The Effects of Visual Interference on Older Adults At-Risk for MCI:

Comparing Object and Scene Memory

by

Celia Fidalgo

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

Graduate Department of Psychology

University of Toronto

© Copyright by Celia Fidalgo 2014
The Effects of Visual Interference on Older Adults At-Risk for MCI: Comparing Object and Scene Memory

Celia Fidalgo
Master of Arts
Graduate Department of Psychology
University of Toronto
2014

Persons with early mild cognitive impairment (MCI) show atrophy in brain regions known to process objects, leaving scene processing regions intact. The MTL is believed to prevent irrelevant visual stimuli from intruding upon memory content. The current study examined whether older adults at-risk for MCI show impaired recognition for objects, and whether visual interference consisting of distracting objects would exacerbate this effect. Participants were classified as at-risk for MCI according to the Montreal Cognitive Assessment (MoCA, Nasreddine et al., 2005). Post-hoc tests revealed that the at-risk group performed significantly worse than controls on object recognition following object interference. Additionally, accuracy in this condition was significantly correlated with MoCA scores. There were no group differences for scene recognition. The results support the view that MTL atrophy damages object representations, leading to a vulnerability to visual interference that is especially detrimental to visual memory for objects.
Acknowledgements

I would like to thank Alana Changoor for the time and care she put into this project, and for her contentiousness with data collection. I would like to thank all the members of the Barense and Lee labs, particularly Edward O’Neil, Rachel Newsome and Danielle Douglas for their useful ideas and comments. Thank you to Matthias Niemeier for being a part of my defense committee and lending your expertise to this project. Lastly I would like to thank my advisors, Dr. Morgan Barense and Dr. Andy Lee, without whom this project would not be possible. Their on-going support, encouragement and guidance has helped shape this thesis as well as myself as a researcher.
# Table of Contents

List of Figures ..................................................................................................................5

1 Introduction ..................................................................................................................6
  1.1 Background ...............................................................................................................6
  1.2 Research question & hypotheses ............................................................................16

2 Methods ......................................................................................................................18
  2.1 Participants ............................................................................................................18
  2.2 Experimental tasks ...............................................................................................19

3 Results .......................................................................................................................22
  3.1 Interfering 1-back Task .........................................................................................22
  3.1 Recognition Data ...................................................................................................24
  3.1 Object Recognition ...............................................................................................24
  3.2 Scene Recognition ................................................................................................28

3 Discussion ..................................................................................................................29

5 References .................................................................................................................Error! Bookmark not defined.35
List of Figures

Figure 1: Schematic of connectivity within the medial temporal lobes........................................ 7

Figure 2: Schematic of the representational hierarchical model............................................... 9

Figure 3: Sample stimuli from Newsome, Duarte and Barense, 2012........................................ 12

Figure 4: Sample stimuli from Watson and Lee (2013).............................................................. 15

Figure 5: Sample stimuli from the current experiment ............................................................... 16

Figure 6: Results from 1-back experiment.................................................................................... 23

Figure 7: Memory accuracy results at test for all conditions....................................................... 25

Figure 8: Response time results at test for all conditions............................................................ 26

Figure 9: Scatterplot from correlational analysis of OR and MoCA.......................................... 27

Figure 10: Scatterplot from correlational analysis of SR and MoCA........................................... 29
1 Introduction

1.1 Background

Neurological Profile of Mild Cognitive Impairment

Early on in the progression of Alzheimer’s disease (AD) cognitive facilities are largely intact and it is only minor lapses in memory that give patients a subjective sense of underlying pathology (Chertkow, 2002). Mild cognitive impairment (MCI) is a clinical syndrome thought to represent this early period when dementia pathology (most commonly AD) is just beginning (Nasreddine et al., 2005). A variety of neuropsychological (Petersen et al., 2001; Smith, Gildeh, & Holmes, 2007) and neuroimaging studies (Korf, Wahlund, Visser, & Scheltens, 2004) have demonstrated the predictive power of MCI as a harbinger for AD and on average, the conversion rate from MCI to AD is roughly 50% within five years post-diagnosis (Gauthier et al., 2006).

Both AD and MCI occur due to neural dysfunction in sub-regions of the medial temporal lobe (MTL), a brain region critical for memory (Nyberg, McIntosh, Houle, Nilsson, & Tulving, 1996). These sub-regions show progressively more diffuse patterns of cortical atrophy at various stages of pathology leading to dementia, and in full-blown AD, it is the entirety of the MTL affected by neurofibrillary plaques and tangles (Hyman, Van Hoesen, Damasio, & Barnes, 1984), most notably the hippocampus (HC) and entorhinal cortex (EC) (Jack et al., 1998; Jobst et al., 1994). In contrast, MCI is characterized by more limited pathology, contained within the lateral EC and not yet affecting the HC (Tapiola, et al., 2008). In one demonstrative study, Pennanen and colleagues (2004) collected HC and EC volumes from healthy controls, MCI and AD patients. Both patient groups demonstrated significantly reduced HC and EC volumes compared to controls, however, the most powerful classification between controls and AD
patients, as well as MCI and AD patients, was HC volume, suggesting that HC atrophy was the distinctive marker of AD. In contrast, the most efficient classifier of MCI compared to controls was EC volume, indicative of its atrophy in early disease stages. More specifically implicating lateral EC, Khan and colleagues (2014) examined the EC using cerebral blood volume (CBV) in human subjects and rat models of AD. Healthy older adults were followed longitudinally, and the pre-clinical scans of those who ultimately converted to AD were compared to those who did not convert. It was found that the only significant difference between the pre-clinical AD group and the healthy non-converters was reduced CBV in the lateral EC. To examine the effects of AD over time, three different rat models of AD were used. Again, reduced CBV was found only in lateral EC when compared at disease onset. Moreover, this reduction was exacerbated with age in two of the three AD models, and in the most severe model, pathology showed a significant interaction with age in both lateral EC and adjacent perirhinal cortex (PRC). This study provides strong evidence that pathology originates in lateral EC and suggests that it spreads to PRC over time. For a schematic of connectivity with MTL, see Figure 1.

**Figure 1.** A schematic of connectivity within the medial temporal lobes. The diagram shows perirhinal cortex projecting to lateral entorhinal cortex and parahippocampal cortex projecting to medial entorhinal cortex. Both the medial and lateral entorhinal cortex project to the hippocampus. It is believed AD pathology begins in entorhinal cortex before subsequently spreading to the adjacent hippocampus. Adapted from Simons and Spiers (2003).
The distinction between the lateral EC-PRC impairment in MCI in comparison to the medial EC-HC pathway impaired in AD is of extreme importance, as the lateral and medial EC are functionally, morphologically and physiologically distinct (Khan et al., 2014). Specifically, the cognitive computations carried out by each region in service of memory are thought to differ according to the class of stimuli being processing. It is believed that the lateral EC-PRC pathway is involved in processing objects while the medial EC-HC pathways processes whole scenes. Given these stimuli-specific differences, we should expect a clear pattern of behavioural impairment among individuals at-risk for MCI, in which they exhibit a deficit in remembering objects compared to scenes under specific memory-taxing circumstances. To better understand the circumstances that tax visual memory most heavily, we can look at the brain from the perspective of the representational hierarchical model.

The Representational Hierarchical Model

The representational hierarchical model describes visual processing as follows: In the earliest stages of visual processing, basic features of stimuli are processed by separate brain regions. Elements like shape, colour and texture are processed in distinct posterior brain areas (e.g. shape in lateral occipital cortex, colour in anterior collateral sulcus and lingual gyrus, texture in posterior collateral sulcus; Cavina-Pratesi, Kentridge, Heywood, & Milner, 2010) and become bound together by more anterior regions in a hierarchical fashion (Saksida and Bussey, 2010). A schematic of this hierarchy is shown in Figure 2, where individual features are represented by A, B, C and D. Features bind to form increasingly complex conjunctions as one moves anteriorly along the ventral surface of the brain. When processing objects, the highest level of representational complexity occurs at the PRC, which sends projections to lateral EC to
form an object-processing pathway (Bussey, & Saksida, 2007). One step up, at the highest level of the hierarchy is the HC, where the entirety of a visual scene is represented (ABCD).

Importantly, because the model describes visual processing in terms of representations, it does not make claims about how representations are utilized by the brain. The model acknowledges that stimulus representations can be important for both memory and for perception. The major tenant of the model is that, if the brain regions that support complex representations are compromised, all functions (both memory and perception) that utilize these representations will also be impaired.

**Figure 2.** A schematic of the representational hierarchical model. Single letters A, B, C and D represent individual features of objects, with successively more complex representations occurring as one moves anteriorly along the ventral visual pathway. These representations culminate in the HC, where the most complex conjunctions of scenes are bound together (Bussey, & Saksida, 2007).

To test this model with regards to object processing in the PRC, Barense, Gaffan and Graham (2007) presented amnesic patients with an array of highly similar objects and asked them to pick the odd-object-out (i.e. an oddity task). Patients had either selective bilateral HC damage or more extensive damage to MTL regions, including the PRC. The target “odd” object was highly similar to three foils. Foils were identical to each other and differed only in terms of viewpoint. This task required patients to mentally rotate and compare complex conjunctions of
object features, a task that is extremely difficult without an intact PRC to bind these features together. Results showed that patients with PRC damage were significantly impaired on this task when objects shared a large number of features. In contrast, patients with selective HC lesions performed normally. Without an intact PRC, an oddity task such as this can only be solved when objects differ on the basis of a single feature; a discrimination that posterior brain regions can handle because feature-binding is not needed. Thus, when the same object stimuli differed by simple visual features, eliminating the need for mental rotation and complex object comparison, patients performed normally on the oddity judgment.

The highest level of the representational hierarchy is the HC. This region is responsible for constructing the visual scenery for a given memory episode and provides the scaffolding upon which a memory episode is founded (Maguire & Mullally, 2013). These scene representations, like the PRC for objects, are complex and composed of integrated features. Lee and colleagues (2005) tested the representational hierarchical model with regards to scenes by examining amnesic patients with HC damage. An oddity judgment task was used, requiring again that patients mentally rotate and compare complex conjunctions of scene features (i.e. walls, windows etc.), a task which requires the feature-binding capabilities of the HC. The results showed that patients had difficulty making oddity judgements when highly similar scenes were presented from different viewpoints. Furthering this point, Lee, Levi, Davies, Hodges and Graham (2007) used a target detection task with face, object, colour and scene stimuli. Patients with AD were asked to determine which of two simultaneously presented morphed stimuli, comprised of a previously learned target and foil, most resembled the original target image. AD patients were impaired on this task when scene stimuli were used, but not face stimuli, which are thought to be processed by PRC. Again, because scene stimuli were blended together, this task
could not be solved on the basis of individual features, and required that the scene target held in memory was complex with integrated features.

**The Perirhinal Cortex and Object Interference**

In the healthy brain, the PRC can easily represent a unique conjunction of object features separately from another similar conjunction (e.g. two highly similar coffee mugs). However, if PRC integrity is compromised, highly similar object representations can succumb to interference, a process by which the posterior ventral visual regions become overwhelmed from a build-up of overlapping, highly similar object features. This occurs when one views many similar objects, and happens frequently in daily life: for example, when searching through a dishwasher full of coffee mugs, it can take time and effort to locate the correct one. Posterior brain regions do not have the capability to bind object features together and without an intact PRC to separately represent object conjunctions, there is no way for the brain to represent one highly similar coffee mug distinctly from another (Cowell, Bussey & Saksida, 2010).

This type of visual interference has been shown to negatively impact performance in tasks that require the use of complex object representations. Newsome, Duarte and Barense (2012) examined individuals with MCI in a perceptual discrimination task, a task that had been previously shown in fMRI to recruit PRC, but not HC (Barense et al., 2012). The authors examined three separate populations: older adults diagnosed with MCI, older adults at-risk for MCI and healthy older controls. Subjects were shown two similar objects side-by-side and required to make same-different judgements. Stimuli were highly similar object-like figures, comprised of an outer shape, an inner shape and a fill pattern (See Figure 3). Two separate interference conditions were presented. In high-level interference, many same-different
Figure 3. Sample stimuli from Newsome, Duarte and Barense, 2012. Participants made same-different judgements about two objects appearing side-by-side. The grey object-like figures are highly similar and share overlapping features with each other. When they are interspersed with highly distinct real-world objects, these features will not interfere with each other in posterior brain regions. However, when many same-different judgements are made in a row with these object-like figures, the ventral visual stream becomes overwhelmed without a healthy PRC to resolve feature level interference.

Judgements were made sequentially, using only the highly similar object-like figures described above. This condition should overload posterior brain regions in MCI and at-risk patients due to hypothesized PRC dysfunction in these groups. In the low-level interference condition, the highly similar object-like stimuli were interspersed with real world objects that were highly distinct. Even though the same-different discrimination task was the same, this condition should prevent a myriad of similar low-level features from building up in the visual stream, regardless of PRC integrity. It was found that both MCI and at-risk groups performed significantly worse than the healthy controls on the high-interference condition. However, with low-interference, performance of both MCI and at-risk older adults improved, although the at-risk group continued
to perform below controls. This pattern of results is highly indicative of impaired PRC in MCI and at-risk groups, and their subsequent inability to resolve perceptual interference.

**The Hippocampus and Scene Interference**

It follows from the previous section that if interference can worsen performance on object discrimination tasks, then interference should produce similarly negative effects on scene discriminations. However, there are no studies to date that have explicitly tested the effects of interference on scene discriminations. Despite the lack of evidence, we can infer that interference at the level of scene stimuli (i.e. seeing many similar wall-, ceiling- and floor-configurations that are highly similar) should have a detrimental impact on patients with HC damage when performing discrimination tasks, such as an oddity task, with scene stimuli. In the aforementioned Lee and colleagues (2005) study, in which HC damaged patients made oddity discriminations about highly similar scenes, interference was not directly manipulated (i.e. all patients were exposed to the same number of highly similar scene stimuli). However, patients’ performance on this task can be interpreted in terms of interference. The foils in the oddity array were meant to be highly overlapping, and create overlapping representations of low-level features in posterior brain areas. Thus, the behavioural impairments that HC patients demonstrate on this task can be thought to occur because the foils create visual interference.

**Interference and Memory**

In individuals with MTL dysfunction, visual interference from perceptually similar items impairs memory in the same way that it impairs perception: by overwhelming posterior brain regions with representations of low-level features that are not bound into unique, holistic representations. Without the PRC or HC to support these complex, holistic representations, items
become easily confused with similar looking items. However, few studies to date have specifically tested whether interference from highly similar scenes or objects can impair subsequent memory for scene or objects respectively in humans. McTighe and colleagues (2010) suggested an interference-based interpretation in explaining the results of an object recognition study using rat models. In this study, rats with PRC damage were given 3 minutes to study an object, after which a one hour delay ensued. During the delay, rats were either kept in a holding cage, or else in a quiet, dark room where visual input was kept to a minimum. It was found that, when kept in a holding cage, PRC damaged rats were equally likely to treat both new and old objects as though they were new. However, their recognition performance was rescued when they were kept in a dark, quiet room during the delay. The author’s explained their findings as resulting from interference when rats were kept in their holding cage. In this condition, the rats were exposed to other visual stimuli that shared features in common with both the study and the novel object. Because their PRC was damaged, they could not maintain complex feature conjunctions and had to rely on representations of simple features to make their recognition judgment.

Only one study to date has examined the effects of object and scene interference on subsequent object and scene memory in humans. Watson and Lee (2013) used a novel interference match-to-sample task in fMRI with healthy young adults. Each trial had three phases: a study phase, an interference phase, and a test phase. See Figure 4 for a layout of the design and sample stimuli. At study, participants were asked to remember an image of an object overlaid on a scene. Both the object and the scene were equally important at encoding, as subjects did not know which stimulus type would be tested. During the interference phase, participants completed a 1-back test comprised of seven sequential images. These images
contained a either a changing scene with an object held constant, or vice versa. Lastly, at test, the target image was presented alongside a foil image. Half of the target and foils differed only by their scene and contained identical objects, while the other half differed only by their object and

**Figure 4.** Sample trials from Watson and Lee (2013). All trials had a study phase, an interference phase, and a test phase. Panel A illustrates the object interference-object recognition condition, in which the interference phase comprises a stream of differing objects overlaid on the studied scene, and the test phase comprises the studied object and a foil object overlaid on a studied scene (i.e. following object interference, memory for the studied object is tested). Panel B depicts the scene interference-object recognition, in which the interference phase comprises a stream of the studied object overlaid on differing scenes, and the test phase comprises the studied object and a foil object overlaid on a studied scene (i.e. following scene interference, memory for the studied object is tested). Also included in the experiment were permutations of these, such that object interference could precede scene recognition and scene interference could precede scene recognition. A star indicates the target item during the interfering 1-back task. Stimulus timing for one trial is indicated in Panel C.

contained identical scenes. This created two recognition conditions depending on the differing stimulus at test – scene recognition (SR) and object recognition (OR) respectively. In a 2x2 design, SR was either preceded by object interference (OI), or by scene interference (SI).
Likewise, OR was either preceded by OI or SI. Predictions were two-fold. First, it was predicted that object interference should impair object recognition to the greatest extent, and that this condition should elicit the most PRC activity. Second, it was predicted that scene interference should impair scene recognition to the greatest extent, and that HC activity should be greatest during this condition. These predictions were confirmed for object recognition. PRC activity was greatest in the face of object interference when making object recognition judgements, as compared to object recognition preceded by scene interference. Moreover, HC activation was greater for scene recognition preceded by scene interference than by object interference. Memory accuracy significantly worse in these two highly interfering conditions compared to conditions where interference and recognition type were incongruent (i.e. SIOR and OISR). Thus, Watson and Lee (2013) found evidence in humans that stimulus-specific interference impairs memory, and recruits MTL regions predicted by the representational hierarchical model. However, this study focused on the ability of neurologically healthy young adults to resolve recognition memory interference. One remaining question, therefore, is whether older adults at risk for MCI will show increased susceptibility to interference, and if so, to which class of stimuli will this deficit emerge.

1.2 Research question & hypotheses

In this study, our goal was to investigate the susceptibility of participants at-risk for MCI to differing levels of interference. Specifically, we aimed to test whether at-risk older adults would show greater impairment in an object interference-object recognition (OIOR) condition compared to healthy older adults. Participants were classified as either healthy or at-risk by the Montreal Cognitive Assessment (Nasreddine et al., 2005), a brief neuropsychological measure developed to distinguish healthy controls from those who may be at-risk for MCI. As
recommended by the developers (Nasreddine et al., 2005), we classified those who scored 25/30 or lower on the MoCA as at-risk for MCI, and those who scored 26/30 or above as a healthy control group. We then administered an interference match-to-sample task similar to that of Watson and Lee (2013) with similar study, interference, and test phases. To compensate for reduced cognitive functioning that occurs in healthy aging (Marquis et al., 2002), we included

**Figure 5.** Examples of the Number Interference-Object Recognition (NIOR, Panel A) and Object Interference-Object Recognition (OIOR, Panel B) conditions from the current study. All trials contained a study, interference, and a test phase. At study, participants viewed an object overlaid on a scene. After study, participants were instructed as to which type of stimulus (object, scene, or number) compose the 1-back task. For number interference, participants were instructed as to whether the top three digits or the bottom three digits would vary. As with Watson and Lee (2013), permutations of all three interference types occurred followed by both recognition types. The star indicated the target for the interfering 1-back task. Stimulus timing for one trial is indicated in Panel C.
fewer interfering images to make the task less challenging. We also included a third condition with minimal visual interference, in which numbers served as the interfering stimuli (NI, see Figure 5). This condition served as a baseline for both object and scene recognition memory. Lastly, during interference, instead of keeping the non-interfering element onscreen during interference (see Figure 4 for Watson and Lee, 2013) we presented the interfering element, either object or scene in isolation, such that interfering objects were shown on white backgrounds and scenes were shown without objects in the foreground (see Figure 5). Similar to Watson and Lee (2013), we hypothesized that both the at-risk group and healthy controls would show lowest recognition scores when the type of interfering stimuli matched the type of stimulus to be remembered (i.e. OIOR conditions compared to SIOR or NIOR, and SISR compared to OISR or NISR). Furthermore, we expected a significant difference between groups such that at-risk older adults would have significantly lower recognition scores on the OIOR condition than the healthy control group, due to their hypothesized lateral EC-PRC dysfunction.

We did not expect to see differences between the two groups on any of the scene recognition conditions. Considering that HC integrity is not thought to differ between early MCI patients and healthy controls, scene representations should be intact and subsequent scene recognition should be equal in both groups.

2 Methods

2.1 Participants

Twenty-seven older adults were recruited through the Adult Volunteer Pool at the University of Toronto St. George Campus. Of these, two were excluded due to not completing the experiment, and another was excluded due to suspected substance use during a break. All
participants were administered the MoCA immediately after the experiment. Based on the recommended 26/30 cut-off score (Nasreddine et al., 2005) the 24 remaining participants were divided into either a healthy control group or an at-risk for MCI group. Fourteen were considered healthy controls ($M_{age} = 66.36, SD = 4.83, 9$ females) and $10$ were considered at-risk ($M_{age} = 67.90, SD = 6.71, 2$ females). There were no significant differences in age ($t(22) = .66, p = .52$) or education ($t(22) = .51, p = .62$) between the two groups. All participants were provided informed consent and were compensated for their time. Participants were tested in the Barense laboratory at the University of Toronto. This study was approved by the University of Toronto Ethics Review Board.

The MoCA scores of healthy controls were significantly higher than those of the at-risk group ($t(23) = 7.77, p < 0.001$). The MoCA was always administered after the experimental task, to prevent potential bias from the experimenter when administering the task.

### 2.2 Experimental task

The task was an interference match-to-sample task adapted from Watson and Lee (2013), in which participants were instructed to study a picture of an object superimposed on a scene and subsequently discriminate the studied stimulus from a foil at test. The task was administered on a laptop using Presentation version 17.1 (www.neurobs.com) and participants were seated approximately 20 inches from the screen.

Every trial contained a study, an interference, and a test phase. At study, the object-scene stimulus was presented onscreen for 2800 ms (see Figure 5). Participants were told to remember both the object and scene across a delay period. Following the study phase, an instruction screen
appeared informing participants which type of interference would ensue: either object, scene, or numbers (control condition). Instructions stayed onscreen until a response was made.

During interference, five stimuli appeared sequentially for 590 ms each and were separated by a fixed ISI of 250 ms. One of the five stimuli repeated (1-back task) and participants were asked to identify this repetition by pressing the spacebar. Interfering stimuli consisted of (1) novel, highly similar objects on white backgrounds (OI); (2) novel, highly similar scenes with no object present (SI) (3) randomly changing numbers (NI). Number interference was included as a control, and was designed to be minimally interfering in terms of visual information but contain a similarly cognitively-demanding 1-back task as OI and SI (see Wixted, 2004 for a discussion of cognitive interference effects on memory). During NI two numbers appeared within a grey-outlined box, one in the top left corner and one in the bottom right corner, each three digits long. Participants were told to watch one of the two numbers (either top or bottom) as per on-screen instructions. The number in this target position sequentially varied five times in a row while the non-target number remained constant. The end of the interference phase was marked by a fixed ISI of 1000 ms, which was followed by the test phase.

At test two object-scene stimuli were presented side-by-side on screen. One image was identical to the studied image (target) and the other image (foil) differed from the target by one element: either the object or scene. This differing element was thus the basis for participants’ recognition memory decision. For object recognition (OR), the target and foil contained identical scenes, and thus only the object could be used to cue recognition. Similarly, for scene recognition (SR), the target and foil contained identical objects, and thus, recognition memory decisions relied on identifying the studied scene. Using numbers 1 and 2 on the keyboard,
participants indicated whether the left (1) or right (2) image was the target. The presentation of the target on the left or right side, as well as the position of the 1-back within the interference sequence (i.e., third–fifth position) were pseudo-random (≤ 3 in a row) and fully counterbalanced. The end of the test phase was marked by a fixed ITI of 1000 ms. The three interference conditions (OI, SI, NI) and two recognition types were combined to result in six different trial types: each of OR and SR could be preceded by OI, SI or NI. There were 36 trials for each condition, resulting in a total of 216 trials across the experiment. The presentation order of trials was based on a Latin matrix design, such that no trial type preceded or followed another for an unequal number of times.

To create the stimuli, images of objects were taken from the Hemera Photo Objects database (Volumes I and II), and virtual reality scenes were created using a commercially available game (Dues Ex, Ion Storm L.P) and a freeware software editor (Dues Ex Software Development Kit v.1112f).

A total of 612 objects and 612 scenes were collected. Of these, 216 object and scene pairs were used to create study items and targets at test, and 108 pairs were used as foils at test. To create OI and SI interfering stimuli, 72 sets of 4 (288) of each stimulus type were used. For NI, Presentation software randomly generated two sets of three digit numbers, in Times New Roman, 72 point font. These numbers were presented in an empty white box that was outlined in grey and identical in size to the picture stimuli. One number was placed on the top left corner of the box, and the other was placed on the bottom right. The position of the target number (top or bottom) randomly varied.

All OI and SI interfering stimuli were designed to be as similar to study images as possible. Interfering objects were chosen from the same semantic category and contained
overlapping features, and interfering scenes contained the same features (e.g. walls/floor/ceiling/textures/cavities) as the study image, rearranged to appear distinct.

Participants were given 12 practice trials, two for each of the six conditions, to ensure understanding of the instructions. These were comprised of 36 novel object and scene stimuli. The order of practice trials was randomized.

After the task was administered, participants were given version 1 of the MoCA as per scripted instructions (Nasreddine et al., 2005).

3 Results

For all necessary mixed ANOVAs and independent-sample t-tests, the Greenhouse-Geisser and non-homogeneity assumed correction for non-sphericity and non-homogeneity of variance were applied respectively, as indicated by adjusted degrees of freedom. All participants performed above chance on recognition in all six conditions (accuracy greater than .50, all t(23) > 12.28). Performance on the 1-back task was measured by d’ (Stanislaw & Todorov, 1999) was also above chance (d’ greater than 0, all t(23) > 8.90). See Figures 6 and 7 for graphs.

3.1 Interfering 1-back Task

To begin, a 2x3x2 mixed ANOVA with factors of recognition type (OR and SR), interference type (OI, SI and NI), and MoCA status (passers and failers) was run on d’ scores for the interfering 1-back task. The 3-way interaction was marginally significant, (F(1.97, 43.42) = 2.75, p = .08). To further examine this, a 2x2 mixed ANOVA of MoCA status and recognition type was conducted. This revealed a significant main effect of recognition type (F(1,22) = 10.69, p < .01) and no interaction between MoCA score and recognition type (F(1,22) = .18, p > .05). A 2x3 mixed ANOVA was also run on MoCA status and interference type. A main effect of
interference was revealed \((F(1.50, 33.06) = 8.45, p < .01)\). Lastly, a 2x3 factorial ANOVA was run on interference by recognition type. This revealed a significant 2-way interaction \((F(2,46) = 14.73, p < .001)\). Paired t-tests revealed that, across both MoCA groups, participants had lower d’ scores on SIOR compared to OIOR \(t(23) = 2.66, p < .05\) and NIOR \(t(23) = 2.22, p < .05\). Participants also had lower d’ scores in SISR compared to OISR \(t(23) = 5.22, p < .001\) and NISR \(t(23) = 4.87, p < .001\). Lastly, participants had lower d’ scores for SISR then SIOR \(t(23) = 4.41, p < .001\). There were no other significant differences between any of the remaining conditions \((p’s > .05)\). We can conclude from these analyses that MoCA passers and failers did not differ significantly differences in their d’ scores. However d’ scores were lower among both

---

**Figure 6.** Results for 1-back performance, as measured by d’ scores. There was a significant difference within groups, such that SI was associated with lower d’ scores than OI and NI within both OR and SR. SI also showed lower d’ scores in SR than OR, as shown by the line over-arching SIOR and SISR. See the discussion for interpretation. *p < .05, **p < .01, ***p < .001.
groups during SI conditions in both recognition conditions (OR and SR). Moreover, SISR d’ scores were lower than SIOR d’ scores. See discussion for interpretation of these results. See Figure 6 for these results.

3.2 Recognition Data

To analyze recognition accuracy, all factors were assessed in a mixed 2x3x2 ANOVA, with recognition type (OR and SR), interference type (OI, SI, and NI), and MoCA-status (passers and failers). This analysis revealed a marginally significant 2-way interaction of recognition by MoCA status ($F(1,22) = 3.59, p = .07$) as well as a 2-way interaction between recognition type and interference type ($F(2,44) = 13.20, p < .001$). There was no significant 3-way interaction.

To further inspect these results, a paired t-test of OR accuracy versus SR accuracy collapsed across interference types was run within MoCA passers, revealing that OR recognition accuracy was significantly higher than SR ($t(13) = 3.27, p < .01$). There were no differences between OR than SR when examining MoCA failers ($t(9) = .09, p = .93$). Due to the trending interaction between recognition type and MoCA status, subsequent analyses were conducted on object recognition and scene recognition separately.

3.3 Object Recognition

To investigate the effects of interference on object recognition, a 3x2 mixed ANOVA was run on interference type (OI, SI and NI) and MoCA status. This analysis revealed a main effect of MoCA status ($F(1, 22) = 5.86, p < .05$) such that MoCA failers performed worse on object recognition across all three levels of interference. There was also a main effect of interference ($F(2, 44) = 23.88, p < .001$) such that all groups performed worse for OI compared to both SI ($t(23) = 7.13, p < .001$) and NI ($t(23) = 4.91, p < .001$).
The 2x3 mixed ANOVA examining recognition scores did not reveal a significant interaction between MoCA status and interference type, \((F(2,44) = .44, p > .05)\). An a priori planned t-test between MoCA failers and passers in the OIOR condition showed that failers performed significantly worse than passers \((t(13.00) = 2.78, p < .05)\). MoCA failers also performed worse than passers on SIOR \((t(11.94) = 2.12, p = .056)\). See Figure 7 for recognition memory scores.

![Recognition Memory Scores](image)

**Figure 7.** Recognition memory scores across all six conditions. Significant differences occurred only for object recognition. Between groups, MoCA failers demonstrated worse performance on OI and SI compared to passers. Within groups, accuracy was lowest for OI, compared to both SI and NI.

+ indicates a trend \((p = .056)\), * \(p < .05\), ** \(p < .01\), *** \(p < .001\).

This pattern was also reflected in response times (RT) across both groups. A 3x2 mixed ANOVA on RT showed no differences between groups \((F(1,22) = .06, p > .05)\), but a main effect of interference \((F(2,44) = 13.14, p < .001)\) such that both groups responded slower at test...
OIOR compared to both SIOR ($t(23) = 4.87, p < .001$) and NIOR ($t(23) = 3.56, p < .01$). See Figure 8 for response time data.

![RTs for Recognition at Test](image)

**Figure 8.** RT results at test across all conditions. Participants were, within groups, significantly slower making OI recognition judgments then NI or SI within object recognition. Conversely, within groups, participants were significantly faster making SI recognition judgments then OI or NI within object recognition. 

* $p < .05$, ** $p < .01$, *** $p < .001$

To further investigate how OIOR was related to MoCA status, we examined the relationship between OIOR recognition accuracy and individual MoCA scores. After controlling for age and education, this correlation was significant ($r = .63, p < .01$) suggesting that recognition accuracy in this condition was related to MoCA scores. Further analyses demonstrated that SIOR was also correlated with MoCA scores, after controlling for age and education ($r = .44, p < .05$), whereas NI did not ($r = .38, p > .05$). Because performance on the OIOR and SIOR conditions were also correlated with each other when accounting for age and education ($r = .87, p < .001$), their correlations to MoCA scores are not independent. We took this dependence into account when testing which measure was more significantly correlated with
MoCA scores by using the Steiger’s t-test (devised by Williams, 1959 and endorsed by Steiger, 1980). This revealed a significant difference between the SI and OI correlations to MoCA scores, such that the correlation between MoCA scores and OI was more significant ($t(21) = 18.02, p < .001$). See Figure 9 for a scatterplot of all three OR conditions and their correlation to MoCA scores.

**Figure 9.** Scatterplots of the residuals for OIOR, SIOR, and NIOR accuracy scores plotted against residuals for individual MoCA scores. Age and education have been regression out. The Pearson’s product coefficient was calculated for each (OIOR, $r = .63, p < .01$; SIOR, $r = .44, p < .05$, NIOR, $r = .38, p > .05$).
3.4 Scene Recognition

To analyze the effects of interference on scene recognition, a 2x3 mixed ANOVA analyzed interference type between groups, within scene recognition. This analysis revealed no significant main difference between groups ($F(1,22) = .45, p > .05$) with a trend towards an effect of interference ($F(2,44) = 2.68, p = .07$). There were also no significant interactions. A 3x2 mixed ANOVA on RT showed no differences between groups ($F(1,22) = .01, p > .05$). However, there was a main effect of interference ($F(2,44) = 3.49, p < .05$) such that both groups responded faster at test for SI compared to both OI ($t(23) = 2.46, p < .05$) and NI ($t(23) = 2.19, p < .05$), despite comparable accuracy across all three conditions. Correlational analyses with age and education controlled revealed no significant relationships between any of the scene recognition conditions and MoCA score (all $r$’s < .40, $p > .05$). See Figure 10 for the correlation scatterplots of SISR, OISR and NISR to MoCA scores.

Because scene stimuli were all virtual and relatively overlapping with each other (all were indoor scenes with similar features: windows, stairs, walls etc.) it was possible that scene interference built up incidentally across trials, simply due to exposure to many similar scene stimuli across trials. This hypothesis was examined in a mixed 2x3 ANOVA for group by interference type, examining only the first 72 trials of the experiment. This cut-off comprised one-third of the experiment and contained an equal number of SI, OI and NI scene recognition trials. This analysis revealed no differences among the three interference types ($F(2,44) = .32, p < .05$) and no group differences ($F(1,22) = 1.24, p > .05$) suggesting that a build-up of scene interference across trials did not explain the lack of interference effects across scene recognition trials.
The main goal of this study was to investigate how mnemonic interference differentially impacts older adults at-risk for MCI compared to their healthy counterparts. A few patterns in the data are noteworthy. Firstly, the results demonstrate impaired object recognition in older adults at-risk for MCI compared to healthy controls. This finding is in line with the hypothesis that at-risk adults may have lateral EC and PRC dysfunction, thus impairing their representations of

**Figure 10.** Scatterplots of the residuals for OISR, SISR, and NISR accuracy scores plotted against residuals for individual MoCA scores. Age and education have been regression out. The Pearson’s product coefficient was calculated for each (OISR, $r = .40, p > .05$; SISR, $r = .03, p > .05$, NISR, $r = .06, p > .05$).

4 Discussion

The main goal of this study was to investigate how mnemonic interference differentially impacts older adults at-risk for MCI compared to their healthy counterparts. A few patterns in the data are noteworthy. Firstly, the results demonstrate impaired object recognition in older adults at-risk for MCI compared to healthy controls. This finding is in line with the hypothesis that at-risk adults may have lateral EC and PRC dysfunction, thus impairing their representations of
complex objects. There is also some evidence to suggest that object recognition for at-risk adults was impaired to a greater extent by object interference (OI) than by a no interference baseline (NI) or by scene interference (SI). Because the 3-way interaction (MoCA status by interference type by recognition type) was not significant, this evidence can be gleaned from the correlation between OIOR and MoCA scores. Although SIOR and OIOR were both significantly correlated to MoCA scores, Steiger’s t-test showed that OIOR was more significantly correlated with MoCA scores than SIOR, even when controlling for age and education.

Thus, as predicted, this study revealed a marked impact of object interference on object recognition, both within and between groups. Within-group effects were expected due to object-specific interference having a greater negative impact on object recognition than scene interference or viewing numbers. This should occur for both at-risk and healthy older adults due to a build-up of low-level object features in posterior regions of the brain. Even with an intact PRC, confusion arises when a delay period is filled with similar-looking objects after encoding a study object. The between-group effects were hypothesized due to potential dysfunction in the at-risk group in areas of the brain known to represent complex conjunctions of objects (lateral EC and PRC) versus controls with a presumably intact PRC. This pattern of results can be contrasted with the complete absence of interference or group effects on scene recognition. Although the lack of interference effects was unexpected, the lack of group differences suggests that MoCA failers have intact scene processing compared to controls, as was predicted. This finding supports the claim that at-risk older adults do not have impairments in their scene processing capabilities.

The pattern of results obtained for object recognition suggests that persons at-risk for MCI have may have difficulties processing and maintaining complex representations of objects,
while preserving the ability to process complex scenes. There is converging evidence that the lateral ER and PRC are critical in processing object representations (Barense et al., 2012) and that these regions are compromised in early stage MCI (Khan et al., 2014). Thus, it is conceivable that early changes in this pathway play a major role in the object recognition deficits observed in the at-risk group. This interpretation is derived from both the group differences in object recognition following object interference, as well as the significant correlation between this condition and MoCA scores. This finding further supports the representational hierarchical model (Bussey, & Saksida, 2007), which suggests that the lateral EC and PRC are especially important for resolving interference by maintaining complex object representations.

There was a trend for group differences in the SIOR condition. Although the correlation between SIOR and MoCA scores was significant, the SIOR condition did not account for any additional variance in MoCA scores that was not already accounted for by the OI condition. While it may be possible that scene interference presented visual features that were similar to that of the study object (i.e. similar colours or shapes were present in the scenes and in the study object) which caused interference, this interpretation seems unlikely considering NIOR performance was not significantly higher than SIOR performance in failers, even though this group showed a significant difference in performance between OIOR and NIOR. Alternatively, we can simply interpret this to mean that interference can account for some, but not all differences in performance between these groups.

This study is joined by others that have implicated impaired object processing in those at-risk for MCI (Newsome, Duarte & Barense, 2012; Barbeau et al., 2004). However, this study is the first to examine the effects of interference on object recognition memory. Moreover, it is the first to find that object recognition performance, when preceded by object interference, is
significantly correlated with MoCA scores, independent of age and education. This has implications for the type of pre-clinical evaluations that may be most sensitive to MCI pathology. Specifically, memory tests that use visual stimuli, as opposed to commonly used verbal memory tests, may be more sensitive to lateral EC and PRC decline.

One unpredicted result occurred for d’ scores during the 1-back task. It was also found that 1-back performance on the SISR was significantly worse than 1-back performance for SIOR for both the at-risk group and controls. This was unexpected, as during the interference phase subjects are completely unaware which recognition type will be probed. Thus, lower performance on SISR compared to SIOR occurred completely by chance. Although 1-back performance during SI was above chance in both conditions, there remains the possibility that subjects did not pay as close attention to the interference phase during SISR as they did during SIOR, which could play a part in explaining why SI did not differentially impact scene recognition as was expected.

A second anomalous result in the current data was the complete lack of interference effects at the level of scene recognition. There are a few plausible explanations for why this may have occurred. One explanation comes from the nature of the virtual scene stimuli, which did not contain the rich, naturalist variation that real world scenes do, and also lacked semantic relevance. Healthy young adults showed scene interference effects (Watson & Lee, 2013) however, previous studies have suggested that older adults benefit from encoding scenes with high complexity and semantic relevance (Smith, Park, Cherry, & Berkovskiy, 1990). Thus, this suggests that older adults were not able to optimally encode the scenes to begin with, compared to their younger counterparts. To this end, real-world scenes could have been used instead of
virtual scenes. These may have boosted relevance of the stimuli to older adults who are not as familiar with virtual scenes as young adults are, and allowed for more stimulus-complexity.

**Future directions**

The present study provides an initial behavioural examination of the relationship between visual interference and object/scene recognition, although there are some questions left for debate. Virtual scenes were used in the current study to enable control of scene-features (i.e. number of walls, windows, ceilings etc.) across interference. However, this meant that the object stimuli used in this study contained more variability across the interference phase than the scenes. It is possible that exposure to a greater number of varying features during interference may impact memory more than exposure to a limited set of features, even if those features are highly controlled such that they are all similar to the study item. To test this hypothesis for scene recognition, a future study will use the same paradigm described here in older adults using real world scenes in the place of virtual scenes. The natural variation that occurs between scenes in nature may introduce more feature-level “noise” in the interference phase, and result in lower recognition for scenes in this condition, but not for objects.

Future work will also adapt the present study to examine the effects of the prefrontal cortex in resolving interference. It is known that the frontal cortex is involved in cognitive control, such as inhibition and selective retrieval (Shimamura & Jurica, 1994; Smith & Jonides, 1999; Stuss, et al., 1982). Thus it is hypothesized that, while the PRC and HC resolve interference at the level of classes of visual stimuli (Watson & Lee, 2013) frontal lobe structures such as the ventrolateral prefrontal cortex (VLPFC) may resolve interference across a broad range of stimuli. Solesio et al. (2009) detected increased activity in MTL and left VLPFC using magnetoencephalography (MEG) in healthy older adults, using retroactive interference for letter
strings. Preliminary results from O’Neil, Watson, Dhillon, Lobaugh and Lee (In prep) show that VLPFC was recruited for both object-and scene-based interference in service of both object and scene memory. Thus, VLPFC appears to be involved in resolving perceptual interference in general at retrieval, regardless of stimulus category. Future research will examine the timeframe at which the VLPFC operates to resolve interference across stimulus categories using electroencephalography (EEG).

In conclusion, the current results contribute to the literature on recognition memory impairments in individuals at-risk for MCI. The data are consistent with the representational hierarchical account, which characterizes the HC and PRC as end points on a hierarchy, each representing distinct classes of visual stimuli at their most complex level. Finally, our results suggest that impairments in persons at-risk for MCI occur not just at the level of memory-processes, but more importantly, at the level of the type of visual stimuli they are viewing, and the extent to which similar stimuli have interfered with that representation (Cowell, Bussey & Saksida, 2010).
References


doi:http://dx.doi.org/10.1037/a0033650


