This is to certify that the
dissertation entitled

AGE DIFFERENCES IN VISUAL MEMORY AND THE RELATION TO EYE MOVEMENTS AND EXECUTIVE CONTROL PROCESSES IN VISUAL SEARCH

presented by

Carrick C. Williams

has been accepted towards fulfillment
of the requirements for the

Ph.D. degree in Psychology

Major Professor's Signature

8/13/03

Date

PLACE IN RETURN BOX to remove this checkout from your record.
TO AVOID FINES return on or before date due.
MAY BE RECALLED with earlier due date if requested.

DATE DUE	DATE DUE	DATE DUE

AGE DIFFERENCES IN VISUAL MEMORY AND THE RELATION TO EYE MOVEMENTS AND EXECUTIVE CONTROL PROCESSES IN VISUAL SEARCH

By

Carrick C. Williams

A DISSERTATION

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

DOCTOR OF PHILOSOPHY

Department of Psychology

2003

ABSTRACT

AGE DIFFERENCES IN VISUAL MEMORY AND THE RELATION TO EYE MOVEMENTS AND EXECUTIVE CONTROL PROCESSES IN VISUAL SEARCH

By

Carrick C. Williams

The current study examined executive control processes in visual search and their consequences for visual memory of the searched objects. Younger and older adults counted the number of targets (identified by a color and category, e.g., yellow car) present in an array containing 12 real-world objects. In addition to the targets, the array contained distractors that had differing relationships to the search target: color distractors, category distractors, and unrelated distractors (objects that were neither the same category nor color as the search target). Executive processes were expected to allocate attention differently to the various classes of objects, leading to varying levels of memory for the different types of distractors. Participants' memory was tested using a surprise token discrimination task after a 10 minute filled interval. Memory for targets was reliably better than for distractors. Of most interest for this study, however, was memory for the distractor items. Color and category distractors were discriminated from foils at similar levels and both were discriminated reliably better than the unrelated distractors. Additionally, younger adults remembered the targets better than older adults, but memory for the distractors was equivalent for the two age groups. Experiment 2 also examined the eye movements that were made during the search task. These measures indicated that viewing

behavior during search was related to the memory that was maintained for the objects. There was an additional advantage for target objects with targets being remembered better than distractors regardless of the number of times they were looked at or how long they were looked at. Older and younger adults were very similar in their viewing behavior.

ACKNOWLEDGEMENTS

There have been many people that have assisted me throughout my time at Michigan State University. First and foremost, I would like to thank Rose Zacks, who has supported me throughout my time here. She has taught me how to be a better researcher and writer and how to think like a researcher. I will always be indebted to her for her constant support. I would also like to thank John Henderson who allowed me to be a part of his eye movement laboratory and encouraged me to pursue this line of research. I would not have been able to get to this point without his help. I would also like to thank the members of my dissertation committee, Tom Carr and Zach Hambrick for challenging me and requiring me to think more deeply about the issues.

There have been many people who have walked in the halls of the Psychology Research Building that have helped me in many ways. The members of the Cognitive Aging Lab and the Eyelab contributed to this work to this in a variety of ways. I would especially like to thank Karin Butler, Doug Davidson, Kate Arrington, Richard Falk, and David Thomas. Each of these people has contributed in a variety of ways to my development as a researcher and a person. I also want to thank Sarah Burnett, Janna Whittenberg, and Katie Paquette for there assistance in running subjects and finding the hundreds of pictures that were the stimuli for these experiments. Additionally, I need to thank Gary Schrock and Andrew Hollingworth for their technical help with the eye tracker. Experiment 2 would not have happened without them.

There are two women who need special thanks. The first is my wife, best friend, and copy-editor, Camilla. Her love is never-ending and helped get me through the trials that accompany graduate school. I hope that I can support her the way that she has supported me. Secondly, I would like to thank Kathleen for listening and helping me understand how it all fits together. Without these women, I would not have made it this far.

Finally, I want to thank my parents and my sister. As the son of two educators, school has always had an important role in my life. I believe that it was their emphasis on education that helped me to decide to pursue this career.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

When looking for a specific book (e.g. a red book) that is in a less than perfectly organized office, one is likely to encounter books that are not the same color, things that are the same color but are not books, and things that are neither books nor the same color. To find a red book in the office, one needs to ignore the distracting objects in the environment and focus on the combination of features that define the target book. The current project was interested in the memory for objects that had been searched earlier, both as targets and distractors. The different objects (i.e., the targets of visual search and the distractors) in the search for the red book are expected to receive differential processing based on their relationship to the search target. It seems reasonable to predict that the relationship of an object to the search target should influence the type of processing that is involved. If a person is looking for a red book, he or she is more likely to glance at a red coffee cup or a blue book (because they share at least one characteristic that defines the target of the search) than a yellow pencil (an object that does not share any characteristic of the search target). This sort of difference in processing could influence the memory that remains for the different objects that were encountered. Additionally, the person would have an advantage if he or she avoided, quickly stopped processing, or quickly forgot the distractor objects so that the search proceeds efficiently. The process of rejecting distractors also most likely affects the memory that remains for the objects that were searched.

The current study examined the role of executive control processes in the selection of target objects in the environment as well as in the ignoring of distractors and the consequences of the search behaviors on visual memory. Specifically, a search paradigm involving displays of 12 pictures of real-world objects was used to investigate how and how much people process different types of objects in the environment and what they remember. When looking through an array of objects, the choice of what to look for segregates the environment into 3 main classes: the object being sought (the target), objects related to the thing being sought (related distractor objects), and objects unrelated to what is being sought (unrelated distractor objects). The experiments described here investigated the effect on memory of the differential processing that executive control processes apply to these different classes of objects. One specific executive control process investigated here is inhibition. Inhibition could play a role by halting the processing of objects that are not the targets of the search. On the assumption of age-related differences in inhibitory control (Hasher & Zacks, 1988), the current study included comparisons of younger and older adults as one means for elucidating the role of inhibitory processing in visual search.

The current project also addressed a topic of debate in the visual processing literature: the extent to which people can remember the visual details of objects once they are out of view. There has been convincing evidence from transsaccadic studies that people do not build up a veridical representation of the visual environment (e.g. Irwin, Zacks, & Brown, 1990; Irwin & Zelinsky, 2002).

Some recent theories have gone so far as to claim that no visual information is maintained (see below). This claim has been questioned by a more moderate stance that claims that although a veridical picture is not stored, some visual details are maintained. The current study sought additional evidence to address whether visual details are maintained for a period of time after attention has been withdrawn from an object. To examine visual memory, the current project used a visual search task in which every object presented was a unique token. The memory test required participants to discriminate between a previously viewed object token and a nonpresented object token of the same type and color. The only information that could be used to distinguish the tokens was the visual details of the tokens because the semantic information was identical. By using unique tokens, the visual memory for individual targets and distractors from the previous search could be evaluated. If memory were maintained for either or both of these types of items, this would argue against the memoryless models of visual perception. Additionally, because the different objects in the search task were more or less likely to be processed, the current project examined the effect of variations in processing on likelihood of visual memory.

Finally, this study examined the eye movements that occur while looking through an object array for a specified target. The eye movement record indicated the probability that an object was looked at, how long different objects were looked at, and whether they were looked at multiple times. These measures could be informative with regard to the two issues that have been discussed thus far, executive processing in search and visual memory.

The following sections divide different aspects of this dissertation into the two main components: visual search and visual memory. For the visual search component, I provide a brief review of the main points in the literature and then examine the executive processes that can affect the processing of the objects in the search, with a special emphasis on inhibition. The visual memory component focuses on the memory that may or may not be maintained after visual processing.

Visual Search

The office description above is an example of a visual search task and demonstrates some complexities that exist when one is looking for a target in a complex environment. Visual search has been extensively studied in cognitive psychology. However, the search tasks are usually much simpler than the office example described above. There are two types of search that are typically studied: feature search and conjunction search. In both types of search tasks, the participant typically searches the display for the presence or absence of a specified target (e.g. Treisman & Gelade, 1980; Treisman & Sato, 1990; Wolfe, Cave, & Franzel, 1989). In a feature search, the target is defined by a feature that the distractor objects lack (e.g. a red T in a field of green Ts). In this case, the target seems to "pop-out" and search proceeds at approximately the same rate regardless of the number of distractor items that are present (Treisman & Gelade, 1980). A conjunction search, on the other hand, defines the target item by the conjunction of two features (usually a shape and color such as red T) within a field of distractor items that each contains one of the target features, but not both (e.g. a field of red Os and green Ts). This search task is difficult and requires that participants search through the items in the display individually. This is a much less efficient search than the feature search, and the more items there are in the array, the more difficult the search task is, as indicated by increased RTs and errors (Treisman & Gelade, 1980; see Wolfe, 1998 for a review).

One of the first comprehensive theories of the processes involved in visual search, Feature Integration Theory, was provided by Treisman and colleagues. Treisman and Gelade (1980) claimed that feature search involves a parallel search process that can examine the entire display and detect the presence of a target feature. This type of search is very rapid and efficient (e.g. under 10 ms/item in the display). On the other hand, according to these authors, conjunction search is a serial, attention-dependent process that requires the viewer to examine, on average, half of the items in the display to find a present target. In Feature Integration, attention is required during a conjunction search to bind the various features (e.g., color and identity; red T) of an item together. A decision about whether or not the item is a target can only proceed after the all of the features that define the item have been bound together. Because the distractors in a conjunction search contain one of the target features, the distractors are likely to receive some activation from the feature it shares with the target, consequently drawing the searcher to them. The serial conjunction search is considerably slower than the feature search and the search time is directly proportional to the number of item in the display (i.e., the search slopes are positive and significantly greater than 0).

Although Treisman and Gelade's (1980) theory provided a basic description of the processes of visual search, there have been demonstrations of search phenomena that do not conform to their theory. Researchers have demonstrated instances of conjunction searches that have shallower search slopes than would be expected (e.g. Treisman & Sato, 1990; Wolfe, et al, 1989). These shallower search slopes are claimed to be the result of the participant's ability to segregate the search display using one of the features that define the target. Wolfe et al. (1989; Wolfe, 1994) describe this as a *guided search*, which allows the participant to perform an efficient search even in a conjunction search task. That is, given that participants are able to limit a search to a subset of the displayed items (e.g. only the red items in a display of red Xs and green Os in which the target was a red O), they are able to perform a feature search for the target.

Much has been learned about the processes involved in search using the techniques described above, but these searches differ from real world searches in several ways with regard to the types of stimuli that are present. In the typical experimental search task, the participant is looking through a rather homogenous set of items (e.g., letters on a blank background). Search arrays typically contain multiple instances of a small set the distractor items (e.g., several red Xs and green Os) repeated on all trials. These items tend to be impoverished in complexity and detail compared to real world objects limiting the extension of the research to more complex real world scenes. In scenes, objects vary on many features (shades of color, orientation, etc.), which could influence the ability of the searcher to find the target object.

The current study took an intermediate step between scenes and typical search tasks by using pictures of real-world objects in a conjunction search task. The objects in the search arrays were targets, distractors that were related to the search target (by either being from the same category or having the same color as the target), and objects that were unrelated to search target. Unlike most research on conjunction search, the targets and distractors were single instances of the particular object (rather than multiple instances of a small set of distractors). A particular instance of an object (an object token) occurred in only one array in the search portion of the experiment. With each object being presented in only one array, the memory for the different objects within each classification in the search space can be examined.

Executive Control and Visual Search

The application of attention to the items within the search space appears to play a critical role in visual search (e.g. Treisman & Gelade, 1980; Treisman, 1998; Wolfe, 1998). While some processing appears not to require the direct application of attention (see Treisman, 1998 and Wolfe, 1998 for a discussion of preattentive processing), there is evidence that more complex searches, like the ones described in this project, require attention to be focused on the various items in the search in order to locate the items (e.g. Shih & Sperling, 1996), conjoin the features of an item (e.g. Treisman, 1988; Treisman & Gelade, 1980), or, more generally, for further processing (e.g. Wolfe, 1994; Wolfe, Oliva, Horowitz, Butcher, & Bompas, 2002).

Because the search task in the current experiment contained objects that differed in their relationship to the searched-for object, the allocation of attention was expected to be unequal for the different classes of objects. The concept of guided search (Wolfe, 1994; Wolfe et al. 1989) indicates that attention is not evenly spread throughout the search display. The guided search notion implies that attention is guided to objects that are likely to be the target rather than in a random fashion.

The selection of which objects to attend to in a visual search task can be influenced by a variety of processes that may bias selection toward some objects and away from others. In this dissertation, I refer to processes that control the deployment of attention to the various objects in the search array as *Executive Control Processes* (e.g. Banich, 2004; Gazzaniga, Ivry, & Mangun, 1998). Executive control processes guide attention to objects that are potential targets and away from those that are less likely to be targets. Additionally, executive control processes can limit (stop) the ongoing processing of nontarget objects that have attracted some initial attention. This definition highlights the importance of the current goal of the system to the allocation of attention. As was stated in Kramer, Scialfa, Peterson, and Irwin (2001), "... attentional control relies on an observer's expectancies about events, and the ability to develop and maintain an attentional set for particular kinds of environmental events." (p. 296).

The focus on attention leads to the issue of measuring where attention is at a particular time. One way to measure where attention is at any one time is through eye movement data. When viewing a scene, the eyes have periods of relative stability (called fixations) punctuated by periods of rapid movement (called saccades). Visual information is effectively acquired only during the fixation periods. The saccades move the eyes rapidly to the next point that the observer intends to process (see Rayner, 1998 for a review). In normal vision, attention tends to precede the eyes to the location of the next fixation and remains there for part of the following fixation (Deubel & Schneider, 1996; Henderson, Pollatsek, & Rayner, 1989; Hoffman & Subramaniam, 1995; Rayner, McConkie, & Ehrlich, 1978). This argues for the use of viewing position as a marker for the location of attention. In other words, if a person views a particular object in a scene or array, it is highly probable that attention has been devoted to the viewed object.

A demonstration of the interrelatedness of the executive control processes, attention, and eye movements is provided by the attentional capture paradigm of Kramer, Theeuwes and colleagues (Kramer, Hahn, Irwin, & Theeuwes, 1999; Theeuwes, Kramer, Hahn, & Irwin, 1998). They demonstrated that attention could be limited in the objects that are attended by either making the stimulus salient enough to be detected or by allowing attention to be adequately focused on the target location. More specifically, participants were presented with an array of 8 grey circles. On each trial, 7 of the circles would change color and participants were instructed to move their eyes to the one that did not change. To examine attention capture, on some trials, concurrent with the color change, another circle was added to the display. The measure of attentional control was the probability of fixations on the added circle even though it was never a target. If attentional control were perfect, the participant would never look to the added circle. However, these studies found that the eyes were drawn to the added circle if it was equiluminant with the other distractors or if there was no indication of the location of the target beforehand. In other words, attentional control failed if the stimulus did not stand out from the background or if the executive process involved in targeting the eye movement was not given adequate focus. On the other hand, if the added circle was salient (i.e. brighter than the other distractors) or if the target location was predictable, the eyes were not directed to the new circle. This indicates that the executive control processes involved can stop the deployment of the eyes to something that would normally draw attention.

Attention is also critical in the formation of memories of the objects that have been encountered in search. Treisman and colleagues (Treisman, 1998; Kahneman, Treisman, & Gibbs, 1992) claimed that attention was critical in the formation of object representations maintained by the visual system (see the discussion of object files below). This claim was expanded (Hollingworth & Henderson, 2002; Hollingworth, Williams, & Henderson, 2001) to compare the relation between fixations and long-term memory of objects. These authors claimed that as objects are attended/fixated, a long-term memory representation is built. Hollingworth et al. (2001) state that "… over multiple fixations on a scene, visual information from local objects accumulates in memory …" (p. 762). However, fixation is not the only influence on memory. Friedman (1979) found that recognition memory was not as strongly related to total fixation time as it was to the probability that the object did not belong to a particular scene. Thus, attention, as indicated by fixations, is a component in the formation of memory but it appears that fixation pattern is not a perfect predictor of memory.

The executive control processes in search involve the allocation of attention (as evidenced by memory measures and eye movement data) to the various objects in the search space. Initially, they can divide the objects into those that will be searched and those that will not be searched based on a feature of the target (as described by Treisman & Sato, 1990). Following this segregation, attention is directed to the potential targets in order to find the target. The executive control processes potentially play another role here because if the object is identified as a distractor, the processing of that object should be halted and attention directed to another object. Following the shift in attention, the eyes move to the next potential object. The earlier that this occurs in the processing of the distractor, the more efficient the search can be (i.e., the faster the searcher can move on and find the target).

In the current study, if the searcher's gaze falls upon an unrelated distractor, he or she could quickly reject it as not the target due to the fact that it shares no features with the target, halting the processing of the unrelated distractor quickly. The related distractors, on the other hand, may require more processing to determine that they are not the target before they can be rejected.

Finally, when a target was encountered in the current task, the searcher not only had to identify it as a target, but he or she also had to increment the target count. This should have required somewhat more extensive processing of the target objects. Overall, search was expected to proceed quickly through objects not related to the targets and to dwell on objects that were related to or were the targets of the search, as evidenced by differences in the memory measures and the eye movement record for the search.

Inhibition appears to play a critical role in the executive control processes that underlie efficient search. Specifically, research (e.g., Koshino, 2001;Treisman, 1998; Treisman & Sato, 1990) has suggested that inhibition plays a role in limiting the processing of nontargets in visual search. In the visual search context, inhibition should work to limit the processing of objects that are not the target of the search. There are two ways that inhibition could work to limit the processing of distracting objects. The first is to inhibit the identity of the items in the search space. Using the features that define the item as a distractor, the identity of the distractor can be inhibited so that it is either never processed or, if processed, is more difficult to reaccess at a later time. The second is on the locations of the distractors in the display. In other words, inhibition could be applied to the spatial points that were occupied by distractors so that anything that occurs in these locations will be harder to access.

There are several phenomena within the context of visual search that appear to result, at least in part, from inhibition operating on the distracting items in the display or on their locations. These include the segregation of the visual field (i.e. guided search), visual marking, inhibition of return, and negative priming. Although Wolfe (1994) claimed that guided search was the result of a process that selected areas of high target probability, Treisman (1998), argued that some of the ability to segregate the search space using a particular feature was the result of objects not related to the target being "selectively shut out" (p. 38) On a similar note, Treisman and Sato (1990) stated that the ability to segregate the search space using features is the result of an inhibitory mechanism that acts on the distracting features. By inhibiting the nontarget features, the search space can be effectively reduced to only those items that contain a specific, selected-for feature.

Visual marking is another phenomenon that appears to involve inhibition (Watson & Humphreys, 1997; 1998). In a visual marking experiment, a person is given a modified conjunction search task in which the search display is presented in two stages. In the first stage, half of the distractors are presented. After a short period of time, the remaining distractors and the target (if one is present on that trial) are added to the distractors from the first stage. This modified search condition, called the gap condition, is compared to search through the same number of items when they are presented all at one time rather than in two stages (a standard conjunction search task). Watson and Humphreys found that search in the gap condition was much more efficient than standard search task, indicating that the searcher was effectively searching through only those items in the second array. They claim that the searcher can use the presentation of the first stage in the gap condition to mark those distractors as not containing the target and thus are only required to search the items presented in the second stage. In other words, the visual system marks the locations of the distractors presented in the first stage as irrelevant and thus not needing to be searched when the second stage items are added. Because the items in the first array no longer influence search, Watson and Humphreys argue that these nontarget items have been inhibited.

The third phenomenon described as an inhibitory process is Inhibition of Return (IOR; Posner & Cohen, 1984). IOR occurs when attention is initially drawn to a location or object and then proceeds to another location. If attention is required to return to the initially cued location (in order to make a response), participants are slower to respond to the target than if it appears at a new location/object. In other words, because the initially cued location was rejected by the attentional system, inhibition was applied to prevent its reselection later, and thus the aftereffect is seen when the participant returns to the location. IOR can also be found for objects independent of the spatial location the object occupies. If an object moves after it has been attended, IOR seems to follow the object in a manner that is consistent with the object-file framework described below. Thus, although it is primarily thought of as a spatial phenomenon, the inhibitory processes involved in IOR may also have an object-based aspect. This means that under certain circumstances if a once-attended object moves, attention will still be less likely to return to that object (Tipper, Weaver, Jerreat, & Burak, 1994).

The final phenomenon related to the selection of a target and the inhibition of distractors is negative priming (e.g. Tipper, 1985; see May, Kane, & Hasher, 1995 for a review). In negative priming experiments, a target and a distractor are presented on each trial. The participant is instructed to respond to the target while ignoring the distractor. On negative priming trials within the experiment, the distractor from the previous trial becomes a target on the current trial. This condition is compared to control trials where there is no relationship between the current trial and the previous trial. What has typically been found is that responses on negative priming trials are slower and less accurate than on control trials. Tipper claimed that these slower responses were the result of an inhibitory mechanism that acted on the representation of the distractor object making it more difficult to access. Negative priming has also been shown to act on the location occupied by a distractor (Tipper, Brehaut, & Driver, 1990). If the participant attempts to access a location that contained a distractor on the previous trial, response times are longer than if there was nothing in that location on the previous trial.

In each of these cases, it can be argued that inhibition plays the role of limiting the influence of information that has been rejected. In the case of guided search, the items that can not possibly be the target are ignored (however, see Wolfe, 1994, for a description of this ability without inhibition). For visual marking, the items that are marked (rejected as not containing the target) are ignored when the additional items are added. In IOR, the location that had been attended to that did not contain the target is more difficult to return to. Finally, in negative priming, the object that was ignored on the previous trial because it was a distractor is more difficult to respond to when it subsequently becomes the target (however, see Neill, Valdes, Terry, & Gorfein, 1992, for an alternative explanation of negative priming). Each of these phenomena contains some aspect to be ignored because it is not or does not contain the target, and processing of that information is either halted or actively suppressed. They appear to apply inhibition to different aspects of a search task and use different functions of inhibition. Although the display types used in most studies of visual search are less complex than the arrays of pictures of real-world objects to be used in the current study, the description of inhibition as a limiting process that can act on the location or identity of an object is applicable here.

As was mentioned earlier, the current study was also interested in age-related differences in visual search. Thus, these inhibitory processes will be considered in relation to the age and inhibition views of Hasher, Zacks and colleagues (Hasher & Zacks, 1988; Hasher, Zacks, & May, 1999). These authors claim that in the course of normal aging, decreases in the efficiency of inhibition can lead to processing too much irrelevant or distracting information. This affects the ability of the person to focus on and process the relevant information. For example, Connelly, Hasher and Zacks (1993) presented younger and older adults with passages to read in one font interspersed with distracting information in another font. They found that older adults were differentially affected by the distracting text compared to younger adults, especially when the distracting information was related to the passage. In other words, older adults were less efficient at ignoring related nontarget information than younger adults, which was indicative of decreased inhibitory efficiency. In the current study, supporting evidence that inhibition is operating in visual search would be present if the older adults searched differently than younger adults and had different memory representations of the objects searched. These differences should be observed in the distractor object conditions because they are the ones that contain competing information that would interfere with the search task.

Aging and Visual Search

Visual search has not been a major topic of study in the field of age-related changes in cognition. Initial studies (Plude & Doussard-Roosevelt, 1989; Zacks & Zacks, 1993) indicate that similar search patterns are present for both older and younger adults. Both age groups are able to effectively use feature searches and are slowed significantly in conjunction searches. However, older adults are slowed more than younger adults by the demands of a conjunction search task. Additionally, there have been demonstrations of similar processing between older adults and younger adults in tasks with search components that appear to rely on inhibition. Studies investigating guided search, visual marking, IOR and location negative priming have all demonstrated similar processing between older adults and younger adults (e.g., Connelly & Hasher, 1993; Kramer & Atchley, 2000; Madden, Gottlob, & Allen, 1999; McCrae & Abrams, 2001). At first glance, at least, this may seem surprising in the context of the Hasher and Zacks' inhibition deficit view and its supporting evidence suggesting that older adults are more affected by distracting elements of the environment. However, a critical aspect of these inhibitory phenomena is that there are few age differences when any of them relies upon the inhibition of a location in the search space rather than the inhibition of the identity or semantic code of an item (Connelly & Hasher, 1993; Kramer & Atchley, 2000; Hartley & Kieley, 1995). Apparently the processes involved in inhibiting spatial locations are preserved throughout the lifespan. This differs from evidence of decreased inhibitory efficiency when the identity of the item is inhibited. There have been demonstrations of age differences in negative priming for the identity of the recently rejected distractor (e.g., Connelly & Hasher, 1993). Additionally, while it is clear that older and younger adults do not differ in IOR for spatial locations, there have been some contradictory findings about age differences in IOR that is tied to an object independently of the spatial location (McCrae & Abrams, 2001). The contrast between the identity and the location of a distracting item seems to have a large impact on age differences in inhibition.

In addition to the differences in the properties (location or identity) that are inhibited, there are other aspects of the stimulus that can affect the likelihood that age differences occur. One aspect is the salience of the distractors in comparison to the target items. As mentioned earlier, Kramer et al. (2001) found that in an attentional capture task, younger adults were able to inhibit their eye movements to a salient sudden onset distractor (in this case, an added distractor that was brighter than the other distractors). However, older adults were less able to prevent eye movements to this salient item. In order for inhibitory processes to be engaged, it appears to be important that the distractor be a viable competitor for attention (i.e., salient in the environment). If the distractor items are not salient, there will be little need to inhibit them and thus no age differences in the responses. In other words, age differences in these tasks will only be found if the nontarget information is both "strong and wrong" (Radvansky & Curiel, 1998, p. 77). The current experiments vary salience by manipulating the relationship between different objects and the search target. If an object is related to the target, then it is expected to be more salient and require more processing than unrelated distractors.

Visual Memory

Earlier studies of visual memory (e.g. Shepard, 1967; Standing, Conezio, & Haber, 1970) found that participants were relatively good at remembering pictures that they had seen even after several days. Counter to these earlier findings, however, there has been a recent debate as to whether or not the visual system maintains information about the visual details of objects in the environment. There have been several demonstrations of insensitivity to relatively large-scale changes to the visual environment in online viewing tasks (e.g., Grimes, 1996; McConkie & Currie, 1996; Simons & Levin, 1998). *Change Blindness*, as this has been labeled, is the demonstration that across a visual disruption (e.g., an eye movement or a briefly presented blank screen), large changes in a scene can be made without the viewer detecting the change. In a classic example (Grimes, 1996), participants viewed pictures while their eye movements were monitored. Changes were made to the picture while the eyes were in motion. During a saccadic eye movement, no useful visual information is acquired by the visual system; thus changes to the scene can be made during a period of functional blindness. In a picture of two wedding attendees wearing differently colored top hats, the hats were shifted between the attendees during a saccade. Few viewers noticed the changes that occurred during the viewing. In a more common technique, two scenes differing in one changed element are repeatedly alternated (separated by blank screens) until a button is pressed or a time limit is reached. The measure of change blindness is the number of cycles that the participant views the scenes prior to detecting the change (if s/he detects it at all). For many changes, it takes several cycles for the change to be noticed. Such change blindness results led some theorists to claim that no visual information is maintained from one fixation to the next (O'Regan, 1992; Rensink, 2000). These theorists argue that if participants had memory of the correct visual details, they should be perfect in change detection. O'Regan (1992) has claimed that there is no need for visual memory due to the fact that if one needs to remember what an object in a scene looks like, one simply has to direct the eyes to that location and resample the information. Rensink (2000; Rensink, O'Regan, & Clark, 2000) has claimed that an object coheres only while it is being currently attended. Once attention is withdrawn, the object representation disintegrates, losing all visual detail memory. Both of these claims point to an impoverished visual memory, contradicting the findings of Shepard (1967) and Standing et al. (1970).

More recent research has called into question models that claim that there is no memory for the visual details of objects and scenes. Hollingworth and

Henderson (2002) found evidence of visual memory in a scene memory experiment. Participants were able to accurately identify the scene they had seen earlier from a foil in which one object had changed (a type, token, or orientation change). The token and rotation changes are of particular interest because in order to perform accurately in the memory test, one needs to remember the visual details of the objects. Additionally, Castelhano and Henderson (2001) have demonstrated that when searching through pictures of scenes, one can remember the visual details of distracting objects from the search. This was true even when one was not expecting a memory test. Both of these studies demonstrate that the visual details of the objects can be remembered.

There appear to be two ways to reconcile findings of preserved visual memory with the change blindness phenomenon. One is that in most change blindness studies, researchers have not made certain that the objects that were changed were actually processed before the change occurred. It seems reasonable to assume that change detection would be nearly impossible if one had not looked at the object before the change occurred. Additionally, the test of change blindness (overt change detection) may not be sensitive enough to determine the memory that is maintained by the visual system. Hollingworth, et al. (2001) found that in a change detection paradigm (a token change experiment), when the participants were tested with overt change detection, they performed better than chance but not exceptionally well. However, they found evidence that when refixating the critical object, participants examined the object longer if the object had changed than if it was the same. This was true even though the participant did not overtly respond that anything had changed in the scene. This indicates that the there may be some level at which the visual details are maintained. In other words, the visual system appears to have more information in it than is evident from overt responses.

Object Representations and Visual Memory

In the office example mentioned previously, the search for the red book took place in a space filled with a variety of objects that could draw attention. However, the concept of the object and its representation was intentionally left implicit. In this section, one of the prominent theories of object representation is discussed along with recent work that discusses the memory maintained for objects after they have been out of sight.

A great deal of research has explored the way that attending an object affects the mental representations of that object. Kahneman, Treisman, and Gibbs (1992) laid out a theory of the mental representation of objects. According to their *object file* framework, when an object in the environment is attended to, a file, metaphorically similar to a file folder, is set up that contains information about the object (e.g., size, color, etc). This file is indexed by the spatial-temporal coordinates of the object, which are updated if the object moves. If the file is accessed at a later time, the information that was stored becomes available to the executive processes and can be used to facilitate the processing of the object. This framework describes several abilities of the visual system, including the ability to track objects as they move within the environment.

Although the object file framework was developed using a simple visual environment, it has been extended to describe the processing of objects in scenes. Hollingworth and Henderson (2002) claim that during the processing of a scene, the information about an attended object is stored in a relatively long enduring format that preserves some of the basic visual details of the object (a *long-term object file*). This information is detailed enough to support discrimination of subtle differences in test stimuli (Hollingworth & Henderson, 2002; Hollingworth, et al., 2001). In these experiments, changes were made to a single object in a scene following a fixation on the object. Participants were able to recognize the change that had occurred at better than chance levels both during the viewing epoch and after a long delay. Objects were changed by either rotating the object 90° in depth or by replacing it with another token of the object. Because neither of these types of changes alters the basic level category of the object, the representation constructed during the viewing of the scene must be detailed enough to detect subtle visual differences in a discrimination task.

Castelhano & Henderson (2001) provided further evidence of long-term object files that is directly relevant to the current study. They demonstrated that participants showed memory for the visual details of items that were not the target of a search in a scene. Participants were able to use long-term representations of the objects to support both token and rotation discriminations. Because participants were able to remember visual details of objects that were *not* the targets, there is a possibility that the variable processing of the different classes of objects could lead to differences in the memory representations of those objects. Unlike the current experiments, however, the objects tested in their experiments were not selected so that they had a specific relationship to the search target. Thus, the distractor objects that were tested may or may not have been related to the search that took place, leaving open the question of the effect of the role that the object played during search on memory.

The critical aspect of the object file framework for the current study is that attention is vital in the formation of the file (Treisman, 1998). As mentioned earlier, it was expected that during a search, attention is applied unevenly to the objects in the search space with some objects (e.g. targets) receiving a great deal of attention and other objects (e.g., background objects and unrelated distractor objects) not being attended to much at all. Differences in the application of attention to objects in a search could lead to variability in the long-term memory representations of these objects. In other words, because attention is not directed to targets and distractors equally in a search array, object files that are created for the various objects will differ in the information contained in them. These differences could lead to large differences in performance on subsequent memory tests.

Current Study

The current study modified the typical search task in both stimuli and dependent measures in order to further study the role played by executive control of visual attention in search. It used real-world objects as the basis for search, and each item appeared in only one array within the search phase of the experiment. These differences from previous procedures allowed the current study to examine the memory that is formed for each object in a search. By using individual tokens of the objects, the memory preserved for visual details of individual objects was examined. Differences in memory for the various classes of objects would provide evidence of differences in the processing that is performed during a search task. It was expected that target objects would be the most likely to be processed in the search, given that they were the goal of the search. The related distractors should be the next most likely to be processed due to their relation to the search targets. The unrelated distractors may be processed little in the search task. Of interest are the comparisons of targets and related distractors and the related distractors and the unrelated distractors. The first comparison, between targets and related distractors, gives an indication of the variable processing that occurs for items that were examined and selected versus those that were rejected. The second comparison, related and unrelated distractors, examines any differences that might be present when some items can be easily rejected and others cannot. The processes applied to these different classes of objects could yield different memory representations. The visual memory test examined the long-term object file representations that are formed during a visual search. The memory test was a two-alternative forced choice token discrimination test. This test is similar to the one used by Castelhano and Henderson (2001) in which they tested the memory of distractor items after a search through a scene.

Additionally, Experiment 2 used eye movement measures as another dependent measure to examine the processing of objects in the visual search task. Eye movement measures (e.g., the likelihood that an object is examined, the number of times that a particular object is looked at, and the length of time that an individual looks at a particular object) were markers for the way that executive control processes are applied to a search. They can be used to evaluate the operation of executive processes during search by examining processing that certain objects in the environment receive based on the way that they are related to the search goal. Finally, the current study used an age group comparison to further examine the role played by inhibition. The claim that older adults have decreased inhibitory efficiency should be reflected in the search pattern. Specifically, age differences in inhibition should be evident in processing of the distractor objects.

EXPERIMENTS 1A AND 1B

Experiments 1a and 1b examined the differences in visual memory for targets and distractors of a visual search task. Participants were given a modified conjunction search task in which they had to count the number of targets that fit a target description. The search was conducted through arrays of 12 real-world objects (see Figure 1). The target of the search was defined by a color-category combination (e.g., the drill that is green). In addition to targets, there were objects that were related to the search targets by either being the same general color as the search target (green things that are not drills) or the same category as the search target (drills that are not green). In most of the research that has examined conjunction search, when the distractors share a feature with the target, the search proceeds more slowly than when the distractors are unrelated to the target. This inefficiency indicates that distractors that are related to the search target are being processed to some extent and subsequently rejected. Both category and color distractors will be examined because if one of these features is used to segregate the search space (in a guided search way), then collapsing across the distractor type would problematic. If, for example, color is used effectively by the participant to divide the search space into objects to look at and those not to look at, then only the related color distractors would be viable competitors for the search target. Thus, in this example the related category objects would effectively be screened out and thus would not be considered. Essentially, these category distractors would appear as unrelated category/color distractors to the participant. The separation of these different types of distractors permits me to examine the possibility that different search strategies could affect the classification of the distractors. Finally, the search arrays contained objects that were not related to the target (objects that were neither green nor drills). Because these objects do not possess a feature that defines the target, it is less likely they will need to be processed during the search.

The first experiment focused on the memory for objects in visual search. Participants were given an unexpected memory test following a filled interval of approximately ten minutes. The presumed difference in the amount of processing of the visual search target, related distractors, and unrelated distractors could lead to differences in the memory. Any cognitive processes that played a role in the selection of targets and the rejection of distractors should influence the memory maintained after search. The processing of targets as the things that were searched for could lead to relatively good memory for these items. Additionally, the executive control processes could include inhibitory processes that limit the processing of the distractors. As mentioned earlier, inhibition could potentially serve different functions for the different types of distractors. Related distractors could be inhibited due to the fact that they are highly likely to draw attention to them and thus need to be inhibited in order for search to proceed. Unrelated distractors may need to be inhibited to prevent the search from processing these items because they are not relevant to the search goal. The potential use of inhibition in the processing of distractors could lead to poorer visual memory performance.

As was mentioned previously, the memory test was a token discrimination test in which participants judged which of two pictures fitting the same description was presented earlier during the search task. This test was designed to measure memory for the visual details of the search objects, rather than their semantic categories, and thus evaluates claims that the visual details of perceived objects are not maintained in memory. Also, because the memory test was unexpected, any learning that took place during the search was completely incidental. Therefore, it tested the representations that were constructed without the intention to remember the visual details.

Because I am interested in the memory for the distractors as well as the targets, it was important to encourage the participant to examine many of the objects during a particular search. In order to accomplish this, I altered the traditional search paradigm in another way: multiple targets. In the object arrays of these experiments there were as few as 0 or as many as 3 instances of the target object (e.g., 3 distinct green drills). The use of multiple targets encouraged participants to continue to search through the object array even after they encountered an instance of the target object, thereby potentially processing other distractors. Participants responded with the number of targets that appeared in the array rather than whether or not the target was present or absent.

Finally, Experiment 1b tested the inhibitory components involved in search by examining the memory that older adults have for the visual details of the objects in search. Typically, older adults perform more poorly on memory tests than younger adults. However, because older adults have decreased inhibitory efficiency, they may process the distractors more than the younger adults. This additional processing may allow older adults to remember the distractors as well as, if not relatively better than, the younger adults. In other words, the additional processing may strengthen the memory for the older adults, and thus they would not demonstrate the typical pattern of age-related declines in memory. However, this memory benefit of the older adults should be limited to the distracting objects in the search.

To preview the results of Experiments 1a and 1b, the visual memory for the targets of visual search was relatively good even after an intervening period of at least 10 minutes. Additionally, related distractors (color and category distractors) were remembered better than chance, although they were recognized at similar levels. Unrelated distractors were recognized at approximately chance levels in each of the experiments. Older adults in Experiment 1b demonstrated relatively well-preserved visual memory for the distractor objects, but not the search targets. These results support the claims that visual memory exists for objects that are searched and that this appears to be tied to the probability that the object was examined. Additionally, there is evidence that inhibition plays a role in search and that older adults do process the distractors more than younger adults.

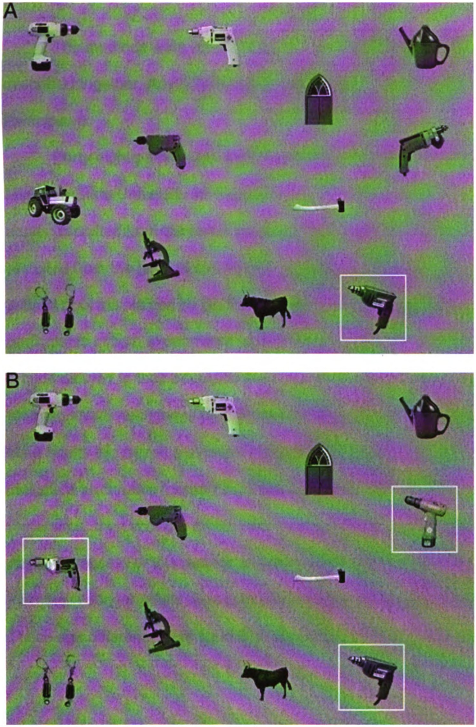

Figure 1. Example of a search display. Images in this study were presented in color. For photocopying purposes, the background presented in this image is lighter than was true in the experiment. The search targets (1 green drill in panel A and 3 green drills in panel B) are highlighted by the white boxes. Other objects include a color distractors (green watering can, upper right), category distractor (yellow drill, upper middle), and unrelated distractors (yellow-handled axe, right center).

Method

The methods were almost identical for experiments 1a and 1b and will be described together. Any differences will be noted.

Participants.

Forty-eight participants were recruited from general psychology courses at Michigan State University for Experiment 1a. Experiment 1b had 24 younger adults (recruited from the same source as Experiment 1a) and 24 older adults recruited from the general community. The older adults were recruited from a subject pool maintained by Dr. Rose T. Zacks. The demographics for the participants in both experiments reported here appear in Table 1. The age groups differed in their education level and vocabulary scores. In the Morningness/Eveningness Questionnaire (MEQ; Horne & Ostberg, 1976) scores, older adults expressed a stronger preference for the morning (higher values indicate a preference for morning times; a score of 59+ equals a morning preference) than younger adults who were neutral (scores 42-58) in their time of day preference. For this reason, an effort was made to test older adults in the morning. Younger adults were primarily tested in the later morning to afternoon. These age differences are typical for experiments run on these samples.

	Age	Education	Vocabulary	MEQ
Experiment 1a				
Younger Adults	18.8 (0.14)	12.5 (0.12)	27.8 (0.53)	41.8 (1.21)
Experiment 1b				
Younger Adults	19.8 (0.20)	13.5 (0.21)	30.2 (0.66)	41.3 (1.40)
Older Adults	73.5 (1.19)	15.5 (0.61)*	35.1 (0.88)*	62.7 (2.57)*
Experiment 2				
Younger Adults	20.0 (0.58)	13.0 (0.23)	28.5 (0.82)	42.4 (2.27)
Older Adults	76.9 (0.93)	14.7 (0.49)*	36.5 (0.57)*	61.8 (1.57)*

*age group comparison $p < .05$

Table 1. Mean (Standard Error) for Age, Education Level, Vocabulary, and Morningness/Eveningness Questionnaire (MEQ).

Design.

Experiment 1a had 2 main factors: number of targets and object type. In the target counting task, the participants had to determine the number of targets that were present in the search array (ranging from 0-3). The other factor was the relation that the objects in the search array had to the search targets. Each search array consisted of four types of items: targets, category distractors, color distractors, and unrelated distractors. The dependent variables of primary interest are the measures of visual memory performance for the 4 different types of array objects. However, measures of search efficiency and accuracy were also examined.

Experiment 1b was identical to Experiment 1a except that in addition to number of targets and object type manipulations, there was also an age group comparison.

Materials

Sixty-four search categories were selected (see appendix). The categories were divided into two groups of 32 categories each. A participant only searched for targets from one of the two groups of categories. Targets were defined by a specific category-color combination. For each category, three colors were selected in which the target could appear (e.g., green, yellow and red drills). There were 8 possible colors that an object could be (black, brown, white, silver, red, blue, yellow, and green). Each color was used equally often as a target color (i.e., for four targets) across categories and participants. For each color within a category, 5 photographic exemplars were selected, primarily from an electronic database of pictures of real-world objects. Each object was resized so that its longest dimension (horizontally or vertically) was 3.5° in visual angle (from a viewing distance of 57 cm) while maintaining its original proportions.

Search arrays were constructed for each color-category combination (see Figure 1). A search array consisted of 0-3 targets (e.g. a green drill), 3-4 category distractors, 3-4 color distractors and 3-4 unrelated distractors.[1] The category distractors were objects from the other two colors of the search category (i.e. red and yellow drills). The color and unrelated distractors were selected from the non-presented set of 32 search arrays for that participant. Thus, the color and unrelated distractors were from categories that were never searched for by a participant. Color distractors matched the target on the color that was being searched for and within an array all came from different categories (e.g. a green watering can, door, earrings, and tractor). Unrelated distractors were not related to the search target by either search category or search color. Each unrelated

[1] The number of color, category, and unrelated distractors was dependent on the number of targets that were present. For search arrays where there were no targets, 4 color, 4 category, and 4 unrelated distractors were presented. For arrays that had one target present, 1 unrelated distractor was removed. For arrays that had 2 and 3 targets, one category and one color distractor, respectively, were also removed.

distractor was a different color and from a different category than the other distractor objects. The objects were counterbalanced in that each object served as a target, a color distractor, a category distractor and an unrelated distractor across participants.

Visual Search.

An array of 12 objects was created for each of the factorial combinations of the number of targets (4 levels), the 3 target colors, and 64 categories. Arrays were 800 x 600 pixels in size (approximately 31° x 23.5°) with a neutral gray background (RGB = 120). Each search category was assigned to 1 of 8 object configurations. The twelve objects were placed in the arrays based on 3.5° x 3.5° squares (This was done so that the object would be contained within the square regardless of which was the longest axis). The presentation squares were arranged with the constraint that objects could not be closer than 3.5° apart from the nearest edge of each square. The objects were no nearer the edge of the display than 40 pixels in the horizontal dimension and 30 pixels in the vertical dimension.

The arrays were presented in two blocks. Each of the 32 arrays appeared in each block once. The number of targets and the specific configuration of objects were changed in each block (e.g., if there were 2 targets in the first viewing, there could be 1 or 3 targets on the second viewing). The changes were made to require the participant to perform the search on the second viewing of the array rather than relying on memory for the answer to the number of targets or the location of the targets/distractors. In order to ensure that a target was processed for a search array, there was always a target present in the second block. Participants were not told that in the second block all of the arrays had at least one target.

All three tested distractors were present both times the array was searched. If there was no target in the first viewing of the array, then the tested target was only viewed once. Otherwise, the tested target was viewed on both presentations of the array.

Visual memory test

The explicit memory test was a two-alternative forced-choice task. One target, one color distractor, one category distractor, and one unrelated distractor were tested from each search array that a participant viewed. Participants were asked to determine which of two pictures (the left picture or the right picture; see Figure 2) was identical to a picture that had been in the earlier search task. The other picture was a non-presented foil that was selected so that it matched the condition of the presented item. In other words, if the presented object was a yellow car, then the foil was also a yellow car that had not been seen by that participant. The memory foils for half of the participants were the presented objects for the other half. Objects were presented in the same size (3.5°) as they were in the search display.

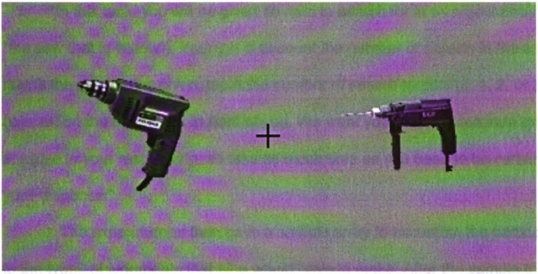

Figure 2. Example of visual memory test stimuli. Participants had to determine which green drill token (left or right) had been presented in the earlier search arrays. Images were presented in color and were the same size as during the search portion of the experiment. For photocopying purposes, the background presented in this image is lighter than was true in the experiment.

Participants in Experiment 1a were only tested on objects from 16 of the 32 search categories that they had seen. The objects from the other 16 arrays were presented in another task, which preceded the explicit memory test. However, the results from that other task will not be discussed here. The objects tested were counterbalanced across participants. Participants in Experiment 1b were tested on objects from all 32 arrays they had seen during the search.

Procedure

Upon arrival, the participant was provided with a brief description of the experiment and given the informed consent form and a general demographic questionnaire. After completing these forms, the experimenter positioned the participant approximately 57 cm from the computer screen and the participant was presented with the following instructions for the search task:

"In this task, you will be given an item to search for in an object array (e.g., "the saw that is yellow"). Your job is to count the number of objects in the array that fit the description given. Input the number of search targets (0, 1, 2, or 3 objects) on the button box in front of you. We want you to be as accurate as possible in your responding, so take as much time as you need to be certain of your response."

The experimenter then gave a sample array to accustom the participant to the types of judgments that s/he would have to make. After the sample trial, the experimenter again emphasized that accuracy in the judgment was the critical component, and answered any questions that arose from the sample trial. If there were no questions, the experimenter began the experiment. Stimuli were presented using E prime version 1.0 software.

Following the search task, the participants had a filled interval during which they completed unrelated tasks (e.g., the Shipley Vocabulary test and the Morningness/Eveningness questionnaire). After finishing these forms, the visual memory test was administered. The participants were told that they would see two pictures and should do their best to decide which one of the pictures was presented during the visual search task. Additionally, they were told that the test would be very difficult and to take their best guess if they were uncertain. The two pictures were presented to the left and the right of the center of the screen. The participant indicated which of the two pictures was presented earlier by pressing either the left or right button on the button box. Half of the targets appeared on the left and half appeared on the right.

Results

The results for Experiment 1a and 1b are divided into two sections: visual search and visual memory test. For all statistical tests, an alpha level of .05 was used to determine statistical significance.

Visual Search

The two measures of interest for the visual search component are search time and accuracy in counting the number of targets present. Because each array was presented twice, the search data are divided into first and second presentation. However, because there was always a target in the second presentation, the analyses are restricted to the cases where there was a target in the array. The results for Experiments 1a and 1b can be found in Table 2.

In Experiment 1a, search times through the search arrays were faster for the second presentation than the first presentation [$F(1, 47) = 112.70$, $p < .001$, $MSE = 1284947$]. This is not surprising given that people were given no practice and only one example prior to beginning the first presentation block. By the second presentation block, the participants had received 32 trials of practice and thus were more efficient in the task. This could also be influenced by repetition priming because the pictures had been seen before. There was no main effect of the number of targets [$F(2, 94) = 1.91$, $p > .10$, $MSE = 845283$]. However, there was an interaction between the number of targets and the presentation [$F(2, 94) = 3.99$, $p = .02$, $MSE = 880041$] with longer searches as the number of targets increased in the first presentation, whereas in the second presentation there was no difference in the search time with more targets. As in the search time, the search accuracy also demonstrated improvement between the first and second presentation [$F(1, 47) = 4.41$, $p = .04$, $MSE = 0.0073$]. There was also a strong effect of the number of targets on accuracy, with accuracy decreasing as the number of targets increased in the array [$F(2, 94) = 16.14$, $p < .001$, $MSE = 0.0178$], and there was no interaction between presentation and number of targets ($F < 1$).

A

	Number of Targets			
	0	1	2	3
Experiment 1a				
Presentation 1	6043 (251)	5701 (227)	5770 (201)	6269 (343)
Presentation 2		4463 (160)	4611 (176)	4412 (163)
Experiment 1b				
Younger Adults				
Presentation 1	6548 (449)	5020 (266)	5335 (331)	5398 (331)
Presentation 2		4377 (256)	4390 (250)	4258 (324)
Older Adults				
Presentation 1	9684 (670)	8959 (707)	10408(1160)	12480(1656)
Presentation 2		8384 (717)	8148 (665)	8800 (698)

B

	Number of Targets			
	0	1	2	3
Experiment 1a				
Presentation 1	0.92 (.016)	0.91 (.017)	0.80 (.024)	0.79 (.026)
Presentation 2		0.91 (.013)	0.85 (.018)	0.81 (.019)
Experiment 1b				
Younger Adults				
Presentation 1	0.94 (.020)	0.95 (.017)	0.85 (.025)	0.81 (.030)
Presentation 2		0.94 (.013)	0.88 (.016)	0.84 (.021)
Older Adults				
Presentation 1	0.89 (.027)	0.90 (.017)	0.70 (.038)	0.67 (.040)
Presentation 2		0.87 (.026)	0.73 (.037)	0.75 (.027)

Table 2. Mean (Standard Error) for (A) Correct Search Times (in ms) and (B) Search Accuracies (proportion correct) for Experiment 1a and 1b.

The major difference between Experiment 1a and 1b was the testing of older adults as well as younger adults in Experiment 1b. Overall, older adults were slower to respond correctly to the search arrays than younger adults [$F(1, 46) = 31.97$, $p < .001$, $MSE = 50457905$]. As in Experiment 1a, correct search times in Experiment 1b were faster for the second presentation of the search arrays than the first presentation [$F(1, 46) = 23.52$, $p < .001$, $MSE = 7264342$]. The effect of presentation was modified by an interaction with age group in which older adults appeared to improve more than younger adults [$F(1, 46) = 3.95$, $p = .053$, $MSE = 7264342$]. Unlike Experiment 1a, however, there was a main effect of the number of targets on search times [$F(2, 92) = 5.25$, $p = .007$, $MSE = 5143581$] with increased search times as the number of targets present in the search array increased. This was also modified by an interaction with age group [$F(2, 92) = 4.30$, $p = .016$, $MSE = 5143581$], meaning that older adults appeared to be more affected by the number of targets in the search array than younger adults. This could indicate greater difficulty for the older adults in the tasks of updating and maintaining the number of targets that one has encountered. The target counting task requires that when one encounters another target, the previous number of targets must be retrieved and then incremented. If either, or both, of these processes were more difficult for older adults, they would have more difficulty as the number of targets in the display increased. As in Experiment 1a, there was an interaction of presentation and target number [$F(2, 92) = 5.33$, $p = .006$, $MSE = 3666895$], indicating that the number of targets had little effect in the second presentation. Finally, there was a marginal three-way interaction of presentation, target, and age group [$F(2, 92) = 2.79$, $p = .067$, $MSE = 3666895$] with older adults improving more with a greater number of targets.

For search accuracy, younger adults were more accurate than older adults [$F(1, 46) = 25.72$, $p < .001$, $MSE = 0.0325$]. In contrast to the search times, there was no main effect of presentation [$F(1, 46) = 1.97$, $p = .17$, $MSE = 0.0123$] or interaction with age group ($F < 1$). However, there was an effect of the number of targets [$F(2, 92) = 43.97$, $p < .001$, $MSE = 0.0135$], with accuracy decreasing as the number of targets in the search array increased. There was also an interaction between the number of targets and age group [$F(2, 92) = 4.58$, $p = .013$, $MSE = 0.0135$] with older adults being more affected by the additional search targets than younger adults, mirroring the search time results. There was neither interaction of presentation and number of targets [$F(2, 92) = 2.23$, $p = .113$, $MSE = 0.0142$] nor a three-way interaction with age group ($F < 1$).

Visual Memory Test

The more important results for Experiment 1a and 1b are the visual memory performance results. It is important to note here that because there were trials in the first presentation block of arrays with no targets present (the 0 target condition), a subset of the target objects for each participant had only one opportunity to be viewed in these experiments. All of the analyses reported in this study, unless otherwise stated, eliminated these singly-viewed target objects from consideration. This ensured that the target objects and the distractor objects (which were always present in both presentations of the array regardless of the number of targets present) had equal opportunities to be viewed within the search portion of the experiment. This amounted to one quarter of the targets being removed from the analyses for each participant.

Because a two-alternative forced-choice design was used, chance level for the memory test was 50%. There are two important tests that address different aspects of this study. The first test is a comparison of the different object conditions (target, category distractor, color distractor, and unrelated distractor) to chance level using one-sample t-tests. This test examines the claim that no visual information is maintained once attention has been withdrawn from an object. If objects in any of the conditions are recognized at better than chance levels, then some information about the objects has been maintained after the visual search task. The second comparison examines the memory for the different types of objects. Because the objects played different roles in the search component of the experiment, it is reasonable to assume that the variable processing that each object received during the search (due to its disparate relationship to the target) would lead to different memory levels. Additionally, the executive processes involved in the rejection of the distractors could also lead to decreased memory performance. It is important to remember that each object in the memory test served as a target, a color distractor, a category distractor and an unrelated distractor across participants and that the memory foils for half of the participants were the presented objects for the other half.

The results of Experiment 1a and 1b are shown in Figure 3. The first important comparison is to chance levels. As can be seen in the top panel of Figure 3 (Experiment 1a), when compared to chance level (.50), the target objects [.88; $t(47) = 27.1$, $p < .001$], the category distractors [.62; $t(47) = 5.39$, $p < .001$], and the color distractors [.60; $t(47) = 6.71$, $p < .001$] were all remembered better than chance. The unrelated distractors, however, were not remembered significantly better than chance [.53; $t(47) = 1.43$, $p = .16$]. When comparing the memory results for Experiment 1b, the same pattern can be seen for the younger adults (bottom panel of Figure 2). Target objects [.86; $t(23) = 19.31$, $p < .001$], category distractors [.61; $t(23) = 5.71$, $p < .001$], and color distractors [.60; $t(23) = 4.33$, $p < .001$] were all remembered better than chance. The unrelated distractors were again not remembered significantly better than chance [.52; $t(23) = 1.35$, $p = .19$]. The older adults (also in the bottom panel of Figure 2) demonstrated a similar pattern with the exception of the unrelated distractors. Older adults remembered target objects [.80; $t(23) = 15.63$, $p < .001$], category distractors [.60; $t(23) = 3.91$, $p = .001$], color distractors [.57; $t(23) = 4.45$, $p < .001$] and unrelated distractors [.56; $t(23) = 4.45$, $p < .001$] better than chance level. The results of Experiment 1a and 1b clearly argue against a visual perception model that does not maintain at least some visual details from objects that have been viewed previously.

The second important comparison examined the differences between the object conditions. In Experiment 1a (top panel of Figure 3) there was a main effect of object condition [$F(3, 141) = 81.73$, $p < .001$, $MSE = 0.0140$], with performance declining in the following order: targets, related distractors and unrelated distractors.[2] The memory for target objects was significantly better than that of the category distractors [$t(47) = 11.89$, $p < .001$] and the color distractors [$t(47) = 13.32$, $p < .001$]. The two related conditions were not significantly different from each other [$t(47) = 0.67$, $p > .20$], and each was significantly better than the unrelated distractor condition [category distractor, $t(47) = 3.53$, $p = .006$; color distractor, $t(47) = 2.85$, $p = .039$].

[2] The level of significance for the comparisons of the different conditions was corrected using a Bonferroni correction for multiple comparisons for each of the experiments described here. The comparisons of the conditions between the two age groups, however, were not corrected in any of the experiments.

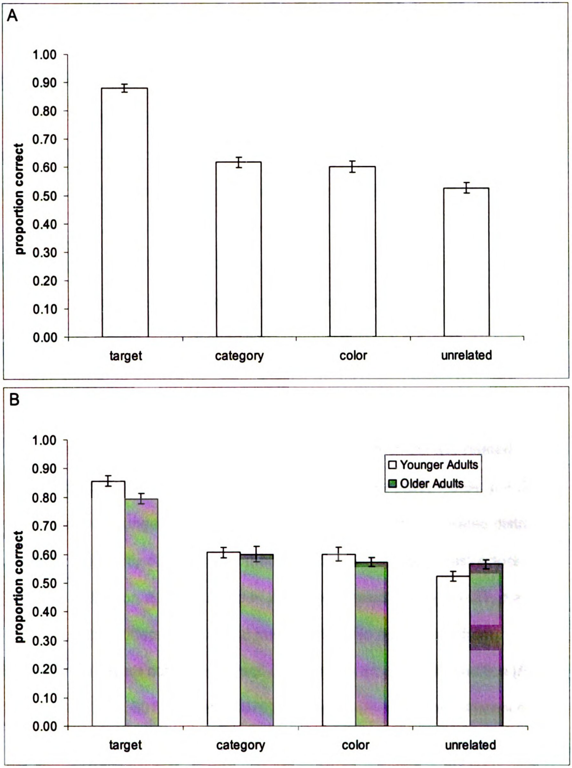

Figure 3. Mean proportion correct for the visual memory test in (A) Experiment 1a and (B) Experiment 1b. The error bars are standard errors.

The same pattern of data was evident for the younger adults in Experiment 1b with a main effect of condition [$F(3, 69) = 77.56$, $p < .001$, $MSE = 0.0067$]. Again, targets were remembered better than the category distractors [$t(23) = 14.41$, $p < .001$] and the color distractors [$t(23) = 9.78$, $p < .001$]. As in Experiment 1a, objects within the two related distractor conditions were remembered at similar levels [$t(23) = 0.27$, $p > .20$], and each was remembered better than the unrelated distractor condition [category distractor, $t(23) = 4.08$, $p = .003$; color distractor, $t(23) = 2.95$, $p = .043$]. The older adults in Experiment 1b, however, demonstrated a slightly different pattern of visual memory. The older adults did demonstrate a main effect of condition [$F(3, 69) = 31.22$, $p < .001$, $MSE = 0.0092$]. Similar to the younger adults, older adults remembered targets better than the related distractors [category distractors, $t(23) = 6.77$, $p < .001$; color distractors, $t(23) = 8.47$, $p < .001$]. Additionally, objects in the two related distractor conditions were remembered at similar levels [$t(23) = 0.94$, $p > .20$]. In contrast to the younger adults, older adults' memory for the unrelated distractors was not significantly different from their memory for the related distractors [category distractor, $t(23) = 1.21$, $p > .20$; color distractor, $t(23) = 0.31$, $p > .20$]. To examine this difference in visual memory, the two age groups from Experiment 1b were compared directly. There was an effect of condition [$F(3, 138) = 98.09$, $p < .001$, $MSE = 0.0079$], but there was no overall difference between the age groups ($F < 1$). There was, however, a significant interaction between the two age groups [$F(3, 138) = 2.82$, $p = .041$, $MSE = 0.0079$]. To explore this interaction, the age groups were compared for each of the object conditions. As expected, younger adults outperformed older adults in their memory for the visual details of the target objects [$t(46) = 2.38$, $p = .022$]. This is consistent with most comparisons of memory between younger and older adults. However, there were no significant differences for related distractor conditions [category distractors, $t(46) = 0.18$, $p > .20$, color distractors, $t(46) = 0.98$, $p > .20$]. Additionally, older adults marginally outperformed younger adults in the unrelated distractor condition [$t(46) = -1.87$, $p = .068$].

An interesting aspect of the design was that a subset of the tested target objects were viewed only in the second of the two presentation blocks, whereas the remainder of the target objects were viewed in both blocks. This was a result of the fact that during the first presentation block, a quarter of the arrays had no targets in the array. By comparing the targets that were viewed in both blocks to those viewed only once, I can provide some indication of the role of additional processing for visual memory. In Experiment 1a, targets that were viewed on both trials (.881) were remembered better than targets viewed on only one trial (.839), but this difference was not significant [$F(1, 47) = 2.37$, $p = .13$, $MSE = 0.0181$]. In Experiment 1b, both age groups had better memory for targets viewed twice (younger adults: .858; older adults: .796) than for targets that were viewed only once (younger adults: .775; older adults: .748). In contrast to Experiment 1a, the difference in the number of viewings was significant [$F(1, 46) = 7.22$, $p = .01$, $MSE = 0.0142$]. There was neither an overall age difference [$F(1, 46) = 2.14$, $p = .15$, $MSE = 0.0219$] nor an interaction of age group and number of viewings ($F < 1$). The lack of an age difference appears to contradict the findings of an age difference in the memory for target objects presented earlier. The target effect described earlier was an analysis of the twice-viewed targets only. However, the presentation block analysis added in once-viewed targets and, as can be seen in the means, the difference between the age groups was smaller in this condition. As mentioned at the beginning of the results section, the two target viewing conditions were not equivalent in the number of trials that were present. The once-viewed targets represent only one quarter of the targets presented (8 targets) and thus reliability of the means in this condition was less robust than those in the twice-viewed condition (24 targets). In fact, the standard deviations of the twice-viewed targets (younger adults: 0.086; older adults: 0.093) were approximately half those in the once-viewed condition (younger adults: 0.180; older adults: 0.154). However, this analysis weighted the viewing conditions equally and thus the smaller age difference and increased noise variance from the once-viewed targets diluted the larger difference in the twice-viewed targets. The t-test for the twice-viewed targets was presented earlier and was significant, but when a t-test was computed for the once-viewed targets, the age difference was not significant [$t(46) = 0.56$, $p > .20$]. Thus, it appears that the paradox of the lack of an age effect in this analysis is an artifact of type of analysis used rather than a limitation of the experiment.

Discussion

The first experiments demonstrate three important points. The first is that participants remembered the targets and the related distractors better than chance. This finding is even more impressive given that the object had been out of sight for at least 10 minutes. The visual memory test used in this experiment limited the information that could be used to the visual details of the object. Because the participant was presented with two tokens of the same object, s/he could not use the knowledge that, for example, a green drill had been presented to aid in the memory test. The test required that s/he remember which token (i.e. which green drill) was seen before to respond correctly. The ability of participants to determine (albeit with some difficulty) the correct token of an object that had been seen before indicates that the visual details of the object were maintained after the object was no longer the focus of attention. This finding argues against the visual theories of O'Regan (1992) and Rensink (2000), which claim that no visual information is maintained after attention has been withdrawn from an object. The current finding indicates that at a minimum, some of the visual details of objects encountered by a viewer were remembered.

The second finding of interest was the difference in the visual memory rates for the different object conditions. The finding that targets were remembered better than the distractor objects may not appear to be much of a surprise. It was, after all, the object for which the searcher was looking. The finding of reliable memory for objects that were not the target of visual search was more surprising. Additionally, visual memory appears to be dependent on the relationship of the object to the search target. Objects that were related to the targets were remembered better than objects that were not related. This supports the expectation that memory is tied to the likelihood that an object is processed. The objects that were related to the search targets were more likely to be examined or examined longer than the unrelated objects because they shared a feature with the target. This seems to have ensured that some of the visual details of the related objects were remembered. For the younger adults in both experiments, the unrelated objects were not remembered better than chance. Finally, the finding that the target objects viewed on both trials were remembered better than those viewed on only one trial demonstrates that the more an object is viewed, the better the memory will be. This is similar to the notion that the higher the probability that an object is viewed the better the memory will be. This will be more thoroughly examined in Experiment 2.

The age similarities and differences in Experiment 1b were also informative. The finding of an age difference in the memory for the target objects was expected. Older adults tend to not perform as well as younger adults in memory tests. In contrast to this typical pattern of results, older adults and younger adults remembered the visual details of the distractor objects equally well. Because this effect was limited to the distracting objects, it appears that the older adults may have allocated relatively more of their search time to the distracting objects than younger adults. Given that older adults had longer overall search times than younger adults, older adults had more opportunities to view the distracting objects. This possibility was examined in Experiment 2. The overall finding of equivalent memory for distracting objects for older and younger adults supports the claims made earlier about the involvement of inhibitory processes during search. If no inhibitory processes were involved in the search, there should be an age difference for all of the different types of objects (with the possible exception of the unrelated objects due to the fact that they were at chance levels for the younger adults). The fact that older adults remember the distractors, but not targets, as well as younger adults supports the claim made earlier that older adults somehow process the distractors more than younger adults. Decreased inhibitory efficiency would lead older adults, in this case, to be more likely to process the distractors than younger adults and thus have a greater chance of remembering them. This increased chance could lead to a relative improvement in memory for older adults in these specific conditions. It is possible that this improvement could extend to the processing of unrelated distractors, which would explain the finding that older adults performed slightly, but not significantly, better than younger adults on these objects. This fits well with the claim of Treisman and Sato (1990) that inhibition's role in visual search is to limit the distribution of attention to those objects that are potential targets.

Experiments 1a and 1b, however, cannot directly measure the processing that an object received and therefore used memory results to infer processing during the search. Experiment 2 more directly measured the processing that occurred during search by examining the eye movements that were made during the search task. By recording where a participant looked and what they looked at, Experiment 2 was able to more precisely determine the processing that the different objects received.

EXPERIMENT 2

The accuracy rate measure used in Experiments 1a and 1b gave an aggregate measure of the processing involved during search. The second experiment attempted to obtain a more fine-grained analysis of the search process while replicating the previous results. Experiment 2 used a similar procedure to Experiment 1 with the exception that during the search task, the participants' eye movements were monitored. By measuring how long, and how many times each of the objects in the array is examined, a clearer picture of the operation of executive processes during a search could be obtained.

In conjunction search tasks, like the ones presented here, there are many potential objects to examine that may or may not share a feature of the target. The second experiment investigated the relation between viewing behavior and visual memory. There have been several examinations of eye movements and visual search. L. G. Williams (1967) found that participants preferentially directed their eyes to stimuli that shared the target color. Other target characteristics, such as size and shape, were not as preferentially selected. Zelinsky (1996) found that participants were more likely to examine distractor objects that shared a feature with the target than those that did not. However, this preference did not account for all of the variance in the object selection, indicating that eye movement guidance during search was not perfect.

It was expected that differences in eye movement behavior would partially account for memory differences. Eye movement measures examine where and for how long the eye dwells when looking at the stimuli. In the current experiment, it was expected that objects that were related to the search would be examined more frequently than those that were not. Targets should be viewed on every trial because the task is to count these objects. Related distractors should be the next most likely to be viewed and the unrelated distractors should be the least likely. The same pattern should follow for the number of separate looks to the objects and the total amount of viewing time on the object.

In addition to the general search aspects, Experiment 2 also examined search differences between younger and older adults. There has been little exploration of the differences in the way that older and younger adults look at the world in general, and specifically in visual search. Scialfa and Joffe (1997) observed eye movements during a visual search task and found that older adults make more saccades than younger adults and have a longer average fixation duration than younger adults. They claimed that this was consistent with a restricted field of view and a general slowing pattern for older adults. However, one critical issue makes the comparison between their study and the current study difficult. Specifically, their particular eye movement measures are not good indicators of differential processing of the various types of objects. The number of saccades made and the average fixation duration reflect the processing of the entire array and do not provide information about the processing of individual distractors. This limits the usefulness of these data for comparison to the current study because in the current study the critical comparison is between different types of objects. Recently, Mayr and Spieler (2002) investigated search differences between older and younger adults in easy search tasks and relatively more difficult search tasks. Older adults produced more fixations in the search regardless of difficulty level. However, there was no difference in the likelihood of refixating an item. These findings are similar to those of Scialfa and Joffe (1997) and are also limited by the fact that results are based on an aggregate average over the entire display.

Kramer, Hahn, Irwin, and Theeuwes (1999) also investigated age differences in eye movement behavior. Using the search task described in the introduction, they investigated the effect of a sudden visual onset on eye movements. They were interested in whether there would be an age difference in the likelihood that a sudden onset would be fixated. They found that both age groups were equally likely to execute an eye movement to the sudden onset if the onset was equiluminant with the other distractor items. This indicated that older and younger adults were equally likely to suppress eye movements when the stimulus was not salient. However, if the added distractor was salient (i.e. brighter than the other objects), younger adults could suppress eye movements to the added distractor but older adults could not. The results of Kramer et al. (1999) are important for the current study. If older adults are able to segregate the search environment based on a feature (as suggested by Plude and Doussard-Roosevelt, 1989), then the objects that are segregated may not be salient and thus there may be no difference between the age groups on the performance on these items. On the other hand, the items that cannot be segregated from the target based on a feature must be individually processed and rejected. This additional processing may make these items salient and thus elicit the age differences described by Kramer et al. (1999). Eye movement measures are required to determine if the search patterns of the older and younger adults are similar.

The current experiment was intended to explore the role of visual processing of search arrays on memory. The purpose of examining the viewing behavior during search was to obtain some insight into the visual memory from visual search. It was expected that different viewing patterns could influence visual memory. The experiment also explored the role of inhibition on search patterns and on eye movement measures. Given the inhibition deficit theory of Hasher et al. (1999), older adults should demonstrate greater difficulty in rejecting distractors than younger adults. This greater difficulty should result in viewing a higher proportion of distracting objects, viewing distracting objects more frequently, and viewing them for a longer period of time. These measures would indicate that older adults have decreased efficiency of inhibitory processing that affects the visual search process. Additionally, the differences between the search tasks used in the studies discussed earlier and that used in this study (real-world objects with many different types of distractors) could lead to a different pattern of results than have been found previously.

The final point to be examined in this experiment is the effect of multiple views of objects on eye movement measures and whether or not there are any age differences in this effect. Althoff and colleagues (Althoff & Cohen, 1999; Ryan, Althoff, Whitlow, & Cohen, 2000) have demonstrated that on previously viewed stimuli, there tend to be fewer fixations and a smaller sampling region.

Experiment 2 can examine this effect on eye movement measures, but there are some limitations. The arrays in the current study were different in the two views in spatial configuration and number of targets. Thus, any advantage from the multiple views may be eliminated by the changes in the stimuli. However, if there is some memory, there may be differences in the eye movement measures used here. Additionally, any age group interaction with presentation block would speak to the role played by the inhibition of previously viewed objects on the allocation of eye movements.

Method

The method used in Experiment 2 closely followed the method of Experiment 1 with the exception that in Experiment 2 the participants' eye movements were monitored during the search task.

Participants.

Twenty-four younger adults and 24 older adults from the same sources as in Experiment 1b participated in this experiment (see Table 1 for demographic information).

Design.

As in Experiment 1b, there were three factors: object type, number of targets and age group. Eye tracking allowed for additional dependent measures to be collected during the search component of the experiment, including the proportion of trials on which an object was examined, number of times that an object was looked at, and the total amount of time spent examining the object.

Materials.

The materials were the same as those in Experiment 1b. However, due to a change in equipment, the visual angle that the display subtended was 12% larger in this experiment than in Experiment 1b. The display subtended 35° horizontally and 26° vertically. The objects along their longest dimension subtended 3.9° with a minimum of 3.9° between the edges of objects.

Equipment

Eye movements were monitored using an ISCAN RK-726PCI pupil tracking system sampling at 240 Hz. This system operates by reflecting an infrared light into the right eye of the participant and then measuring the reflection of the infrared light from the eye using a camera sensitive to this wavelength of light. The ISCAN system calculates two reflections: one from the pupil and one from the cornea. The two reflections are used to calculate the center of vision, which is then output to the display computer (to be exact, the pupil is the point of highest absorption of infrared light on the eye, thus position of the pupil is the point of the lowest reflection). Prior to data collection, the output from the ISCAN system and the display computer were calibrated using a 9-point calibration screen. The accuracy of the calibration was checked periodically throughout the experiment. The calibrated position is accurate to less than 1° of visual angle both horizontally and vertically. Because of this limitation, the scoring region of each object (the area in which a fixation must fall to be counted as on the object) was slightly larger than the object itself (0.4° larger than the object). The ISCAN equipment can handle some minor head movements by the participant and thus no bite bar was required. However, a chin rest was used to limit head movements to some degree.

Procedure

The procedure was the same as Experiment 1b with the stated exceptions that were required to institute eye tracking. Following the presentation of the sample display, the participant was informed that while they were looking for the objects described, their eye movements would be monitored. The participant was required to place his/her head in a chin and forehead rest to maintain relative stability during eye tracking. After the participant was comfortable in the chin rest, the experimenter adjusted the eye-tracking camera to obtain a trackable image. The participant was then asked to fixate on each of 9 points on an otherwise blank screen for calibration. After calibration was completed, it was immediately checked to determine if calibration was sufficient. If not, the 9-point sequence was repeated. A trial began with a display of the search target description (e.g., "the saw that is yellow"). The participant read the description and looked back to a central box. When the experimenter determined that the participant was looking at the central box, the search array was presented. The participant viewed the array and counted the targets while their eye movements were monitored. After each trial, the calibration screen was presented, which allowed the experimenter to determine if the system was still tracking adequately. The memory test proceeded identically to Experiment 1b.

Eye tracking analyses.

The eye tracking data consist of XY coordinates of the calibrated eye position for each sample of the eye tracking system. The ISCAN system used in this experiment samples at 240 Hz or roughly one sample every 4-5 ms. To create a more stable eye tracking record, every sample was averaged with the 2 preceding and the 2 following samples. This was done during analysis after eye tracking had been completed. Fixations were determined by grouping consecutive samples that were no more than 8 pixels in Euclidian distance from the previous sample. Any fixation that was less than 90 ms or greater than 4000 ms was discarded. One trial from one older adult was eliminated in the eye tracking results due to an experimenter error. All trials from all of the other participants were analyzed.

All of the analyses were performed on object regions. An object region was defined as the 3.9° x 3.9° box (+0.4° in each dimension) centered on the object that had been used to place the object in the array. Fixations were determined to be on a particular object if it fell within this region. An example of the scoring region can be seen in Figure 5.

Results

Search Results

As can be seen in Table 3, the overall search times were faster than in the first experiment. Additionally, the accuracy rates were worse than in the first experiment. While this could be evidence of a speed-accuracy trade-off, I believe that this it is more likely that the changes in the procedure required for eye tracking led to these differences. The use of an eye tracker may have made participants focus more on the task at hand (especially the older adults) and thus sped up their performance. Additionally, because of the eye tracker, participants were unable to look at the buttons used to input their responses. This likely decreased the accuracy of the responses.

The search results were analyzed as in Experiment 1b. Overall, older adults were slower to respond correctly to the search arrays than younger adults [$F(1, 42) = 12.12$, $p = .001$, $MSE = 34215880$][3]. Again, correct search times were faster for the second presentation of the search arrays than the first presentation [$F(1, 42) = 14.68$, $p < .001$, $MSE = 3236603$]. This difference was modified by a marginal interaction with age group [$F(1, 42) = 3.06$, $p = .088$, $MSE = 3236603$], with older adults appearing to improve more in the second presentation. As in Experiment 1b, there was an increase in the search time as more targets were introduced into the array [$F(2, 84) = 4.64$, $p = .012$, $MSE = 3584358$], and there was an marginal interaction with age group [$F(2, 84) = 2.56$, $p = .083$, $MSE = 3584358$] whereby younger adults' search in the second viewing was practically unaffected by the number of targets. Older adults appeared to continue to take more time as the number of targets in the second presentation increased. There was neither an interaction of presentation and number of targets [$F(2, 84) = 1.36$, $p > .20$, $MSE = 3726271$] nor a three-way interaction ($F < 1$).

For search accuracy, younger adults were more accurate than older adults [$F(1, 46) = 63.74$, $p < .001$, $MSE = 0.0646$]. As in the search times, there was an

[3] Four older adults did not provide any correct responses in the 3-target condition and thus were excluded from the search time analysis. As mentioned earlier, the change in procedure may have led to decreases in accuracy.

effect of presentation [$F(1, 46) = 5.51$, $p = .023$, $MSE = 0.0189$], with accuracy improving in the second presentation. There was, however, no interaction with age group ($F < 1$). This indicates that both age groups were able to improve their performance equivalently. There was an effect of the number of targets [$F(2, 92) = 52.48$, $p < .001$, $MSE = 0.0241$], with accuracy decreasing as the number of targets the search array increased. Additionally, there was an interaction between the number of targets and age group [$F(2, 92) = 23.93$, $p < .001$, $MSE = 0.0241$], with older adults being more affected by the additional search targets than younger adults. In contrast to Experiment 1b, there was an interaction of the presentation and the number of targets [$F(2, 92) = 5.98$, $p = .004$, $MSE = 0.0184$], with the accuracy improving most in the 3-target condition across the two presentations. There was no three-way interaction with age group ($F < 1$).

A

	Number of Targets			
	0	1	2	3
Younger Adults				
Presentation 1	4985 (326)	4463 (238)	5005 (363)	4924 (311)
Presentation 2		4287 (276)	4455 (256)	4261 (317)
Older Adults				
Presentation 1	7656 (720)	6500 (581)	7645 (838)	8848 (1521)*
Presentation 2		5938 (475)	6543 (557)	6974 (785)

B

	Number of Targets			
	0	1	2	3
Younger Adults				
Presentation 1	0.91 (.026)	0.89 (.023)	0.84 (.029)	0.75 (.025)
Presentation 2		0.87 (.021)	0.80 (.025)	0.87 (.028)
Older Adults				
Presentation 1	0.84 (.027)	0.80 (.021)	0.55 (.048)	0.37 (.057)
Presentation 2		0.82 (.030)	0.57 (.041)	0.49 (.047)

*Four older adults did not have any correct responses in the 3-target conditions in the first presentation.

Table 3. Mean (Standard Error) for (A) Correct Search Times (in ms) and (B) Search Accuracies (proportion correct) for Experiment 2.

Visual Memory Test

Again the more important results are the visual memory performance results. The results of Experiment 2 are shown in Figure 4. As in Experiment 1b, the visual memory results for each age group were compared against chance levels. As can be seen in Figure 4, the memory results of Experiment 2 demonstrated a similar pattern to that seen in Experiment 1b. For younger adults, target objects [.86; $t(23) = 19.67$, $p < .001$], category distractors [.60; $t(23) = 6.35$, $p < .001$], and color distractors [.60; $t(23) = 5.25$, $p < .001$] were all remembered better than chance. In contrast to Experiments 1a and 1b, unrelated distractors were remembered significantly better than chance as well [.55; $t(23) = 3.36$, $p =$

.003]. Older adults demonstrated a similar pattern to Experiment 1b with the exception of the unrelated distractors. Older adults remembered target objects [.76; $t(23) = 11.11$, $p < .001$], category distractors [.55; $t(23) = 2.87$, $p = .009$], and color distractors [.58; $t(23) = 4.21$, $p < .001$] better than chance. However, older adults did not remember the unrelated distractors [.53; $t(23) = 1.61$, $p = .12$] better than chance level.

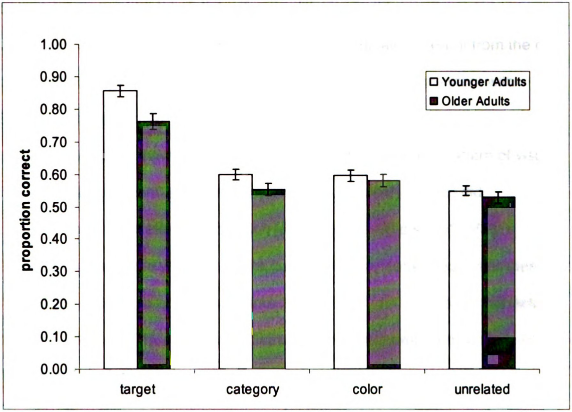

Figure 4. Mean proportion correct for the visual memory test in Experiment 2. The error bars are standard errors.

In the comparison of differences between the object conditions for the younger adults in Experiment 2, there was a main effect of condition [$F(3, 69) = 80.43$, $p < .001$, $MSE = 0.0057$]. Again, targets were remembered better than category distractors [$t(23) = 9.98$, $p < .001$] and color distractors [$t(23) = 11.70$, p

$< .001$]. As in Experiment 1a and 1b, objects in the two related conditions were remembered at similar levels [$t(23) = 0.14$, $p > .20$]. However, unlike in Experiment 1a and 1b, the related distractors were not remembered significantly better than the unrelated distractors [category distractor, $t(23) = 2.28$, $p = .20$; color distractor, $t(23) = 2.02$, $p = .33$]. These comparisons were not significant with the Bonferroni correction. However, using a less stringent criterion for comparisons, the unrelated distractor condition was different the category distractor condition [$t(23) = 2.28$, $p = .032$] and marginally different from the color distractor condition [$t(23) = 2.02$, $p = .055$]. This pattern is consistent with Experiments 1a and 1b.

Older adults, however, demonstrated a slightly different pattern of visual memory in Experiment 2 than in Experiment 1b. The older adults did demonstrate a main effect of condition [$F(3, 69) = 41.40$ $p < .001$, $MSE = 0.0066$]. Similar to the younger adults, targets were remembered better than the related distractors [category distractors, $t(23) = 8.11$, $p < .001$; color distractors, $t(23) = 7.79$, $p < .001$], and related distractors were remembered similarly [$t(23) = 1.20$, $p > .20$]. Older adults' memory for the unrelated distractors was not significantly different from their memory for the related distractors [category distractor, $t(23) = 1.24$, $p > .20$; color distractor, $t(23) = 2.06$, $p > .20$][4].

As in Experiment 1b, the two age groups were compared directly. There was an effect of condition [$F(3, 138) = 116.69$, $p < .001$, $MSE = 0.0062$].

[4] For the older adults, the difference in memory between the color distractors and the unrelated distractors was significant ($t(23) = 2.06$, $p = .051$) using less stringent comparisons than the Bonferroni correction. However, the difference between the category distractors and the unrelated distractors was not significant even by less stringent measures.

However, in contrast to Experiment 1b, there was a difference between the age groups [$F(1, 46) = 6.75$, $p = .013$, $MSE = 0.0034$]. There was a marginally significant interaction of age group and object condition, [$F(3, 138) = 2.35$, $p = .075$, $MSE = 0.0062$]. To explore the interaction, the age groups were compared for each of the object conditions. As expected, younger adults outperformed older adults in their memory for the visual details of the target objects [$t(46) = 3.07$, $p = .004$]. Additionally, as in Experiment 1b, there were no significant age differences for the color distractor condition [$t(46) = 0.60$, $p > .20$] or the unrelated distractor condition [$t(46) = 0.88$, $p > .20$]. The category distractor did, however, yield a marginally significant age difference with younger adults performing better than older adults [$t(46) = 1.95$, $p = .057$]. This last difference contrasts with the results of Experiment 1b.

As in the Experiment 1a and 1b, the targets viewed on only one trial were compared to targets viewed on both trials. Both age groups had better memory for targets viewed twice (younger adults: .855; older adults: .764) than for those viewed once (younger adults: .784; older adults: .696). Consistent with Experiment 1b, the difference in the number of viewings was significant [$F(1, 46) = 8.92$, $p = .005$, $MSE = 0.0130$]. However, in contrast to Experiment 1b, there was the expected age difference in this experiment [$F(1, 46) = 8.46$, $p = .006$, $MSE = 0.0115$]. Finally, there was no interaction of age group and number of viewings ($F < 1$). Again, the number of viewings possible seems to influence visual memory. This will be further examined using the eye movement data.

Eye Movement Results

There are several ways to interpret the eye tracking data. These data will be discussed in two sections: age comparisons of eye movement behavior during the search portion of the experiment and the relationship of viewing behavior to visual memory. Both sections examined the viewing behavior for the objects that were tested from each array. This means that eye tracking results for one target, one category distractor, one color distractor, and one unrelated distractor from each array were examined. However, because the participants did not know which object was going to be tested (or for that matter that there was a test at all) while they were viewing the array, the tested objects are equivalent to the other objects in each condition. The three measures of specific interest were the proportion of arrays in which an object was viewed (proportion viewed), the number of separate looks to an object (number of entries), and the total time that an object was examined during the search. The comparison of visual memory and viewing behavior was only preformed for the number of entries and the total time analyses. An example scan pattern can be seen in Figure 5.

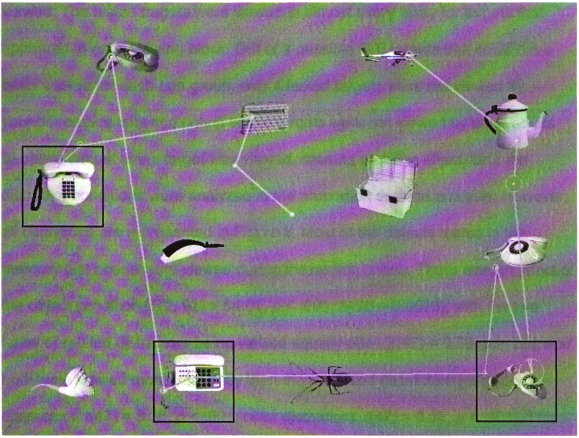

Figure 5. A example of the scan pattern for a younger participant looking for white telephones. The saccades are represented by the lines and fixations are represented by the circles. The size of the circle is proportional to the fixation duration. The three white telephones are highlighted in the figure by the black boxes, which are the size of the scoring region used. Any fixation that fell within the region was counted as on the object. The color distractor was the white pipe (lower left corner), the category distractor was the yellow telephone (middle right), and the unrelated distractor was the green lady's wallet (left center). For photocopying purposes, the background presented in this image is lighter than was true in the experiment.

Proportion Viewed.

The proportion viewed measure determines the proportion of arrays in which a particular object was looked at in either (or both) of the trials that an array was seen. "Looked at" in this case means that at least one fixation landed in the object region. This fixation could have been as short as 90 ms, but as long as the fixation was contained in the object region, the object was counted as viewed. The tested targets were viewed in almost every array for targets that appeared in each viewing block. Out of a possible 576 targets that could have been viewed for each age group, only 4 tested targets were not viewed by younger participants and only 6 tested targets were not viewed by older adults. Because almost every target was viewed, causing a ceiling effect, only the distractor conditions were analyzed in the proportion entered analysis. However, all conditions are represented in Figure 6. Most of the objects tested in the memory test phase were viewed during the search phase. There was an effect of the object condition [$F(2, 92) = 54.01$, $p < .001$, $MSE = 0.0073$], with the two types of related distractors being viewed equally often [$t(47) = 0.78$, $p > .20$], and both were viewed more frequently than the unrelated distractors [category distractors, $t(47) = 8.36$, $p < .001$; color distractors, $t(47) = 8.56$, $p < .001$]. This pattern is similar to that of the memory results. This similarity supports the importance of viewing the object for finding memory for the visual details. There was neither an effect of age group ($F < 1$) nor an interaction of age group and object condition [$F(2,92) = 1.24$, $p >.20$, $MSE = .0013$).

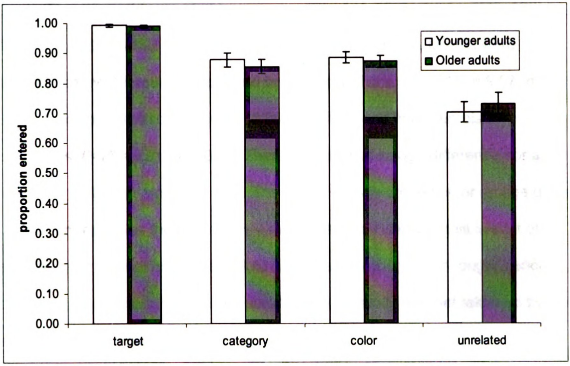

Figure 6. Mean proportion of memory-tested objects entered during the visual search task in Experiment 2. The error bars are standard errors.

Entry Analysis.

The number-of-entries analysis is a more fine-grained analysis than the proportion entered analysis because a participant could look at a particular object several times on one trial. Entries can be described as the number of separate looks to an object. For example, in keeping track of the number of entries to a green drill, a participant could fixate at the green drill (Entry 1), and then fixate a yellow drill or other objects, eventually fixating the green drill (Entry 2) once again. This pattern would yield an entry count of 2 for that trial. If during the second viewing of the array the green drill were viewed 3 times, the green drill would have an entry count of 5. If visual memory is dependent on the amount of processing an object receives during search, then the number of separate looks to an object could serve as a predictor of the memory that is retained.

The different types of objects were entered at different rates [$F(3, 138) = 140.94$, $p < .001$, $MSE = 0.164$]. As can be seen in Figure 7, targets were entered the most frequently, followed by category distractors [$t(47) = 9.97$, $p < .001$], then color distractors [$t(47) = 2.93$, $p = .034$], and finally unrelated distractors [$t(47) = 9.91$, $p < .001$]. There was neither an age difference nor an interaction with age group (*F*s < 1). The lack of an age difference or an age group interaction replicates the proportion viewed analysis. However, this is a bit of a surprise given that older adults looked at the search arrays for a longer period of time than younger adults. The additional time apparently was not taken up by searching the objects multiple times.

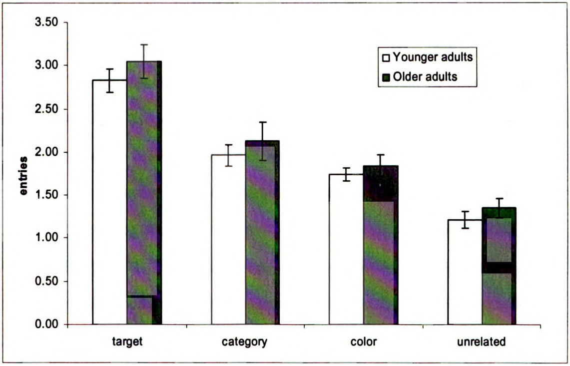

Figure 7. Mean number of entries into the object regions of the tested objects during search in Experiment 2. The error bars are standard errors.

Total Time Analysis.

The final eye movement analysis to be discussed here is the total time analysis. The total time is simply the total number of milliseconds that a participant viewed an object combined across the two viewings. This is most fine-grained analysis discussed here as a participant could enter an object infrequently but still spend a great amount of time examining the object during those infrequent entries. Only those objects that were viewed at least one time were included in the total time analyses. The total time could be more informative than entries or proportion entered as it can be thought of as a direct measure of processing time.

The total time analysis yielded similar results to the entry analysis with a main effect of object condition [$F(3, 138) = 162.47$, $p < .001$, $MSE = 63562$; see Figure 8]. Target objects were looked at longer than category distractors [$t(47) = 12.15$, $p < .001$]. Category distractors were in turn viewed longer than color distractors [$t(47) = 3.37$, $p = .01$], followed by unrelated distractors [$t(47) = 10.10$, $p < .001$]. In contrast to the entry analysis, however, there was an age effect, with older adults looking at objects longer than younger adults [$F(1, 46) = 8.82$, $p = .005$, $MSE = 67917$]. This is not surprising given that older adults had longer search times. It appears that the extra search time for the older adults is spent dwelling on the individual objects rather then more extensively searching the array. There was also an interaction between the type of object and age group [$F(1, 46) = 5.03$, $p = .002$, $MSE = 63561$]. The interaction was caused by the fact that older adults spent much more time examining the target objects than the younger adults in comparison to the other conditions.

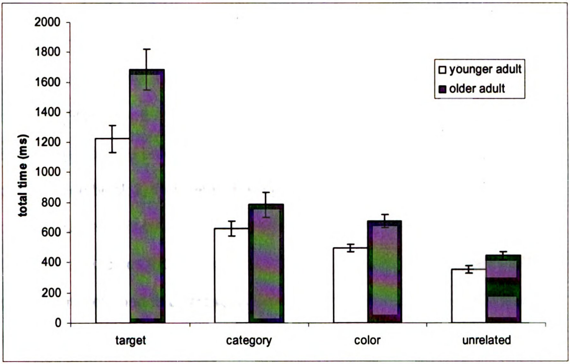

Figure 8. Mean total fixation time within the object regions of the tested objects during search in Experiment 2. The error bars are standard errors.

Viewing Trial and Target Count Analyses

Because the arrays were presented in two blocks, differences in the two viewings for each of the eye movement measures could be examined. Additionally, the effect of the number of targets in the array for each trial (target count) was examined. For all of the analyses in this section, four factors were analyzed: object condition, age group, viewing trial, and target count of the array.[5]

Viewing trial

For the proportion entered and the number of entries measures, the only significant effect was a main effect of viewing trial in the number of entries analysis [$F(1, 46) = 5.70$, $p = .021$, $MSE = .179$]. In presentation block 1, the tested objects were entered on average 1.01 times per object whereas in presentation block 2, they were entered on average 0.95 times per object. No other significant effects or interactions with viewing trial were found (all Fs < 1.78). This indicates that, although the same proportion of objects were entered, participants returned to previously viewed objects (on a particular trial) less frequently in the second presentation block.

As in the number of entries, there was a main effect of viewing trial on the total time measure [$F(1, 46) = 19.21$, $p < .001$, $MSE = 62744$] with objects being looked at for 494 ms on average in the first presentation block and 429 ms in the second block. However, in contrast to the number of entries analysis, there was an interaction between the presentation block and the object condition [$F(3, 138) = 9.46$, $p < .001$, $MSE = 34804$]. This appeared to be the result of the greater

[5]These analyses were performed in a different manner than the other eye movement analyses. Rather than combining the two viewing trials, these analyses examined the viewing behavior for each trial separately. Only those objects (targets and distractors) that came from arrays with at least one target present on both viewing trials were included, eliminating objects from 8 of the 32 arrays viewed for each participant. The differences in the data used here make direct comparisons to previous analyses, especially in the proportion entered analyses, difficult. Any missing cell in the analysis for the total time measure was filled with the participant's condition average. All of these missing cells (5 for younger adults and 1 for older adults) were in the unrelated distractor condition.

drop in total time for objects in the target condition than objects in the distractor conditions. No other interaction was significant (all Fs < 1.26).

Target Count

There were differences in the proportion entered [$F(2, 92) = 26.56$, $p < .001$, $MSE = 0.0242$] and the number of entries [$F(2, 92) = 9.75$, $p < .001$, $MSE = 0.113$] as the number of targets increased in an array. The average proportion entered for all objects fell as the number of targets increased (1 target = 0.73; 2 targets = 0.70; 3 targets = 0.65) as did the number of entries (1 target = 1.04 entries; 2 targets = 0.99 entries; 3 targets = 0.93 entries). There was also an interaction between object condition and target count [proportion entered, $F(6, 276) = 3.00$, $p = .007$, $MSE = 0.0232$; number of entries, $F(6, 276) = 4.43$, $p < .001$, $MSE = 0.0841$]. The interaction was the result of both measures decreasing for the distractor conditions only. The target condition was examined on an equal proportion of trials and with an equal number of entries regardless of number of targets present. A possible reason for this interaction is that participants were spending more time viewing the targets when there were more targets present in order to keep track of them. There was a numerical (though not significant) increase in the total time spent on target objects as the number of targets increased (1 target = 768 ms; 2 targets = 787 ms; 3 targets = 802 ms). Though this difference is not significant, it may be an indicator of the reason for the interaction in the other measures. No interactions were significant for the total time measure (all *F*s < 1.27).

Regression analyses

The next section examines the relationship of the different eye movement measures to the visual memory test accuracy. It was expected that the more an object was processed, the greater the memory test accuracy would be. Regression analyses were computed for both the number of entries and the total time measures.

Entries

The analysis regressed the number of entries onto accuracy from the memory test for each object condition, resulting in a point-biserial correlation. As was done in Hollingworth and Henderson (2002), a procedure was used for the regression analyses that accounted for the fact that there were 128 observations from each of the 24 different subjects in each age group. This procedure involves first removing the variance attributable to the individual participant's means (through the use of dummy variables for each participant) and then determining if there was an effect of the predictor variable (entries) on the dependent variable of interest (memory test accuracy). In other words, the regression analyses used here were hierarchical regression analyses that first removed the variance attributable to the participant's overall mean, and then examined the effect of the predictor variable. The data are presented in Figure 9. For the figure, the entries were divided into quartile bins for each object condition for each participant. The mean accuracy for each quartile is presented in the figure.

The regressions were performed separately for each condition. The statistics provided here are the F values for the change in the R^2 of the regression model above the individual participant variance. For younger adults (top panel of Figure 9), there was a significant relationship between the number of entries and memory test accuracy for the category distractors [r_{pb} = .16, $F_{change}(1, 743) = 18.39$, $p < .001$], and color distractors [r_{pb} = .10, $F_{change}(1, 743) = 7.55$, $p = .006$]. There was not a significant relationship between memory test accuracy and the entries in the target condition [r_{pb} = .04, $F_{change}(1, 551) = 10.2$, $p > .20$] or unrelated distractor condition [r_{pb} = .05, $F_{change}(1, 743) = 1.51$, $p > .20$]. For older adults (bottom panel of Figure 9), there was a significant relationship between entries and accuracy for the category distractors [r_{pb} = .09, $F_{change}(1, 742) = 6.47$, $p = .01$]. Unlike younger adults, however, older adults did not demonstrate a relationship between accuracy and entries in the color distractor condition (r_{pb} = -.02, $F_{change} < 1$). Older adults also did not demonstrate a relationship between the number entries in the target condition [r_{pb} = .07, $F_{change}(1, 551) = 2.50$, $p = .12$][6] or the unrelated condition and accuracy [r_{pb} = .06, $F_{change}(1, 742) = 2.49$, $p = .11$].

---

[6] As in most of the analyses described in this study, the target condition regressions reported above were performed on the data from targets that could be viewed twice. However, it is possible to examine the relationship of memory and the entries for all targets. If number of entries is related to visual memory, then the number of opportunities that one has to view the target is not as critical as the number of separate looks to the object. Therefore, an additional regression between the number of entries and visual memory was computed with all targets included. For both age groups there was a significant correlation of memory and entries [younger adults, r_{pb} = .08, $F_{change}(1, 743) = 4.69$, $p = .03$; older adults, r_{pb} = .08, $F_{change}(1, 742) = 4.71$, $p = .03$].

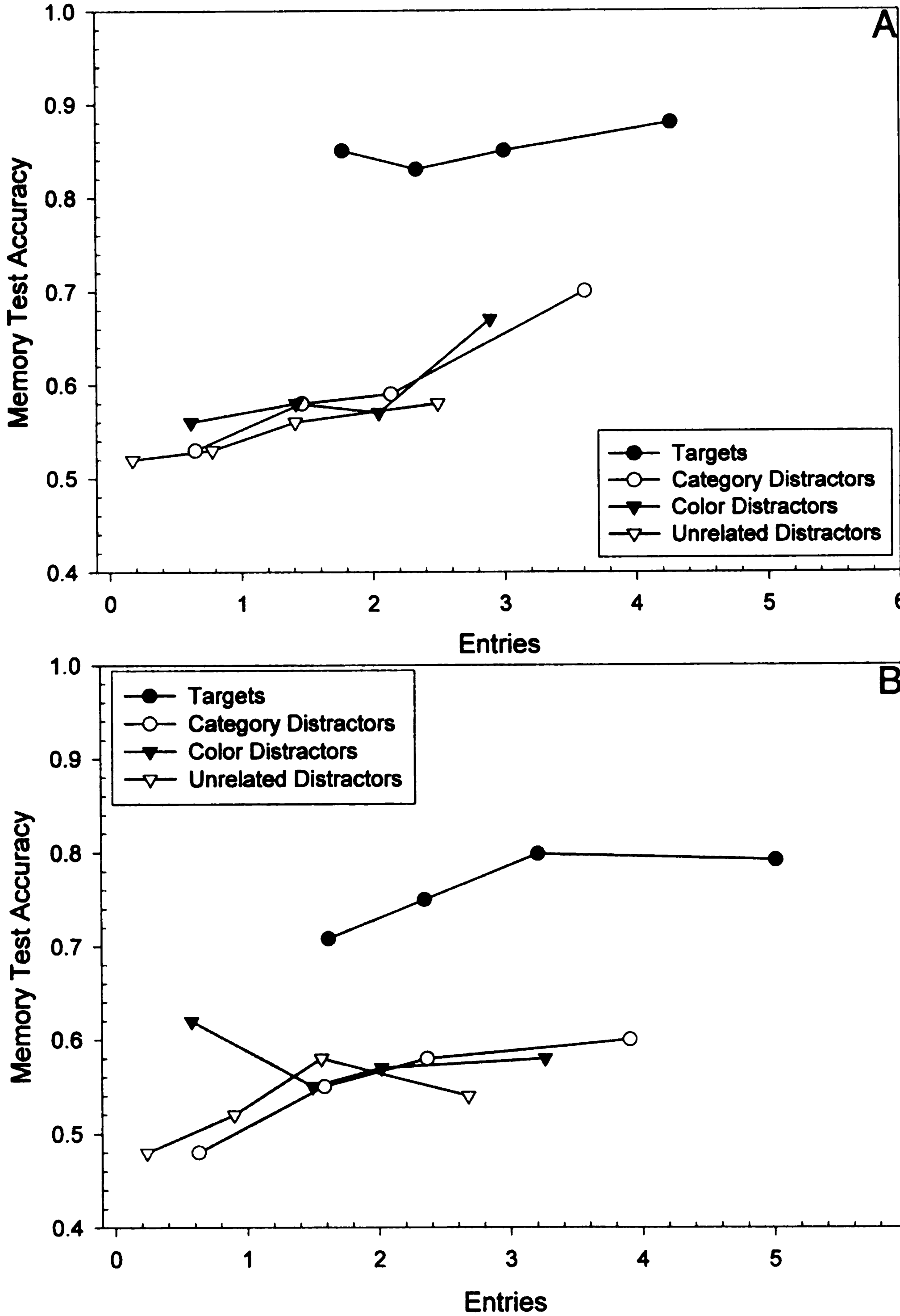

Figure 9. Memory test accuracy as a function of entries. The data points are the average of each quartile of entries within each condition. The panel A contains the data for younger adults and panel B contains the data for older adults.

One interesting aspect of the regression analyses is that it appears that the target objects were remembered better that the distractors regardless of the number of separate looks to the objects. This is evident from Figure 9, which shows that even in the quartile with the most entries for each of the distractor conditions (all of which are have more entries than the than the smallest number of entries quartile for the target objects), memory performance does not reach the level of the worst quartile for the target objects.

Total Time

The same type of regression analysis related the total time and memory test accuracy within each object condition. As in the entry analysis, younger adults (top panel of Figure 10) demonstrated a significant relationship between total time and memory test accuracy for category distractors [r_{pb} = .19, $F_{change}(1, 656) = 25.50$, $p < .001$], and color distractors [r_{pb} = .13, $F_{change}(1, 656) = 11.58$, $p = .001$]. The relationship between visual memory and total time spent on targets was marginally significant [r_{pb} = .08, $F_{change}(1, 548) = 3.45$, $p = .06$]. Replicating the entry analysis, there was no significant relationship between total time spent on an object in the unrelated distractor condition and memory test accuracy (r_{pb} = .03, $F_{change} < 1$). For older adults (bottom panel of Figure 10) there was a significant relationship between total time and accuracy for category distractors [r_{pb} = .12, $F_{change}(1, 631) = 8.71$, $p = .003$]. Total time spent viewing color distractors demonstrated a marginal relationship with accuracy [r_{pb} = .07, $F_{change}(1, 644) = 3.53$, $p = .061$]. Older adults did not demonstrate a relationship between total time and accuracy for targets [r_{pb} = .07, $F_{change}(1, 545) = 2.42$, p = .12][7] or unrelated distractors (r_{pb} = .04, $F_{change} < 1$).

The total time regression analysis yielded a similar pattern to the number of entries analysis, with target objects being remembered better than distractor objects regardless of the total time spent examining the objects. It is apparent from Figure 10 that for both age groups target objects were remembered better than distractors at all levels of total time and that memory performance in the distractor conditions does not reach the level of the lowest quartile for the target objects.

[7] Again, an additional regression was computed for target objects. In this regression of total time and visual memory accuracy, all targets viewed at least once were included. Again, both age groups demonstrated a significant relationship between total time spent viewing the target objects and memory test accuracy in this analysis [younger adults, r_{pb} = .10, $F_{change}(1, 734) = 7.74$, p = .006; older adults, r_{pb} = .08, $F_{change}(1, 717) = 4.05$, p = .045]

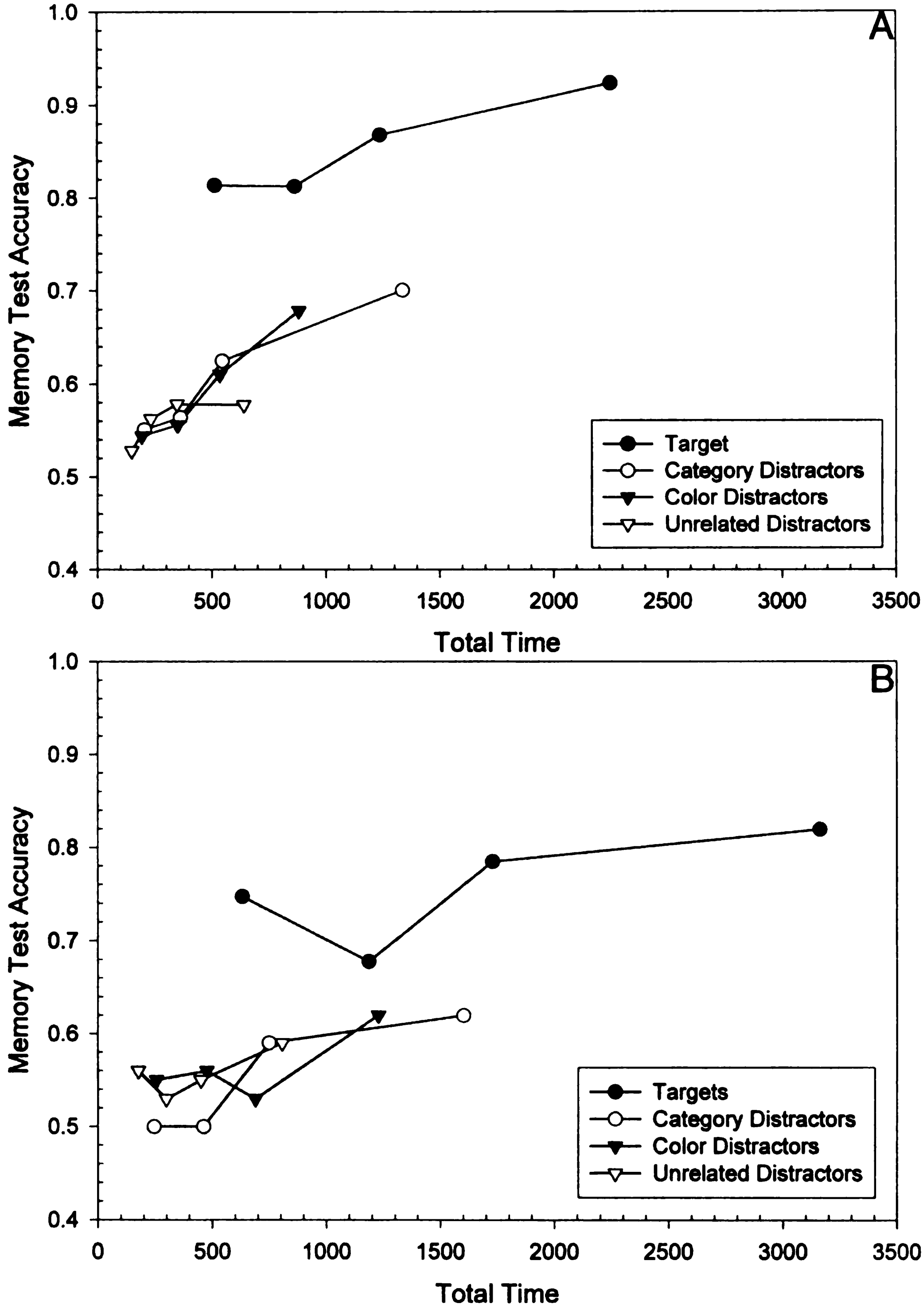

Figure 10. Memory test accuracy as a function of total time. The data points are the average of each quartile of total time within each condition. The panel A contains the data for younger adults and panel B contains the data for older adults.

Discussion

The primary goal of the second experiment was to examine the visual memory from search as a function of the viewing behavior that occurred during search. Visual memory should be tied to viewing behavior, which in turn should be tied to the application of executive control processes. Certain objects could be viewed more frequently or for more time than others based on their relationship to the search target. Differences in the viewing behavior of the two age groups could indicate the contribution of inhibition. The data from this experiment clearly support the role of viewing behavior in visual memory for different objects, but evidence for the contribution of inhibition is less clear.

The visual memory results of Experiment 2 were similar to those of Experiment 1b. As in Experiment 1b, younger adults remembered target objects better than related distractors, which were remembered better than unrelated distractors. Older adults again showed better memory for target objects than distractors, and the distractors were remembered at similar rates, though the category distractors were remembered slightly better than the unrelated distractors. The differences in the memory pattern were evident in the comparisons to chance because younger adults remembered unrelated distractors better than chance, whereas older adults did not. This is the opposite pattern to that seen in Experiment 1b. This different pattern of results in comparison to chance seems to indicate a small memory effect for the unrelated distractors in both age groups; however, it may be easy to miss. The replication of the finding that older adults could remember distractors as well as younger adults (with the possible exception of category distractors in this experiment) supports the claims made in Experiment 1b. The advantage for older adults in memory for distractor objects indicates that only these objects were differentially available to them in comparison to the younger adults.

The replication of the memory pattern from Experiment 1b was important as it supports the claims of Experiment 1a and 1b that visual memory can exist even after a period of time in which the object is out of sight. The finding that visual memory is detailed enough to support token discrimination supports the claims of Hollingworth and Henderson (2002) that there are long-term object files that contain some visual information about objects that were processed previously.

Turning now to the critical eye movement data, Experiment 2 demonstrated that the eye movement data generally parallel the memory data. Overall, most of the tested objects were viewed at least once during the search task. Even in the unrelated condition, objects were viewed at least once in approximately 70% of the arrays. This seems to indicate that simply having viewed the object (viewed here means that at least one fixation fell in the object region during the search) is not sufficient for remembering the object. Otherwise, the participants would have been considerably more accurate overall on the memory test. However, from another perspective, the proportion-entered analysis showed a pattern that mirrored the visual memory results, with the target being viewed in almost every array and showing the highest memory rates. Related distractors were viewed in fewer arrays than the target, but category and color distractors were viewed on an equal proportion of the arrays. This similarity in the proportion viewed mirrors the similarity in the visual memory performance. Unrelated distractors were viewed on the smallest proportion of trials and had the worst memory performance for the younger adults. Older adults also showed similar patterns between the proportion entered and the visual memory results with the exception that unrelated distractors were not necessarily remembered more poorly than related distractors.

The number of entries analysis and the total time analysis showed a pattern similar to the memory results, and they each demonstrated a relationship to accuracy on the visual memory test. These two eye movement measures are related in that an increase in entries for an object increases the likelihood that the object will be viewed for a longer period of time, but, as was mentioned earlier, they are not necessarily perfectly correlated. In the end, the two measures yielded similar patterns of results. Target objects were entered the most frequently and were looked at for the longest amount of time, and unrelated distractors were viewed the least frequently and for the shortest time. Category distractors received the second most frequent entries and the second longest fixation time. However, in contrast to the proportion analysis and the visual memory results, color distractors were entered significantly fewer times than category distractors.

The difference between the two types of related distractors in the entry and total time analyses indicates that while the objects were viewed on an equal proportion of trials, they were not viewed with equal frequency or for an equal length of time. One potential reason for this difference is that it may be easier to determine the category membership of an object in this experiment than the predominant color of the object. Because the stimuli were photographs of real-world objects, lighting differences and other factors made the hues of a particular color look different. Take, for example, the green drill. The green used could vary from a yellowish-lime green to a more bluish-green while still maintaining the property of green. The decision about the color of an object may be relatively more difficult than the identification of the photographs as members of a semantic category. This is a possibility because the objects were chosen so that their semantic labels would be easily identified. Thus, even when a participant landed on a color distractor, it would be much easier to determine that it was not a member of the target category than to label its exact color. If this were the case, it would explain the findings of increased looks to and time spent on the category distractors. Additionally, real-world objects are rarely just one color. A yellow car, for example, could contain several other colors. The tires, the grille, and the bumpers could all be (and most likely were) a color other than yellow. However, because the prominent color of the object was yellow, it was still referred to in this experiment as a yellow car. It seems reasonable to suggest that if the prominent color of some objects was more difficult to determine, then a participant would require more time or more looks to the object to accurately judge the color. This would lead participants to look at the category distractors less than the color distractors. Thus, given the pictures used here, it appears that it is easier to say that a drill is a drill than to determine the color of the drill.

The presentation block analyses provided evidence that some aspects of viewing behavior were affected by repeated viewings of the same objects. This was surprising given the number of changes between the two arrays and supports some of the claims of Althoff and colleagues (Althoff and Cohen, 1999). The lack of an age interaction with the viewing factor indicates that older adults were as capable as younger adults of using memory to aid in the deployment of the eyes to the various objects in an array.

The regression analyses for the entry and total time data indicate that for the related distractor conditions, the more an object is viewed, the better visual memory tends to be. The target objects and unrelated distractors did not demonstrate this relationship. Although the results were mixed, there does appear to be some relationship between the viewing behavior and memory test accuracy. By demonstrating this relationship, this study provides evidence of the role of viewing behavior in the formation of memory. The lack of a relationship in the unrelated distractor conditions is likely the result of the fact that memory is barely better than chance in that condition. The lack of systematicity in the memory data in this condition would make trying to find a relationship with another variable difficult. A restriction of range does not appear to be an issue in the target condition which makes the lack of a correlation puzzling. Another issue is that the significant correlations were relatively small and thus accounted for only small portions of the variance in memory performance. However, it is important to remember that the search task was separated from the memory test by a filled interval of at least 10 minutes, which could have increased the noise in the memory test performance. In general, the regression analyses support the notion that visual memory is at least partially dependent on how the object was viewed during the search task.

Although the regression analyses demonstrate some relationship between viewing behavior and the visual memory results, target objects were remembered better than distractor objects regardless of the viewing that a distractor object received. Target objects are looked at more frequently and for a longer time, but by examining Figures 9 and 10, it is apparent that memory for target objects is privileged beyond what would be expected based on viewing time. The privileged status of target memory indicates that there is something more to the role played by these objects in search. One possible explanation is that because the target is the goal of search, its representation in memory is tagged to be remembered. Another possibility is that rather than a benefit for target objects, distractor objects are impaired because they are not the goal of the search. In other words, distractor objects (regardless of relationship to the target) are tagged as such and forgotten due to either decay or active suppression. Unfortunately, it is impossible for this experiment to separate these two explanations for the finding of better overall memory for target objects. Regardless, it is important that target objects are remembered better overall because it demonstrates an additional aspect to memory performance that is not dependent on viewing behavior.

The lack of an age difference in the proportion entered and the number of entries analyses indicates that older adults were not searching through more objects than younger adults. Additionally, the total time analysis demonstrated an interaction in which older adults were processing the distractor objects as much as younger adults. The interaction of age group and object condition was primarily caused by a large age difference in the target condition and no age difference in the category distractor condition. A test of the application of inhibition in this study was a difference between younger and older adults on distractor objects. It was critical for the inhibition argument that the older adults process the distractor objects more than younger adults. However, the results of the eye movement analyses did not demonstrate any age interactions that would result from the application of inhibition. The two age groups were equally likely to enter distractor objects and older adults did not spend differentially more time examining the distractor objects. There are two possible reasons for this finding: 1) the search task used here does not require the application of inhibition, or 2) the type of inhibition used in the search task is age invariant. Either of these is a possibility given the results. The search task itself may not require the participant to inhibit the distractor objects because they were not sufficient competitors for search. Thus, no age differences would be expected on eye movement measures. The age differences in memory would result from other (potentially inhibitory) mechanisms that operate outside of the search itself. The other possibility is that the type of inhibition that is applied during search is age-invariant. This would place the current task in a class of supposedly inhibitory paradigms such as visual marking, IOR, and spatial negative priming, that all demonstrate age-invariance in the application of inhibition. Unfortunately, the current experiment cannot differentiate between these two possibilities. Further research will be required to distinguish between these two explanations.

GENERAL DISCUSSION

The current study had three main goals. The first was to examine the visual memory maintained from visual search. The second was to examine the role of executive control processes in search and the subsequent effect on memory for objects that were not the target of search. The final goal was to explore potential age differences in the search of and subsequent memory for targets and distractors of a visual search.

With respect to the first goal, the current project found that people could remember the visual details of objects that had been both the targets and distractors in a visual search task. The issue of what remains after attention has been withdrawn has led some researchers (O'Regan, 1992; Rensink, 2000) to rather extreme views of the paucity of visual memory, with some researchers claiming that there is nothing at all maintained by the visual memory system. The current study found that these claims greatly underestimate the amount of information that is maintained. Each of the experiments in the study demonstrated above-chance memory for the targets of search and for distractors that were related to the search targets replicating findings of preserved memory of the visual details from previous studies (Castelhano & Henderson, 2001; Hollingworth & Henderson, 2002). These studies had found relatively long term memory for the details of objects after instructions to either memorize the scene or search the scene. The current study was a stringent test of the maintenance of visual details in memory. Firstly, participants did not expect the memory test, meaning that they had no reason to attempt to memorize the objects in the array. Additionally, the objects were learned in an array that did not form a coherent scene, limiting the role of organization strategies in memory. Finally, the visual memory test used in this experiment required that participants decide which of two tokens of an object was presented. The test was devoid of context from the search phase (see Figure 2), and thus the decision could be based on only the visual details attached to the object. Given the demanding nature of the memory test, the finding of preserved visual memory in these experiments is even more impressive.

The second goal was to examine the role played by executive control processes in search, as evidenced by the effect of an object's relationship to the search target on the memory maintained after viewing the array. The experiments presented here clearly demonstrate that the memory that is maintained is influenced by the role played by the object in the search. Objects that were the targets of search were remembered relatively well. Target objects were entered the most frequently and were viewed for the longest time. Of greater interest was the memory for distractor objects. The finding that related distractors were remembered better than unrelated distractors (at least by younger adults) indicates that executive processes are involved in the selection of objects to be examined. The eye movement data support this claim because related distractors (both category and color distractors) were viewed more frequently than unrelated distractors. Thus, the processes involved are able to select objects related to the target and can limit the processing of unrelated distractors. The processes were not perfect in their ability to prevent entries to the unrelated distractors, as evidenced by the fact that the approximately 70% of the tested unrelated distractors were entered on at least one viewing of the arrays. This proportion was significantly less than distractors that were related to the search target, but it still demonstrates that executive processes could not perfectly guide the search. The inability of search processes to ignore the unrelated distractors indicates that in this experiment, the inhibitory processes described by Treisman and Sato (1990) could not completely eliminate consideration of the objects that did not share a feature with the target. This could be the result of the differences in the use of real-world objects, which vary in many aspects, in this experiment as opposed to traditional laboratory stimuli, which tend to be rather homogenous. However, given that the number of entries and the total time were significantly less than for the related distractors, it appears that the executive processes involved in search can limit the processing of objects unrelated to the search once they have been so identified.

These experiments demonstrate the importance of the selective processing that occurs in visual search not only for the efficiency of the search itself, but also for the memory that remains afterwards. The memory patterns generally mirrored viewing behavior during the search. The more an object is examined in the search, the better memory tends to be as evidenced by the regression analyses for the related distractors. The more frequently an object is examined or the more time spent viewing an object, the more accurate the visual memory tends to be. Unfortunately, this was not true for targets or the unrelated distractors. The finding that targets were recalled better than would be expected from viewing behavior indicates that while there is some relationship between viewing behavior and memory, other processes appear to play a role as well. Further research will be needed to explore the contribution of nonsearch aspects to the visual memory of targets.

The third goal of this project was to examine differences between younger and older adults in their memory of objects encountered during search and their viewing behavior during search. The hope was to examine the role played by inhibition in the memory that was built during the search task. With regard to memory, older and younger adults were relatively similar in their memory for objects encountered during search. The only condition that consistently yielded an age difference was the target condition, with younger adults outperforming older adults. This is the typical finding in experiments that examine age differences in memory. In contrast, younger and older adults performed equally well in their memory for distractor objects (with the exception of a marginal difference in category distractors in Experiment 2). This demonstration of equivalent memory for distractor objects supports a claim that older adults process these objects more than younger adults, which in turn could be evidence of inhibition operating during search. Because this was limited to the conditions that the searcher was trying to avoid, the age equivalence could be the result of older adults processing the distractor objects to a greater extent due to an inability to effectively filter them out. However, in the eye movement analyses, there were few age differences, and those present did not support the additional processing argument. Older adults entered the distractor objects as frequently as younger adults and, although they looked at the distractor objects longer than the younger adults, this was not specific to the distracting conditions. The lack of an age effect in the distracting conditions indicates that differences in the viewing behavior for distracting objects were not the cause of the age equivalence in memory for these items. In fact, older adults spent significantly more time processing target objects and still demonstrated comparably worse memory. It is therefore reasonable to assume that the age difference that allowed older adults to remember the distracting objects as well as younger adults can be found in processes that continue after the search has been completed.

With respect to the inhibition deficit claim of Hasher and Zacks (1988), this experiment was unable to find evidence of age-related inhibition differences in the search through an array of real-world objects. It appears that inhibition could be operating in restricting the objects that are examined. The lack of an age difference in the search processes seems to indicate that, at the least, this type of inhibition does not diminish as people age. However, the finding that older adults were able to remember the distracting objects as well as younger adults does suggest that older adults are less able than younger adults to effectively inhibit distractors after the search has been completed.

Given the lack of an age difference in the eye movement measures during search, it appears likely that the age difference that allowed the distracting objects specifically to be remembered as well for older as for younger adults occurs following the search. This argument is similar to that of Hartman and Hasher (1991). In their experiment, participants were required to generate endings to sentences. They were then given an ending to remember that either matched or did not match the ending that was generally produced. Of interest was the access that individuals had to the ending that they had generated after being told that they had to remember another ending (called the disconfirmed ending). The authors found that older adults had better access to the disconfirmed endings they had produced (using an implicit memory test) compared to younger adults. They claim that older adults were not as efficient at suppressing these generated endings, and thus the disconfirmed endings could more readily accessed (see also May, Zacks, Hasher, & Multhaup, 1999).

In the current study, the distractor objects could be more readily available after the search for older adults. In other words, once the long-term object file of a distractor is constructed during the search, it is possible that inhibition operates on it to prevent its reactivation because the object has been identified as a distractor. Older adults are not as effective as younger adults at suppressing these long-term object files allowing those objects to be accessible. This is analogous to the argument Hartman and Hasher (1991) made because the older adults have more ready access after the search has been completed to objects that were previously rejected.

Summary and Conclusion

Overall, the current study demonstrates that even when people are not intending to remember the visual details of objects during search, they demonstrate relatively good visual memory. People are also able to remember the details of objects that they were not intending to find in a search. These findings argue against any model of visual perception that does not maintain some visual details after an object has been viewed. The total time examined and number of viewings also appear to contribute to the visual memory for at least some of the objects. It was further evident that the role of an object in the search was critical for the finding of memory, with memory being found primarily for objects that were related to the search target. There was evidence of age differences in visual memory, but this does not appear to be the result of age differences during the search itself. Thus, there was mixed evidence for age-related inhibition deficits in the task. Returning to the office search example presented in the introduction, it appears that people can remember a red coffee mug or a blue book when they look for a red book. However, people tend to not remember the yellow pencil on the desk.

APPENDIX

Target Category	Color 1	Color 2	Color 3
Set 1			
Apple	Red	Green	Yellow
Axe Handle	Red	Brown	Yellow
Backpack	Blue	Yellow	Red
Basket	Brown	White	Red
Binoculars	Black	Green	Silver
Bird	Yellow	White	Green
Boat	White	Blue	Brown
Briefcase	Black	Brown	Silver
Bucket	Brown	Red	Silver
Camera	Silver	Yellow	Black
Car	Yellow	Blue	White
Cat	Black	Brown	White
Chair	Blue	Yellow	Green
Cow	Brown	White	Black
Dogs	White	Black	Brown
Door	Green	Blue	Brown
Earrings	Green	Silver	White
Garbage Can	Blue	White	Green
Guitar	Brown	Red	Black
Hand Gun	Silver	Black	Brown
Lamp	Blue	Silver	Black
Lock	Yellow	Green	Silver
Microscope	White	Black	Red
Pan	Silver	Black	Green
Pen	Yellow	Red	White
Telephone	White	Yellow	Blue
Pot	Silver	Red	Yellow
Suitcase	Red	Brown	Blue
Telescope	Black	Silver	Blue
Tractor	Green	Blue	Red
Truck	Red	Green	Yellow
Watering Can	Green	Silver	Blue
Set 2			
Beetle	Green	Brown	Red
Bicycle	Red	Green	Yellow
Boots	Brown	Black	Yellow
Drill	Green	Yellow	Red
Fish	Silver	Blue	Brown
Glasses	Blue	Black	Brown

Hairdryer	Silver	Blue	White
Hammer	Silver	Red	Black
Hat	Yellow	Green	White
Iron	White	Silver	Blue
Knife Handle	Silver	Brown	Black
Leaf	Yellow	Red	Green
Lighter	Green	Brown	Silver
Microphone	Black	Silver	Blue
Motorcycle	Red	Yellow	Blue
Mug	Blue	Yellow	White
Pipe	White	Brown	Green
Pitcher	Yellow	White	Silver
Airplane	White	Silver	Green
Pliers Handle	Red	Blue	Silver
Purse	Brown	Green	White
Scissors Handle	Black	Red	Blue
Screwdriver Handle	Blue	Black	Red
Shoes	Yellow	White	Silver
Stapler	Red	Silver	Black
Teapot	White	Yellow	Red
Toolbox	Black	Red	Yellow
Train Car	Brown	Green	Black
Typewriter	Green	White	Brown
Umbrella	Blue	White	Yellow
Lady's Wallet	Brown	Black	Green
Wheelchair	Black	Blue	Brown

REFERENCES

Althoff, R. R. & Cohen, N. J. (1999). Eye-movement-based memory effect: A reprocessing effect in face perception. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 25,* 997-1010.

Banich, M. T. (2004). *Cognitive neuroscience and neuropsychology* (2nd ed.). Boston, MA: Houghton Mifflin Company.

Castelhano, M. S., & Henderson, J. M. (2001). Detailed visual memory in scenes following intentional and incidental learning tasks. Paper presented at the 42nd annual meeting of the Psychonomic Society, Orlando, FA.

Connelly, S. L., & Hasher, L. (1993). Aging and the inhibition of spatial location. *Journal of Experimental Psychology: Human Perception and Performance, 19,* 1238-1250.

Deubel, H. & Schneider, W. X. (1996). Saccade target selection and object recognition: Evidence for a common attentional mechanism. *Vision Research, 36,* 1827-1837.

Friedman, A. (1979). Framing pictures: The role of knowledge in automatized encoding and memory for gist. *Journal of Experimental Psychology: General, 108,* 316-355.

Gazzaniga, M. S., Ivry, R. B., & Mangun, G. R. (1998). *Cognitive neuroscience: The biology of the mind.* New York: W. W. Norton & Company.

Grimes, J. (1996). On the failure to detect changes in scenes across saccades. In K. Akins (Ed.), *Perception: Vancouver studies in cognitive science* (Vol. 5, pp. 89-110). Oxford, England: Oxford University Press.

Hartley, A. A., & Kieley, J. M. (1995). Adult age differences in the inhibition of return of visual attention. *Psychology and Aging, 10,* 670-683.

Hartman, M., & Hasher, L. (1991). Aging and suppression: Memory for previously relevant information. *Psychology and Aging, 6,* 587-594.

Hasher, L. & Zacks, R. T. (1988). Working memory, comprehension, and aging: A review and a new view. In G. H. Bower (Ed.), *The psychology of learning and motivation* (Vol. 22. pp. 193-225). San Diego, CA: Academic Press.

Hasher, L., Zacks, R. T., & May, C. P. (1999). Inhibitory control, circadian arousal, and age. In Gopher, D., & Koriat, A. (Eds.), *Attention and performance XVII: Cognitive regulation of performance: Interaction of theory and application.* (pp. 653-675). Cambridge, MA: MIT Press.

Henderson, J. M., Pollatsek, A., & Rayner, K. (1989). Covert visual attention and extrafoveal information use during object identification. *Perception & Psychophysics, 45,* 196-208.

Hoffman, J. E., & Subramaniam, B. (1995). The role of visual attention in saccadic eye movements. *Perception and Psychophysics, 57,* 787-795.

Hollingworth, A., & Henderson, J. M. (2002). Accurate visual memory for previously attended objects in natural scenes. *Journal of Experimental Psychology: Human Perception and Performance, 28,* 113-136.

Hollingworth, A., Williams, C. C., & Henderson, J. M. (2001). To see and remember: Visually specific information is retained in memory from previously attended objects in natural scenes. *Psychonomic Bulletin & Review, 8,* 761-768.

Horne, J. A., & Ostberg, O. (1976). A self-assessment questionnaire to determine morningness-eveningness in human circadian rhythms. *International Journal of Chronobiology, 4,* 97-110.

Irwin, D. E., Zacks, J. L. & Brown, J. S. (1990). Visual memory and the perception of a stable visual environment. *Perception & Psychophysics, 47,* 35-46.

Irwin, D. E., & Zelinsky, G. J. (2002). Eye movements and scene perception: Memory for things observed. *Perception and Psychophysics, 64,* 882-895.

Kahneman, D., Treisman, A., & Gibbs, B. J. (1992). The reviewing of object files: Object-specific integration of information. *Cognitive Psychology, 24,* 175-219.

Koshino, H. (2001). Activation and inhibition of stimulus features in conjunction search. *Psychonomic Bulletin and Review, 8,* 294-300.

Kramer, A. F., & Atchley, P. (2000). Age-related effects in the marking of old objects in visual search. *Psychology and Aging, 15,* 286-296.

Kramer, A. F., Hahn, S., Irwin, D. E., & Theeuwes, J. (1999). Attentional capture and aging: Implications for visual search performance and oculomotor control. *Psychology and Aging, 14,* 135-154.

Kramer, A. F., Scialfa, C. T., Peterson, M. S., & Irwin, D. E. (2001). Attentional capture, attentional control, and aging. In Folk, C. & Gibson, B. (Eds.) *Advances in Psychology, Vol. 133: Attraction, distraction, and action: Multiple perspectives on attentional capture.* Amsterdam: Elsevier Sciences.

Madden, D. J., Gottlob, L. R., & Allen, P. A. (1999). Adult age differences in visual search accuracy: Attentional guidance and target detectability. *Psychology and Aging, 14,* 683-694

May, C. P., Kane, M. J., & Hasher, L. (1995). Determinants of negative priming. *Psychological Bulletin, 118,* 35-54.

May, C. P., Zacks, R. T., Hasher, L., & Multhaup, K. S. (1999). Inhibition in the processing of garden-path sentences. *Psychology and Aging, 14,* 304-313.

Mayr, U., & Spieler, D. H., (2002). Eye movements during visual search. Poster presented at the biannual meeting of the Cognitive Aging Conference, Atlanta, GA.

McCrae, C. S., & Abrams, R. A. (2001). Age-related differences in object- and location-based inhibition of return of attention. *Psychology and Aging, 16,* 437-449.

McConkie, G. W., & Currie, C. B. (1996) Visual stability across saccades while viewing complex pictures. *Journal of Experimental Psychology: Human Perception and Performance, 22,* 563-581.

Neill, W. T., Valdes, L. A., Terry, K. M., & Gorfein, D. S. (1992). Persistence of negative priming: II. Evidence for episodic trace retrieval. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 18,* 993-1000.

O'Regan, J. K. (1992). Solving the "real" mysteries of visual perception: The world as an outside memory. *Canadian Journal of Psychology, 46,* 461-488.

Plude, D. J., & Doussard-Roosevelt, J. A. (1989). Aging, selective attention, and feature integration. *Psychology and Aging, 4,* 98-105.

Posner, M. I., & Cohen, Y. (1984). Components of visual orienting. In H. Bouma & D. G. Bouwhuis (Eds.) *Attention and Performance X: Control of Language processes.* (pp. 531-554). Hillsdale, NJ: Erlbaum.

Radvansky, G. A., & Curiel, J. M. (1998). Narrative comprehension and aging: The fate of completed goal information. *Psychology and Aging, 13,* 69-79.

Rayner, K. (1998). Eye movements in reading and information processing: 20 years of research. *Psychological Bulletin, 124,* 372-422.

Rayner, K., McConkie, G. W., & Ehrlich, S. (1978). Eye movements and integrating information across fixations. *Journal of Experimental Psychology: Human Perception and Performance, 4,* 529-544.

Rensink, R. A. (2000). The dynamic representation of scenes. *Visual Cognition, 7,* 17-42.

Rensink, R. A., O'Regan, J. K., & Clark, J. J. (2000). On the failure to detect changes in scenes across brief interruptions. *Visual Cognition, 7,* 127-145.

Ryan, J. D., Althoff, R. R., Whitlow, S. & Cohen, N. J. (2000). Amnesia is a deficit in relational memory. *Psychological Science, 11,* 454-461.

Scialfa, C. T., & Joffe, K. M. (1997). Age differences in feature and conjunction search: Implications for theories of visual search and generalized slowing. *Aging, Neuropsychology, and Cognition, 4,* 227-246.

Shepard, R. N. (1967). Recognition memory for words, sentences, and pictures. *Journal of Verbal Learning and Verbal Behavior, 6,* 156-163.

Shih, S. I., & Sperling, G. (1996) Is there feature-based attentional selection in visual search? *Journal of Experimental Psychology: Human Perception and Performance,* 22, 758-779.

Simons,-Daniel-J; Levin,-Daniel-T. (1998). Failure to detect changes to people during a real-world interaction. *Psychonomic Bulletin and Review, 5,* 644-649.

Standing, L., Conezio, J, & Haber, R. N. (1970). Perception and memory for pictures: Single-trial learning of 2500 visual stimuli. *Psychonomic Science, 19,* 73-74.

Theeuwes, J., Kramer, A. F., Hahn, S., & Irwin, D. E. (1998). Our eyes do not always go where we want them to go: Capture of the eyes by new objects. *Psychological Science,* 9, 379-385.

Tipper, S. P. (1985). The negative priming effect: Inhibitory priming by ignored objects. *Quarterly Journal of Experimental Psychology: Human Experimental Psychology, 37A,* 571-590.

Tipper, S. P., Brehaut, J. C., & Driver, J. (1990). Selection of moving and static objects for the control of spatially directed action. *Journal of Experimental Psychology: Human Perception and Performance, 16,* 492-504.

Tipper, S. P., Weaver, B., Jerreat, L. M., & Burak, A. L. (1994). Object-based and environment-based inhibition of return of visual attention. *Journal of Experimental Psychology: Human Perception and Performance, 20,* 478-499.

Treisman, A. (1988). Features and objects: The fourteenth Bartlett memorial lecture. *Quarterly Journal of Experimental Psychology, 40A,* 201-237.

Treisman, A. (1998). The perception of features and objects. In Wright, R. D. (Ed.) *Visual attention* (pp. 26-54). New York: Oxford University Press.

Treisman, A. M., & Gelade, G. (1980). A feature-integration theory of attention. *Cognitive Psychology, 12,* 97-136.

Treisman, A., & Sato, S. (1990). Conjunction search revisited. *Journal of Experimental Psychology: Human Perception and Performance, 16,* 459-478.

Watson, D. G., & Humphreys, G. W. (1998). Visual marking of moving objects: A role for top-down feature-based inhibition in selection. *Journal of Experimental Psychology: Human Perception and Performance, 24,* 946-962.

Watson, D. G., & Humphreys, G. W. (1997). Visual marking: Prioritizing selection for new objects by top-down attentional inhibition of old objects. *Psychological Review, 104,* 90-122.

Williams, L. G. (1967). The effects of target specification on objects fixated during visual search. *Acta Psychologica, 27,* 355-360.

Wolfe, J. M. (1994). Guided Search 2.0: A revised model of visual search. *Psychonomic Bulletin and Review, 1,* 202-238.

Wolfe, J. M. (1998). Visual Search. In Pashler, H. (Ed.), *Attention* (pp. 13-73). Hove, East Sussex, UK: Psychology Press.

Wolfe, J. M., Cave, K. R., & Franzel, S. L. (1989). Guided Search: An alternative to the feature integration model of visual search. *Journal of Experimental Psychology: Human Perception and Performance, 15,* 419-433.

Wolfe, J. M., Oliva, A., Horowitz, T. S., Butcher, S. J., & Bompas, A. (2002). Segmentation of objects from backgrounds in visual search tasks. *Vision Research, 42,* 2985-3004.

Zacks, J. L., & Zacks, R. T. (1993). Visual search times assessed without reaction times: A new method and an application to aging. *Journal of Experimental Psychology: Human Perception and Performance, 19,* 798-813.

Zelinsky, G. J. (1996). Using eye saccades to assess the selectivity of search movements. *Vision Research, 36,* 2177-2187.