCI patients' recognition memory performance will be enhanced for the low interference condition, compared to the high interference condition.
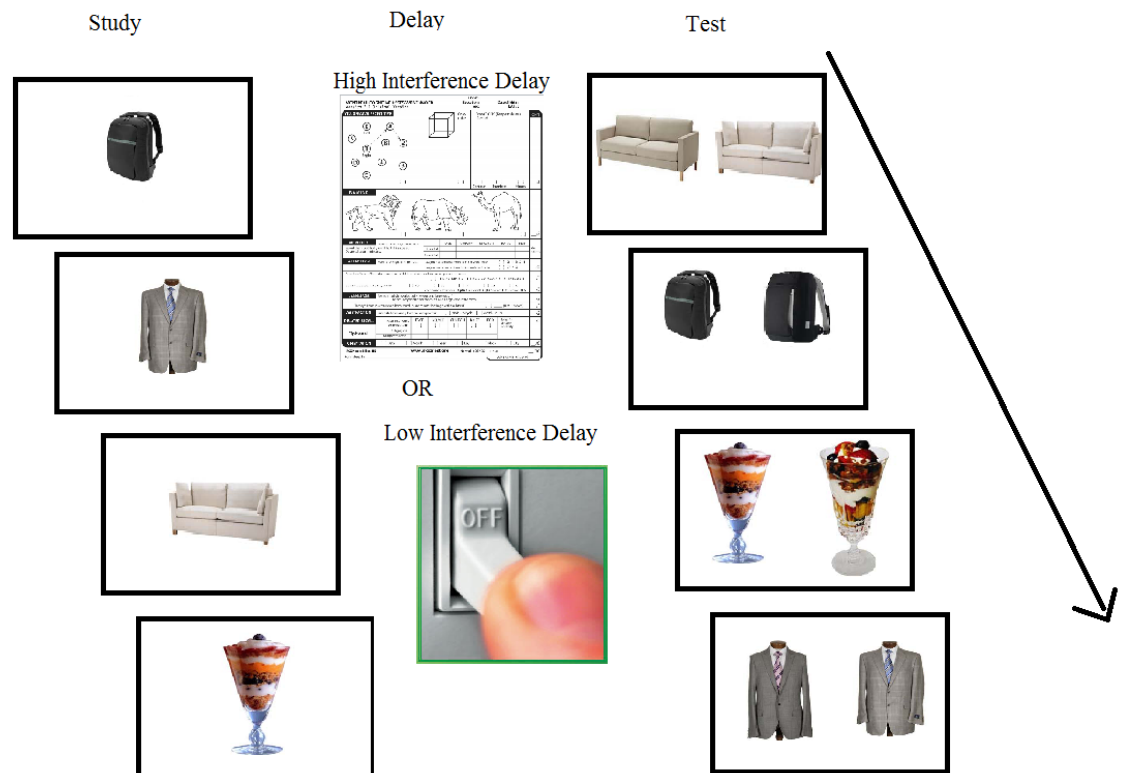
Figure 8. Retroactive perceptual interference task. At study, participants will see a list of objects. Thesewill be incidentally encoded with the question, does this fit in a shoebox? At test, participants will be asked whether the object seen previously is on the left or right. The critical manipulation happens during the delay. In high interference conditions, standard psychometric tests will be administered for 10 minutes. In low interference conditions, participants will sit in a dark, quiet room for 10 minutes.

To examine proactive interference effects, we will explore the same perceptual recognition task as described above, but with a ten minute period of interference immediately prior to study **(Figure 9)**. In the high interference condition, psychometric tests will be administered before the study of a list of objects. In the low interference condition, participants will sit in a dark, quiet room before study. The delay period will consist of a ten minute break, followed by a forced choice recognition test between the target and very perceptually similar foils. We hypothesize that MCI patients' will show a benefit for the low proactive interference condition, as opposed to the high proactive interference condition. Together, these two studies will address whether MCI patients are equally susceptible to proactive or retroactive interference.
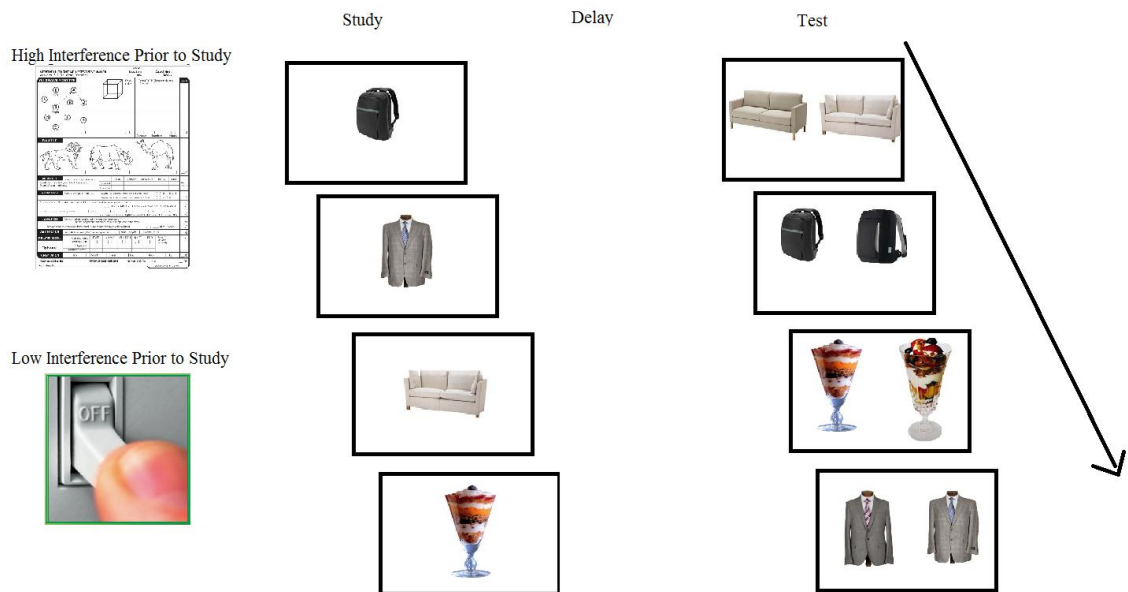
Figure 9. Proactive perceptual interference task. At study, participants will see a list of objects. These will be incidentally encoded with the question, does this fit in a shoebox? After a delay, participants will be asked whether the object seen previously is on the left or right. The critical manipulation happens during before study. In high interference conditions, standard psychometric tests will be administered for 10 minutes. In low interference conditions, participants will sit in a dark, quiet room for 10 minutes.

4.3 Potential Limitations

The concept of MCI has evolved to include multiple domains of cognitive impairment, in addition to memory impairments. Thus, MCI diagnosis usually also has a subtype of amnestic or nonamnestic, single or multiple-domain (Lehrner et al., 2008). In the present study, six of the eight patients presented with multiple-domain MCI. It is important to consider that a group of solely single-domain amnestic MCI patients might have a different pattern of results than our heterogeneous sample. However, in the MCI population, it is exceedingly rare to find single-domain amnestic MCI cases (Lehrner et al., 2008), thus was not possible for our patient selection.

One might argue that the retro-cue is really tapping into iconic memory, and not VSTM. However, this is not the case. Iconic memory, as described in the Introduction, is a brief sensory storage of a visual image. It lasts for less than 1000 ms, lasting for approximately 300-500 ms on average (Lin-Lu et al., 2005), and the retro-cue appears after a 1000 ms delay. Additionally, iconic memory decays even faster for MCI patients, at approximately 70 ms (Lin-Lu et al., 2005). This provides further evidence that the effects we see in the present study are not due to iconic memory, but rather reflect a component of working memory.

4.4 Conclusions

In summary, we provide evidence that MCI patients show a benefit from a retro-cue. The retro-cue enhances memory capacity estimates in both MCI patients and controls, but importantly, the retro-cue brings the MCI patients up to the level of controls in the simu-cue condition. Our results suggest that MCI patients may not have a limited capacity, per se, but are more susceptible to effects of interference.

References

Adamo M, Pun C, Ferber S (2009) Driven from distraction: Attentional selection improves visual short term memory in older adults. Journal of Cognitive Neuroscience Suppl S:149.

Ahmed S, Mitchell J, Arnold R, Dawson K, Nestor P, Hodges J (2008) Memory complaints in mild cognitive impairment, worried well, and semantic dementia patients. . Alzheimer Dis Assoc Disord 22:227-235.

Alescio-Lautier B, Michel B, Herrera C, Elahmadi A, Chambon C, Touzet C, Paban V (2007) Visual and visuospatial short-term memory in mild cognitive impairment and Alzheimer's disease: Role of attention. Neuropsychologia 45:1948-1960.

Alvarez G, Cavanagh P (2004) The capacity of visual short-term memory is set both by information laod and by number of objects. Psychological Science 15:106-111.

Beck A, Ward C, Mendelson M, Mock J, Erbaugh J (1961) An inventory for measuring depression. Arch Gen Psychiatry 4:561-571.

Benton A, Varney N, Hamsher K (1978) Visuospatial judgment. A clinical test. Arch Neurol 35:364-367.

Bublak P, Redel P, Sorg C, Kurz A, Forstl H, Muller H, Schneider W, Finke K (2011) Staged decline of visual processing capacity in mild cognitive impairment and Alzheimer's disease. Neurobiol Aging 7:1219-1230.

Conway A, Cowan N, Bunting M (2001) The cocktail party phenomenon revisited: The importance of working memory capacity. Psychon Bull Rev 8:331-335.

Cowan N (1999) An embedded-processes model of working memory. In: Models of working memory: Mechanisms of active maintenance and executive control(Miyake, A. and Shah, P., eds).

Cowan N (2001) The magical number 4 in short-term memory: A reconsideration of mental storage capacity. Behavioral and Brain Sciences 24:57-185.

Cowan N (in press) The magical mystery four: How is working memory capacity limited, and why? Current Directions in Psychological Science.

Cowan N, Beschin N, Della Sala S (2004) Verbal recall in amnesiacs under conditions of diminished retroactive interference. Brain 127:825-834.

Della Sala S, Cowan N, Beschin N, Perini M (2005) Just lying there, remembering: Improving recall of prose in amnesic patients with mild cognitive impairment by minimising interference. Memory 13:435-440.

Drachman D, Leavitt J (1972) Memory impairment in the aged: Storage versus retrieval deficit. Journal of Experimental Psychology 93:302-308.

Folstein M, Folstein S, McHugh P (1975) "Mini-Mental State": A practical method for grading the cognitive state of patients for the clinician. Journal of Psychiatric Research 12:189-198.

Gopie N, Craik F, Hasher L (2011) A double dissociation of implicit and explicit memory in younger and older adults. Psych Science 22:634-640.

Hamm V, Hasher L (1992) Age and the availability of inferences. Psychology and Aging 7:56-64.

Hasher L, Zacks R (1988) Working memory, comprehension, and aging: A review and new view. In: The psychology of learning and motivation: Advances in research and theory, vol. 22 (Bower, G., ed) New York: Academic Press.

Kane M, Bleckley M, Kathryn M, Conway A, Engle R (2001) A controlled-attention view of working-memory capacity. Journal of Experimental Psychology: General 130:169-183.

Kaplan E, Goodglass H, Weintrab S (1983) The Boston Naming Test. Philadelphia: Lea & Febiger.

Kim S, Hasher L, Zacks R (2007) Aging and a benefit of distractability. Psychonomic Bulletin and Review 14:301-305.

Landman R, Spekreijse H, Lamme V (2003) Large capacity storage of integrated objects before change blindness. Vision Research 43:149-164.

Lehrner J, Maly J, Gleiss A, Auff E, Dal-Bianco P (2008) Neuropsychological performance and mild cognitive impairment subtypes in patietns reporting cognitive problems attending a memory outpatient clinic. European Journal of Geriatrics 10:1-10.

Lepsien J, Griffin I, Devlin J, Nobre A (2005) Directing spatial attention in mental representations: Interactions between attentional orienting and working-memory load. Neuroimage 26:733-743.

Lepsien J, Nobre A (2007) Attentional modulation of object representations in working memory. Cerebral Cortex 17:2072-2083.

Lin-Lu Z, Neuse J, Madigan S, Dosher B (2005) Fast decay of iconic memory in observers with mild cognitive impairments. PNAS 102:1797-1802.

Luck S, Vogel E (1997) The capacity of visual working memory for features and conjunctions. Nature 390:279-281.

Lustig C, Hasher L (2001) Interference. In: Encyclopedia of Aging, vol. 3rd (Maddox, G., ed), pp 553-555 New York: Springer-Verlag.

Lustig C, Hasher L, Zacks R (2007) Inhibitory deficit theory: Recent developments in a "new view". In: The place of inhibition incognition(Gorfein, D. and MacLeod, C., eds) Washington, DC: American Psychological Association.

Makovski T, Jiang Y (2007) Distributing versus focusing attention in visual short-term memory. Psychonomic Bulletin and Review 14:1072-1078.

Makovski T, Sussman R, Jiang Y (2008) Orienting attention in visual working memory reduces interference from memory probes. Journal of Experimental Psychology: Learning, Memory, and Cognition 34:369-380.

Matsukura M, Luck S, Vecera S (2007) Attention effects during visual short-term memory maintenance: Protection or prioritization? Percept Psychophys 69:1422-1434.

Morris J (1993) The Clinical Dementia Rating (CDR): Current version and scoring rules. Neurology 43:2412-2414.

Nasreddine Z, Phillips N, Bedirian V, Charbonneau S, Whitehead V, Collin I, Cummings J, Chertkow H (2005) The Montreal Cognitive Assessment, MoCA: A brief screening tool for mild cognitive impairment. Journal of American Geriatrics Society 53.

Newsome R, Duarte A, Barense M (2011) Perceptual processing impairments in MCI patients are related to perceptual interference Journal of Cognitive Neuroscience S41.

Pashler H (1988) Familiarity and visual change detection. Perception and Psychophysics 44:369-378.

Petersen R (2004a) MCI as a useful clinical concept. Geriatric Times 5.

Petersen R (2004b) Mild cognitive impairment as a diagnostic entity. Journal of Internal Medicine 256:183-194.

Petersen R, Negash S (2008) Mild cognitive impairment: An overview. CNS Spectrums 13:45-53.

Petersen R, Stevens J, Ganguli M, Tangalos E, Cummings J, DeKosky S (2001) Practice parameter: Early detection of dementia: Mild Cognitive Impairment (An evidence-based review). Report of the Quality Standards Subcommittee of the American Academy of Neurology, Neurology 56:1133-1142.

Reisberg B, Ferris S, deLeon M, Crook T (1982) The global deterioration scale for assessment of primary degenerative dementia. Am J Psychiatry 139:1136-1139.

Reitan R, Wolfson D (1985) The Halstead-Reitan Neuropsychological Test Battery: Therapy and clinical assessment. Tucson, AZ: Neuropsychological Press.

Rowe G, Valderrama S, Hasher L, Lenartowicz A (2006) Attentional disregulation: A benefit for implicit memory. Psychology and Aging 21:826-830.

Serences J, Shomstein S, Leber A, Golay X, Egeth H, Yantis S (2005) Coordination of voluntary and stimulus-driven attentional control in human cortex. Psych Science 16:114-122.

Todd J, Marois R (2004) Capacity limit of visual short-term memory in human posterior parietal cortex. Nature 428:751-754.

Vogel E, Woodman G, Luck S (2001) Storage of features, conjunctions, and objects in visual working memory. Journal of Experimental Psychology: Human Perception and Performance 27:92-114.

Vogel E, Woodman G, Luck S (2006) The time course of consolidation in visual working memory. Journal of Experimental Psychology: Human Perception and Performance 32:1436-1451.

Wechsler D (1945) Wechsler memory scale. (Corporation, P., ed) San Antonio, TX.

Wechsler D (1981) Manual for the Wechsler Adult Intelligence Scale - Revised. In: Psychological Corporation New York.

Wood N, Cowan N (1995) The cocktail party phenomenon revisited: How frequent are attention shifts to one's name in an irrelevant auditory channel? J Exp Psychol Learn Mem Cogn 21:255-260.

Xu Y (2002) Encoding color and shape from different parts of an object in visual short-term memory. Perception and Psychophysics 64:1260-1280.

Table 1.

	MCI 1	MCI 2	MCI 3	MCI 4	MCI 5	MCI 6	MCI 7	MCI 8
Demographics								
Age	65	68	61	50	78	64	55	76
Education	14	15	12	21	16	13	18	18
Gender	F	M	F	M	M	F	M	F
Diagnosis	Amn + Lang	Amn	Amn + Lang	Amn + Ex +Vs	Amn + Ex	Amn	Amn + Ex+Lang	Amn+ Lang
Raw Test Scores								
MoCA	-	-	24	27	26	27	26	26
MMSE	24	23	28	30	28	30	30	30
WMS-R IA	15	5	14	16	11	6	9	14
WMS-R IIA	13	4	12	15	10	5	8	13
CDR	0.5	0.5	0.5	0.5	0	0.5	0.5	0.5
WAIS-R	20	-	17	22	19	16	19	-
Trails A	46	34	52	-	48	35	15	27
Trails B	117	171	162	-	102	75	43	53
JOLO	16	-	20	-	22	20	24	-
FAS	23	-	30	53	24	33	47	-
Category Fluency: Animals	19	17	16	28	10	23	34	18
Category Fluency: Vegetables	12	9	15	25	6	15	19	14
WAIS-R Digit Symbol	45	36	66	-	37	54	64	59
Boston Naming Test	25	30	21	-	25	25	25	18
Digits Forward	6	10	7	10	9	9	11	11
Digits Backward	5	6	4	11	3	5	10	9
Clock Drawing Test	11	12	13	5	8	13	13	13
GDS	1	7	2	1	2	1	3	-
Beck Depression Inventory	4	-	1	5	-	2	12	-
Word List Delayed Recall	2	3	5	5	5	6	6	7

Demographics and neuropsychological information for patients.