Eye movement measures of semantic priming

by Amy Elizabeth Alberts

A Thesis Submitted In Partial Fulfillment of the requirements for the degree of Master of Science in Applied Psychology
Montana State University

Abstract:
The eye movement-based memory effect, manifest by changes in viewer eye behavior toward familiar versus novel images, is a mandatory outcome of prior exposure. An episodic eye movement-based memory effect for images of objects was demonstrated in one experiment. Episodic (Experiment 1) and semantic memory (Experiment 2) of object images were tested using 5 eye movement variables. Participants in Experiment 1 studied a group of images and were tested on recognition of images they were or were not exposed to in the study phase. Participants in Experiment 2 studied a group of images and were tested with images semantically related or unrelated to those in the study phase. ANOVA and Discriminant analyses indicated differences in Experiment 1 between novel and familiar images based on eye movement measures. Results suggest that image sampling behavior is mediated by only the episodic memory system. Conclusions surround the reliability and validity of using the eye movement-based memory effect as a measure of prior exposure.

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APPROVAL

Of a thesis submitted by

Amy Elizabeth Alberts

This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies.

Leann M Stadtlander	(Signature)	4/19/00 Date
Frank M Marchak	(Signature)	4/17/00 Date

Approved for the Department of Psychology

A. Michael Babcock	(Signature)	4/17/00 Date

Approved for the College of Graduate Studies

Bruce R. McLeod	(Signature)	4-24-00 Date

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DEDICATION

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ABSTRACT

The eye movement-based memory effect, manifest by changes in viewer eye behavior toward familiar versus novel images, is a mandatory outcome of prior exposure. An episodic eye movement-based memory effect for images of objects was demonstrated in one experiment. Episodic (Experiment 1) and semantic memory (Experiment 2) of object images were tested using 5 eye movement variables. Participants in Experiment 1 studied a group of images and were tested on recognition of images they were or were not exposed to in the study phase. Participants in Experiment 2 studied a group of images and were tested with images semantically related or unrelated to those in the study phase. ANOVA and Discriminant analyses indicated differences in Experiment 1 between novel and familiar images based on eye movement measures. Results suggest that image sampling behavior is mediated by only the episodic memory system. Conclusions surround the reliability and validity of using the eye movement-based memory effect as a measure of prior exposure.

INTRODUCTION

Eye-Movement Measures of Semantic Priming

According to Tulving (1990), memory can be broken down into three distinctive parts: episodic, semantic, and procedural. Episodic memory refers to the explicit recollection of an event. Semantic memory dissociates itself from episodic memory in that there is no specific event acting as a reference point for the memory. In this case, the act of remembering a semantic memory is implicit in nature. Finally, procedural memory refers to the act of re-enacting a set of steps that lead the individual to a final goal. Procedural memory is typically implicit (e.g., tying a shoe), yet can have episodic reference.

The dissociations between these memory systems have been the source of an enormous amount of research. Investigators have concerned themselves mostly with the episodic and semantic systems. The phenomenon of priming has been the focus of many of these studies. Priming is defined as the enhanced ability to successfully identify a perceptual stimulus as a function of prior exposure to that stimulus (Tulving & Schacter, 1990). The concept of stimulus "identification" in priming studies has been expanded to include recognition, recall and regeneration of primed stimuli, success in word-fragment completion tasks, and exaggerated physiological reactions to primed stimuli (i.e. reaction time and event related potentials (ERP)). Classic priming studies follow a study-test format. Participants are given a set of stimuli (e.g., words, objects, or faces) to study, and then are tested on their ability to identify the stimuli during the test phase. The major question priming studies are concerned with is the type of test material that will facilitate respondent's ability to identify the stimuli from the study phase (herein referred to as the "targets"). It is generally conceded that stimuli that will facilitate recall of a target can be perceptual and conceptual in nature. Perceptual stimuli denote the basic features of a given item in that the shape of the test stimuli greatly resembles that of the target. Conceptual stimuli denote the meaning of the given item; the meaning of the test stimuli is the same (or near to the same) as the target. Therefore, stimuli that are structurally similar to the target will facilitate recall, as well as stimuli that are conceptually related to the target. Recall of the studied material is measured in a variety of ways. Methods of measuring facilitation of target recall include percent correct in regenerating the target (e.g., free recall, word and object completion, general knowledge tests, and semantic cues), reaction time, and event-related potentials.

Although episodic memory has shared the priming spotlight with semantic memory, for the remainder of this review semantic priming will be discussed. Priming studies are designed so that participants need not make conscious reference to the study phase in order to recall the targets. Numerous mediators have been identified that influence individuals' ability to recall the target. These mediators fall under the following categories: general knowledge, perceptual characteristics, and association/categorical relatedness. Studies that employ a general knowledge test of priming have used both words and objects. A typical general knowledge test was employed by Blaxton (1989) where participants primed with a word (bashful) were asked a question during the test phase that relied on semantic memory (Which of the seven dwarves comes first alphabetically?). However, since Blaxton's work, the concept of general knowledge has evolved to include the constraints of familiarity and plausibility. Postle and Corkin (1999) showed that the prior knowledge of a word affects the word completion task. For example, although participants showed enhanced ability filling in the missing letters to complete a target (Bashful: B _ s _ f _ _), that ability was greatly compromised if the target word was not already familiar to them. This effect of general knowledge is seen with objects as well. Schacter and Tulving (1990) determined that participants did not prime to impossible objects (e.g., objects that are not possible in three dimensional space). Therefore, it can be concluded that general knowledge constraints surround the concepts of familiarity of words and plausibility of objects in priming studies.

Perceptual characteristic constraints on semantic priming are generally concerned with the degree to which modification of the studied material will adversely affect subsequent target recollection. There are four categories of perceptual manipulations that dominate the priming literature: degradation, orientation, physical attributes, and structural similarity. Degradation of the target is used with both words and objects. As mentioned above, word-completion tasks dominate priming studies for words. These tests consistently show that priming allows for regeneration of the target even under the constraints of profound word degradation. For objects, contrast and illumination effects have been manipulated (Srinivas, 1996). In Srinivas' work, it was concluded that object identification was dependent on "...abstract descriptions of objects shape...irrelevant (of) perceptual changes such as contrast, illumination, size, and right-left orientation (p. 1132)." Further evidence for the lack of perceptual effects on semantic priming comes from depth rotation and foreshortening manipulations of objects (Lawson & Humphreys, 1998). Lawson and Humphreys determined that depth rotation and foreshortening of test stimuli did not affect the respondent's ability to prime to the studied material. However, these results regarding orientation are constrained by the work of Uttl and Graf (1996) who compared the amount of time participants took to name a slowly faded-in object picture during the test phase. Three conditions of semantic priming to objects were employed. Respondents studied a group of stimuli and were presented with either the same object with the same axis orientation, the same object with different axis orientation, or a non-studied stimulus. It was concluded that priming was moderately affected by axis orientation. According to their work, although priming was apparently independent of axis orientation (speeded identification of studied stimuli compared to unstudied), the speed in picture identification was slower when the axis orientation was manipulated. It can be inferred from these studies of perceptual characteristics that under conditions where objects presented to participants are normalized (appear as they would in real life), semantic priming is quite salient.

The physical attributes of words and objects have been manipulated by the use of color and pattern. The studies that address this problem appear at first glance to be at odds in their conclusions. Wippich and Mecklenbräucker (1998) conducted a study to assess the effect of color on recall of episodic and semantic priming tasks. Participants in this investigation studied colored words and pictures during the study phase. In the test phase, participants were shown black and white versions of either the studied pictures, or pictures that were semantically related to the test targets. When asked to select a color to correspond with the black and white version, subjects were more likely to choose the color the target was presented in during the study phase. Cave, Bost, and Cobb (1996) determined that color and pattern were rarely used to determine object identity in episodic memory tests. Although Cave et. al., concluded that color and pattern did not affect semantic priming at all, the tests they employed were quite different from that of Wippich and Mecklenbräucker. The Wippich and Mecklenbräucker study treated color as an independent variable, almost as if color was an object in and of itself. Wippich and Mecklenbräucker determined that color – if treated as a stimulus - could be primed. This conclusion does not bring into question the results obtained by Cave et. al., due to the vastly different ways color was treated in these studies. Therefore, although color as a perceptual characteristics can be primed, it is not a necessary physical attribute for semantic object priming.

The structural similarity between objects presented in the study and test phase is the final category of perceptual characteristics that influence semantic priming. Lloyd-Jones and Humphreys (1997) concluded that in naming structurally similar objects (e.g., fruits and vegetables), a degree of cost is apparent. In other words, there is visual competition between objects that look similar (e.g., apples and oranges), which manifests itself in a delay in naming the object appropriately. Barry, Johnston, and Scanlan (1998) identified this cost under very similar experimental conditions as well. It can be concluded from these results that priming's reliance on structural characteristics can adversely affect the phenomenon if one is not careful in the design of an experiment.

The final mediator for semantic priming involves the degree to which targets displayed during the study phase are semantically associated to those in the test phase. The notion of semantic-relatedness priming for studied targets has been supported in recent work with ERP (Holcomb & McPherson, 1994; McPherson & Holcomb, 1999). Interpretation of ERP recordings is beyond the scope of this review, but it will suffice to say that ERPs for identified objects give a N300 reading, while unidentified objects record a N400 reading. Priming studies using ERP are designed in the typical priming manner; participants study a set of either words or objects, and are tested on their identification of target stimuli during the test phase. Both words and objects have shown reliable effects of identification with ERP. For example, words and objects that are unrelated to the study phase record a N400 reading. This "odd-ball" effect is explained in terms of intense processing of the unfamiliar stimuli. For words it is assumed that a non-word activates intense lexical searching – the respondent is searching for similar words, definitions of fragments of the non-word, etc. The same explanation is given for non-objects – the respondent is searching for object-fragment identification. These results are further supported by Barry, Johnston, and Scanlan (1998) who concluded that objects (e.g., comb) that are categorically (e.g., nail-file) and associatively (e.g., brush) related will prime. Barry et. al., also concluded that faces of individuals that are typically associated with each other (e.g., Tom Cruise – Nicole Kidman) will prime, but this priming is not evident with faces that are categorically related (e.g., Julia Roberts). From this work we can conclude that the association and categorical processing of semantic memory is evident in priming studies.

The special case of face identification has received a great amount of attention from both neurological and cognitive researchers. There are a number of reasons why face identification is particularly important. First, face identification is an especially difficult process if one considers the fact that the basic features of faces are typically the same (e.g., two eye, nose, mouth, etc.). Because of these structural similarities, our identification mechanisms must be intensely fine-tuned to accommodate to the small differentiations between faces. This assumption of a fine-tuned system for face identification is indirectly supported by classification of the neurological disorder of prosopagnosia (the specific inability to identify faces). Research with primates has also lent support to the brain's specificity in face identification. It has been concluded that certain cells in the primary visual cortex of a monkey respond only to other monkey's faces. On a semantic level, the work by Barry, Johnston, and Scanlon (1998), points to the assumption that faces are not categorized like objects. For instance, individuals are typically seen as members of a number of different categories (e.g., family, friends, companion, etc.) Although this may also be the case for objects, the results obtained by Barry et. al. imply that the semantic memory of an individual includes their category, but that category does not organize our representations of individuals. In the case of people, our semantic memory process tends to inter-connect individuals, not categorize.

The investigation of face-identification has been the focus of work by individuals at the University of Illinois/ Urbana-Champagne (UIUC) (e.g., Althoff, 1998; Althoff &

Cohen, 1999). It is their contention that the eye is an example of a sensory processor that is subject to fine-tuning (e.g., "plastic changes") as a result of prior exposure. It is believed that this "fine-tuning" is most salient under priming conditions. Althoff and Cohen conducted a number of experiments where participants simply viewed pictures of faces that were known to them (famous) or unknown (non-famous) while an eye-tracker mapped the movement of the eyes over the given image. Several eye movement variables were measured and derived from the raw data. These variables included the number of fixations made on the image, the number of regions sampled where fixations tend to clump on the image, the mean fixation time, and derived variables that measured the degree of statistical dependency within the eye movement transition patterns. The results were not only consistent, but also extremely robust. In cases where participants viewed images of familiar faces, there were fewer fixations to fewer regions of the face and a lower level of statistical dependency in the pattern of eye movement transitions between regions as compared to unfamiliar faces.

Cohen, Althoff, Webb, McConkie, Holden and Noll (1997) used pictures of buildings as experimental stimuli. A number of reasons were given for testing buildings. First was the desire to generalize the eye-movement results from faces to objects. As most people had not had personal, real-world experience with the famous faces they viewed, it was prudent to ask if the eye-movement effect with famous faces was simply a stimulus item effect. Second, if dissociations are found between an eye-movement test of buildings and faces, these data could greatly affect present theories pertaining to the organization of memory. The same format as with the face studies was used to study buildings. The familiar condition consisted of pictures of academic buildings on the UIUC campus that respondents had unquestionably seen. The unfamiliar condition consisted of pictures of building that were similar in structure, yet were on a campus respondents had not been to. The data displayed the same trend of constrained-unfamiliar/unconstrained-familiar eye movements as faces. The sum of the work performed at UIUC pointed toward the conclusion that a sensory processor (the eye) had finally been determined that could display the effects of prior exposure on the brain.

The first objective of the present set of experiments was to expand the work conducted at UIUC. Experiment 1 attempted to replicate the results found in Cohen et. al. (1997), using pictures of common objects (e.g., wrench) rather than buildings. Second, this investigation applied the use of eye-movement data as a measure of prior exposure within a semantic priming design. Ultimately, the main experimental questions surrounds the efficacy of using eye-movement data as a measure of prior exposure to objects (Experiment 1), and as a measure of semantic priming for images semantically related to the study phase (Experiment 2). Two hypotheses were proposed: 1) Eye movement patterns for pictures of objects that were presented in the study phase will be different from those not seen in the study phase; and 2) Eye movement patterns for pictures of objects that are semantically related to the study phase will be different from those for pictures of objects unrelated to the study phase. The results of these two experiments offer further insight into the efficacy of using eye-movement data as a measure of episodic and semantic priming.

GENERAL METHODS

In two experiments, eye movement data were collected during test phases while participants viewed images of objects that were or were not previously viewed (Experiment 1), and associated or unassociated to objects presented in the study phase (Experiment 2). The first experiment followed a classic priming study-test format where participants viewed a set of object images, and were then tested on their identification of those stimuli by means of the eye-movement data. The experimental design of the second study was different from that of the first experiment. Experiment 2 followed a semantic test format where the presentation of the study image (target) was immediately followed by images of an associated or non-associated object (see Appendix B for complete stimulus list). The particulars of each experiment will be further explained in the Procedure section.

Participants

A total of 45 (Exp.1, N = 28; Exp. 2, N = 17) individuals participated in these studies. All participants were members of the Montana State University community from whom informed consent was obtained. Participants received extra credit in their Psychology courses in compensation for their participation. All participants reported normal, or corrected to normal, vision.

Materials

Stimuli were a set of 72 color images of objects presented on a computer monitor. Object images were taken from Hemera Photo Objects 10,000 Premium Image Collection®. All images were imported into Adobe Photoshop® and resized to approximately 580 X 452 pixels. The object in the images all had normal orientation on the picture plane. The images were saved in .bmp format in and were presented via a Cedrus SuperLab Pro Experimental Lab Software® experiment.

Apparatus

Eye movement data were collected using an ISCAN ETL-400 Remote Eye Tracking Laboratory, which sampled eye position at 60Hz with a resolution of 0.30 degrees of visual angle. Eye movements were tracked by a video camera positioned approximately 32 inches from the participant, directly underneath the computer screen and 12 inches below the approximate eye position. The eye-tracker beamed a small infrared light into the left eye. The ISCAN software monitored the eye movements via measurement of the reflection of infrared light off the cornea and the center of the pupil. The eye-tracking system used the distance between these reflections to ascertain the movement and positioning of the eyes.

Participants were seated in a chair approximately 32 inches from the participant monitor, a Dell® M1110 monitor with 1024 pixels horizontally (85 Hz refresh rate) by 768 pixels vertically (68.59 Hz refresh rate), on which the object images were displayed. A Dell OptiPlex GX1®, Pentium II, 400L+ MHz computer ran the Cedrus SuperLab

Pro® Experiment, which controlled image presentation. The ISCAN® Data Acquisition software (DAQ3 53k) controlled the eye tracker on a second Dell Optiplex GX1®, Pentium II, 400 MHz operator computer. On-line eye tracking performance indicators were visible to the experimenter on the operator monitor and on a third monitor. The third monitor allowed input from 4 sources via a Robot® MV87 Color Quad video window splitter, which separated the monitor display into 4 quadrants. This Toshiba® monitor displayed real-time conditions on the Operator monitor in quadrant one, an image of the participant's eye as recorded by the eye tracker in quadrant two, and the image on the participant monitor with eye movements superimposed over the image in quadrant three (quadrant four was not used). The experimenter was able to monitor eye movements and the tracking software in real-time in order to assess eye tracking performance.

Procedure

All participants were tested individually. In all conditions, the purpose of the study was explained to the participants before the onset of the study. Participants sat 32 inches in front of the participant video monitor. When the calibration procedure was performed, five white crosses were displayed on a black background on the participant monitor. The crosses were placed in a rectangular fashion with two upper crosses at a horizontal distance of 580 pixels from each other. Two lower crosses were directly parallel to the upper crosses, 452 vertical pixels from the upper crosses, and 580 horizontal pixels from each other. In the direct center of this rectangle was the fifth (center) cross. Viewers were instructed to fixate to each particular cross location until consistent values of eye location were obtained for all five benchmark locations. This calibration procedure allowed the eye-tracking software to map the participant's fixation points to specific image locations while viewing an image.

Participants in the study phase of Experiment 1 were presented with five exposures of each image, for a total of 120 presentations of a 24-image set (see Appendix A for stimuli list). The participants' eye movements were not recorded during the study phase. The images were presented randomly for five seconds each. After a 2-5 minute break between the study and test phase, participants were guided through the calibration procedure that took approximately 5 minutes. Once reliable eye tracking was established, the test phase began. Before each test image was presented the participant was asked to fixate on a cross displayed in the center of the screen. This center-fixation procedure served two purposes: 1) verified reliable eye tracking, and 2) allowed for eye positioning at the beginning of each study trial to begin at the same location. Participants were presented with one exposure of 12 studied images and 12 unstudied images for the duration of five seconds each. Test phase images were presented in a random order.

Experiment 2 consisted of 24 associate priming tests. Participants in this experiment were tested in 24 sets. Each set consisted of a study and test phase. The study phase involved a five-second presentation of a given image for five consecutive repetitions (see Appendix B for stimuli list). One to three seconds after the study phase, the participant was presented with an image that was or was not a semantic associate of the target image for five seconds. The immediacy of associate image presentation was advisable according to Bruce (1986), in which it was concluded that semantic relatedness was salient for only about five seconds. At the beginning of each associate set, the calibration screen was displayed. The experimenter verified eye positioning by requesting that the participant fixate on each benchmark location. If eye positioning was unreliable, the calibration procedure was again employed until the participant's eyes were tracked reliably. After recalibration (if necessary), the experimenter displayed the center-fixation cross. When the participants' eye had fixated on the center, the target image was displayed. This procedure was repeated for each study and test image. There was a 30-second break between each set of associate tests and the associate sets were randomly presented.

SuperLab Pro sent a pulse to the eye tracking software to begin and end data recording for every test image (approximately 296 data points for a five second presentation). A separate data file was created by the Cedrus SuperLab Pro Experiment that specified the order in which the images were displayed. The eye movement data recorded by the ISCAN software was then associated with the picture order.

Data Analysis

The purpose of the data analysis was to determine the effects of prior stimulus exposure on measures of eye movements. The first step in the process was to convert the continuous data recorded by the eye tracker into distinct data points. The ISCAN Point-of-Regard (PFA1 00B) software was used to convert raw eye movement into X, Y picture coordinates (horizontal and vertical eye position by pixel) of every fixation. The default values in the PFA1 00B software for minimum eye fixation duration (100ms) and maximum spatial deviation were used (± five pixels horizontal, by ± three pixels vertical). These fixation points were then converted into a data matrix where eye position (horizontal and vertical pixel location) was recorded for each fixation along with information regarding the fixation start and end time.

Since fixation points tend to clump in areas of importance to the viewer, a "nearest neighbor" algorithm was used to determine the regions most meaningful to the participant. There are two reasons why the proximity algorithm was used. First, previous research using eye movement data to predict prior exposure consistently concluded that meaningful regions are idiosyncratic and stereotypical to each participant (Altoff and Cohen, 1999). Use of only a priori calculation of meaningful regions would not allow for the constraint of this previous finding. Secondly, because in previous work the eye movement data were almost exclusively used to measure face identification, the use of a proximity algorithm allows for generalizability across stimulus types. For instance, the eyes, nose and mouth are intuitively the meaningful regions in face identification. Yet, those consistent features were not necessarily the predictors of face identification for particular participants, and are not features of most "known" objects.

MATLAB was used to determine the regions created by the participant (for each picture viewed) by analysis of the point-of-regard data. Fixations within a 30-pixel radius were considered a part of the same region. Fixations outside of this 30-pixel radius were considered a part of a different region. Variables such as fixation duration, saccade duration, and mean X, Y location of regions were also computed.

Three direct measures were taken of the eye movement behavior: total number of fixations on the image; first-return fixation; and number of regions sampled. Number of fixations was computed from the raw point-of-regard fixation analysis. First return fixation to a previously viewed region was computed using MATLAB by determining the number of fixations the viewer engaged in before returning to a region previously sampled. Number of regions sampled was a simple count of the number of regions created on a particular image by participants. Two indirect (or derived) measures were taken as well. Information measures, S1 and S2, were calculated to determine the relative degree of statistical dependency, or constraint, in the fixation patterns exhibited by a participant viewing a particular image. This involved the construction and analysis of Markov transition matrices, which indicate the degree to which fixations to a particular region are statistically dependent on the location of the prior fixation(s). Zero-order Markov matrices denote the overall relative frequencies of fixations landing in a particular region. For example, for a given participant viewing a given image, the proportion of the total fixations on the image that landed in each Region 1, 2, etc., were recorded. In first-order transition matrices, which describe single-step transitions, the columns of the matrix represent the region of the current fixation location while the rows represent the region of the previous fixation. Cell values are calculated by dividing the fixation counts for each pairing by the total number of fixations in the matrix, yielding the relative probability of that transition occurring. Second-order Markov matrices describe two-step transitions in a three-dimensional table, with the columns representing the region of the current fixation, while the rows of the x-axis represent the region of the immediately preceding fixation, and rows of the z-axis represent the regions preceding that of those on the x-axis.

To determine the degree of statistical dependency between a current fixation location and the location of previous fixations, a quantitative measure of *entropy*, or randomness, of fixation transitions can be calculated (Hacisalihzade, Stark, & Allen, 1992). This measure compares the degree of randomness in the cells of the matrix to that which would be predicted based only on row and column totals. Determination of the amount of randomness contained in each cell was calculated using the following formula:

$$I=P(i)*\log2(1/P(i)),$$

where P(i) represents the relative probability in a particular cell. By totaling the cells in the matrix, an overall measure of randomness contained within the matrix was obtained.

Higher degrees of randomness within the entire matrix were indicated by the matrix randomness-total. Yet, this randomness could be predicted in part by the row or column totals, the zero-order values, irrespective of the amount of information a given cell may convey, since disproportionate viewing of individual regions increases the likelihood of transitions between them. Because of this, cell values were subtracted from the sum of the row and column totals, and divided by the column totals to normalize the measure across number of fixations (S1 = (ΣI column total + ΣI row total - ΣI cells)/ ΣI column total). This measure, S1, describes the degree of randomness in the 1-step transitions made by the participant's viewing of the image. If S1 increased, it was concluded that the transitions from one region to another were dependent upon each other. In other words, the previous fixation point constrained, or predicted above a chance level (or in this case above what the row or column would have predicted), the region of the fixation of the next eye movement. The reverse of this was true as well in that as S1 decreased, the less constrained, or the less statstical dependency between, the eye movements. This same technique could be applied to the second-order Markov matrices to derive a measure of second-order constraint, S2.

To ascertain the effects of prior exposure, ANOVAs for Experiment 1 and 2 were conducted on the eye movement variables by picture type, collapsed across participants. The eye movement variable trends were expected to follow the results obtained by the UIUC group. Higher values on measures for the unfamiliar pictures were believed to be indicative of higher amounts of information transmittal about the image (Althoff, 1997). Therefore, it was expected that mean eye movement variable trends would be higher for unfamiliar objects in Experiment 1 and unassociated objects in Experiment 2.

To ensure that results from the ANOVA were not due to differences in the physical characteristics of the object pictures, a three-factor Factor Analysis, using Principle Component Extraction and varimax rotation, was computed for each picture, collapsed across subjects. The first three eigenvalues (a numerical index representing the variance associated with a particular factor) for each picture were placed into a between-subjects MANOVA to determine if there was an effect of picture. The MANOVA provided information regarding the main effects and interactions of subject, picture, and treatment. As Clark (1973) points out, a single ANOVA to test for treatment effect assumes no interaction between subject, picture, and treatment. A full MANOVA, however, offers information about the reliability of a treatment effect by testing for interactions between treatment and picture. Given a situation where an interaction was found between treatment and picture, it was assumed that the picture(s) may have dictated eye movements more readily than the treatment (e.g., familiar/unfamiliar).

A discriminant analysis was used to determine the eye-movement variables that best predicted the effects of prior exposure. Discriminant analysis is a procedure for finding a combination of several variables that maximizes the distance between two groups of observations (in this case, primed and unprimed stimuli) defined on several variables (Klecka, 1987). Discriminant functions that used all possible combinations of three of the five eye-movement variables were computed using SPSS for each participant across the studied and non-studied items. The discriminant function that accounted for the highest percentage of correct group classification was noted and individual and group mean classification accuracy scores were then computed. It is important to note that different variables may be used for classification accuracy scores across participants. It was expected that classification accuracy scores would be above a chance level.

RESULTS AND DISCUSSION

Experiment 1

A repeated-measures ANOVA was computed on the eye movement variables, collapsed across subjects, by picture type. The ANOVA (see Table 1) showed significant differences between the treatment conditions (F [1, 347] = 13.82, p = 0.00). To examine the possibility of an item effect, a factor analysis was computed for each picture. Using three eigenvalues (one for each principle component) from the factor analysis, a MANOVA computed to determine if eye movements differed as a function of picture type (familiar/unfamiliar) showed no significant effect, F_1 (1, 24) = 0.00, p = 0.99; F_2 (1, 24) = 0.05, p = 0.82; F_3 (1, 24) = 0.04, p = 0.85. A within-subjects discriminant analysis was then conducted. Mean classification accuracy scores were computed for each subject (see Table 2) with an average classification accuracy of 70.97%.

Experiment 2

A repeated-measures ANOVA was computed on the eye movement variables, collapsed across subjects, by picture type. The ANOVA (see Table 1) showed no significant differences between treatment conditions (F [1, 239] = 0.25 p = 0.62). To examine the possibility of an item effect, a factor analysis was computed for each picture. Using three eigenvalues (1 for each principle component) from the factor analysis, a MANOVA computed to determine if eye movements differed as a function of picture type (associate/unassociated) showed no significant effect, F_1 (1, 24) = 1.97, $p = 0.17$; F_2 (1, 24) = 1.12, $p = 0.30$; F_3 (1, 24) = 0.88, $p = 0.36$. A within-subjects discriminant analysis was then conducted. Mean classification accuracy scores were computed for each subject (see Table 3) with an average classification accuracy of 71.36%.

Results of Experiment 1 support the hypothesis that episodic priming for objects can be measured via eye movement variables. The significant mean eye movement variable differences (see Table 1) indicate a very robust eye movement effect of episodic object priming. The discrimination accuracy scores for Experiment 2 (71.36%) implies differences in eye movement behavior as a function of semantic relatedness between study and test phase. However, the lack of significant differences in the repeated-measures ANOVA (between the picture types on the eye movement variables) suggests different processing of semantically associated and unassociated images was not found under the present conditions. These results are not consistent with previous research on semantic priming.

Results of Experiment 1 are consistent with the work conducted by the UIUC group (Althoff & Cohen, 1999). The UIUC group utilized a wide variety of eye movement variables to measure the effects of prior exposure. They concluded that these eye movement variables described scanning patterns that are predictable within-subjects, and dependent on the novelty of the target image (e.g., higher values for number of fixations, number of regions sampled, and the constraint measures). Their results are explained in terms of an information-processing model, wherein image features offering the most information about image identity indirectly dictate eye movements. The stereotypical and idiosyncratic nature of these eye movement patterns are further denotative of an individual's inclination to extract as much information as possible about a novel image. Therefore, higher values of number of fixations, number of regions sampled, and the constraint measures for a novel compared to a familiar image are indicative of a higher degree of information transmitted about the image. Although this trend is idiosyncratic to an individual, it is expected that even between subjects, higher values will be obtained for the eye movement variables for novel stimuli (Althoff, 1998). As can be seen in Table 4, the mean trends for each eye movement variable (collapsed across subjects) are consistent with this prediction for Experiment 1.

Results of Experiment 2 are not consistent with work conducted by Barry, Johnston and Scanlan (1998) on object and face semantic priming, and McPherson and Holcomb (1999) on the measurement of semantic priming with ERP. The Barry, Johnston and Scanlan study lends further justification to the argument that our memory systems categorize animate and inanimate objects in very specific ways. Yet, the use of reaction time as a measure of these memory systems grants little insight into how episodic and semantic information is processed in the brain. The ERP work is successful in measuring the effects of episodic and semantic priming via the magnitude of (relatively unspecific) electrical activity in the brain. It seems prudent to consider the possibility that the ERP readings are somehow related to enhanced reaction time, but not to the eye movement-based memory effect. The differential reaction time and ERP readings that are associated with objects consistent or inconsistent with the study phase, may be dissociated from the cortical changes measured by the eye movement-based memory effect. The similarity between the experimental designs of Experiment 2 to the reaction time and ERP work makes the dissociation between these priming measures even more plausible.

The results of Experiment 2 are consistent with the information-processing theory used by the UIUC group, however. Physical image features are assumed to be the cornerstone of the eye movement-based memory effect. Nevertheless, without testing for semantic priming, it is not obvious whether this eye movement effect is feature-based, meaning-based, or both. In the present study the eye movement-based memory effect was present in measurement of feature based memory – or in Tulving and Schacter's (1990) estimation, episodic memory.

Results from the present set of experiments should be evaluated in light of their consistency and deviation from previous work on priming and the eye movement-based memory effect. The experimental manipulation of familiarity rather than a priori exposure to experimental stimuli will first be considered. Second to be discussed will be the lack of required behavioral responses by participants as compared to the UIUC work. Thirdly, the lack of stimulus standardization will be considered. Each of these issues should bring the results of Experiment 1 and 2 into focus, and establish grounds to compare these results to memory systems theory.

In Experiment 1 and 2 familiarity was manipulated and any prior experience with the specific object image was neither assumed nor controlled for. The results for Experiment 1, specifically the comparatively lower discriminations between the familiar and unfamiliar objects, and the lack of support for Experiment 2's hypotheses, might be a result of the experimental manipulation of object familiarity. A major difference between the present studies and Cohen's 1998 study of building recognition is the lack of experimental control over familiarity. Cohen concluded that marked changes in eye movements for face images were evident after five, five-second exposures. These eye movement patterns are assumed to be indicative of incrementally less image information transmittal. However, it might be the case with object priming that Cohen's rules of exposure to faces (to produce the eye movement-based memory effect) are not applicable to objects.

A study phase to experimentally manipulate familiarity was not employed for the building study, and it is assumed that participants' experience with the building was much higher than five, five-second exposures. Due to the fact that participants in the Cohen building study were not only familiar with the buildings in 3-dimensional space, they also (most likely) had experienced the buildings under various angles and light conditions, and may have actually been inside the buildings, points to a much higher level of perceptual experience with the images. Therefore, further consideration of the degree to which one needs to be familiar with an object to effect an eye movement change is advisable given the results of the present work, as well as work by Cohen (1998) and Marchak & Alberts (1999).

Participants in Experiment 1 and 2 were not asked to complete an overt task at any point in the study or test phases. This method deviates from the protocol employed by the UIUC group. Participants were typically required to judge (via button presses) the familiarity of the picture. Cognitive tasks such as judgement of the emotion of the viewed face were also employed. Only one study, conducted by Althoff (1998), used a truly cognitive task-free method. In this study, Althoff tested seven amnesic patients with severe declarative deficits. He found that eye movements for novel versus familiar faces are considerably different in measures such as number of regions sampled, first return fixation, and the information measures, even without cognitive tasks. Althoff then concluded that eye movements are consistently different for familiar versus unfamiliar faces, regardless of participant's ability to make declarative responses. The success of Experiment 1 supports their conclusions, suggesting that behavioral judgements of prior exposure or emotion are not a necessary component of the eye movement-based memory effect. However, the lack of a behavioral response may have contributed to the failure of Experiment 2 to show a semantic-based eye movement effect. Further consideration of the use of behavioral responses with the eye movement-based memory effect, with special attention to semantic priming, is suggested.

Another difference between the present set of experiments and those conducted by the UIUC group is the degree of stimulus standardization employed. For example, the UIUC group paid special attention to the illumination and orientation of the faces. Stimulus complexity was not explicitly controlled in the UIUC work because faces can be assumed to be an equally complex set of stimuli. The present set of experiments used objects that were not standardized for mean luminance or complexity (e.g., number of contours, etc.) Although no item effect was found for the stimuli used in this experiment, it is advisable that in replication – especially any attempt at replication of Experiment 2 – standardized objects sets (Snodgrass and Vanderwart, 1980) should be used.

The importance of the results for the present set of experiments is apparent when compared to memory system theory (Tulving & Schacter, 1990). Tulving and Schacter's compartmentalization of memory into three parts (episodic, semantic, and procedural) implies that these memory systems' function, location, and methods of modification are different. A hierarchy of cognitive ability is further implied in that episodic memory is supposedly based on perceptual characteristics only, semantic on stimulus meaning, and procedural on higher-order temporal and spatial abilities. The fact that transmittal of episodic information is supported (Experiment 1), yet evidence for semantic information transmittal is not (Experiment 2), points to the conclusions made by Tulving and Schacter. The possibility that the eye movement-based memory effect is a measure of a strict implicit/episodic effect is supported as well.

Overall, the present studies offer further insight into the efficacy of using eye movements as a measure of prior exposure. Support is offered that this effect generalizes to objects (Experiment 1). Evidence is also proposed that semantic relationships are not detectable via eye movements (Experiment 2). The consistency of the results for Experiment 1 with the UIUC studies points to the validity of this method of memory assessment.

The lack of support for the use of eye movements as a measure of semantic priming in Experiment 2 indicates some areas to consider in future research. Investigations focusing on measurement of semantic relationships via the eye movement-based memory effect should control for individual differences in semantic relatedness between objects. For example, the associate pairs might not have been salient to individual participants. It would also be prudent to consider a complete within-participants design where eye movements for episodically and semantically related objects can be compared within participants.

Although memory measurement is an obvious achievement of the eye-movement-based memory effect, it cannot be ignored that this method of assessment is based largely in the theory that the brain changes as a result of prior exposure. The ERP research provided the strongest biological explanation of priming's effects. However, the cortical changes that manifest themselves via the eye movement-based memory effect further supports the hypothesis that prior exposure changes cortical pathways. The degree of these changes, and the stimuli salient to this process should be explored in subsequent research with amnesiacs. It would be prudent to investigate the possibility that the strict implicit/episodic effect found in Experiment 1 is generalizable to all individuals (amnesiac or not) and all stimuli (e.g. faces, different object classes, etc.).

The results of the present study can be used in the search for reliable theories of memory construction, and valid tests of prior exposure. Historically, dissociations between memory measures has played a major role in deciphering data that supports or contradicts memory system theories (Blaxton, 1989). The fact that the present study displayed an obvious dissociation between semantic and episodic measurement via an eye movement measure indirectly supports memory systems theory. The results also offer insight into the efficacy of using eye movements as a measure of prior exposure to objects. The fact that the eye movement variable trends fell in step with the memory systems proposed Tulving and Schacter (1990) supports the validity and reliability of this technique as a measure of episodic memory.

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APPENDICES

APPENDIX A

TABLES

Table 1. ANOVA Tables for Eye Movement Variables

Tests of Within-Subjects Effects, Experiment 1					
	SS	df	MS	F	p
EMV	39398.63	4	9849.66	2154.22	0.00
Error(EMV)	6346.31	1388	4.57		
PICS	61.05	1	61.05	13.82	0.00
Error(PICS)	1532.55	347	61.05	4.42	
EMV * PICS	89.44	4	22.36	9.27	0.00
Error(EMV*PICS)	3348.80	1388	2.41		

Tests of Within-Subjects Effects, Experiment 2					
	SS	df	MS	F	p
EMV	34303.67	4	8575.92	1448.04	0.00
Error(EMV)	5661.83	956	5.92		
PICS	1.57	1	1.57	0.25	0.62
Error(PICS)	1534.97	239	6.42		
EMV * PICS	9.62	4	2.41	0.73	0.57
Error(EMV*PICS)	3145.24	956	3.29		

Table 2. Classification Accuracy Scores For Each Participant, Experiment 1

Subject	Wilks' λ	χ^2	df	p	% Accuracy
1	0.82	3.92	5.00	0.56	70.80
2	0.75	5.50	5.00	0.36	70.80
3	0.40	16.87	5.00	0.01*	91.30
5	0.57	11.12	5.00	0.05*	75.00
6	0.92	1.71	5.00	0.89	58.30
7	0.83	3.65	5.00	0.60	70.80
8	0.60	10.06	5.00	0.07	79.20
9	0.87	2.63	5.00	0.76	66.70
10	0.82	3.87	5.00	0.57	62.50
11	0.88	2.54	5.00	0.77	75.00
12	0.90	2.15	5.00	0.83	62.50
13	0.57	11.07	5.00	0.05	83.30
14	0.70	6.86	5.00	0.23	75.00
15	0.70	6.94	5.00	0.23	75.00
16	0.87	2.79	5.00	0.73	66.70
17	0.61	9.79	5.00	0.08	75.00
18	0.69	7.23	5.00	0.20	66.70
19	0.85	3.16	5.00	0.68	62.50
20	0.81	4.05	5.00	0.54	66.70
21	0.91	1.77	5.00	0.88	54.20
22	0.26	26.59	5.00	0.00*	87.50
23	0.50	13.47	5.00	0.02*	83.30
24	0.60	10.10	5.00	0.07	70.80
25	0.78	4.93	5.00	0.42	58.30
26	0.89	2.35	5.00	0.80	54.20
27	0.74	5.86	5.00	0.32	79.20
28	0.54	11.88	5.00	0.04*	75.00
29	0.62	9.19	5.00	0.10	70.80
M	0.71	7.22	5.00	0.39	70.97

* $p \leq .05$

Note: "% Accuracy" is the percent of selected original grouped cases correctly classified in the discriminant analysis.

Table 3. Classification Accuracy Scores For Each Participant, Experiment 2

Subject	Wilks' λ	χ^2	df	p	% Accuracy
1	0.78	4.76	5.00	0.45	75.00
2	0.83	3.58	5.00	0.61	70.80
3	0.75	5.71	5.00	0.34	75.00
4	0.69	7.31	5.00	0.20	75.00
5	0.85	3.09	5.00	0.69	62.50
6	0.48	14.36	5.00	0.01*	87.50
7	0.70	6.94	5.00	0.23	79.20
8	0.76	5.36	5.00	0.37	66.70
9	0.81	4.20	5.00	0.52	75.00
10	0.92	1.64	5.00	0.90	66.70
11	0.59	10.25	5.00	0.07	79.20
13	0.79	4.71	5.00	0.45	62.50
14	0.86	2.87	5.00	0.72	75.00
15	0.94	1.12	5.00	0.95	70.80
16	0.78	4.82	5.00	0.44	62.50
17	0.95	0.96	5.00	0.97	58.30
M	0.78	5.10	5.00	0.49	71.36

* $p \leq .05$

Note: "% Accuracy" is the percent of selected original grouped cases correctly classified in the discriminant analysis.

Table 4. Eye Movement Variable Means

Means - Experiment 1						
		NFIX	FRF	NREG	S1	S2
Familiar	M	8.97	4.16	4.42	0.55	0.76
	N	348.00	348.00	348.00	348.00	348.00
	SD	3.27	3.29	1.89	0.29	0.37
Unfamiliar	M	9.54	4.76	5.09	0.59	0.82
	N	347.00	347.00	347.00	347.00	347.00
	SD	3.04	3.24	2.09	0.26	0.33

Means - Experiment 2						
		NFIX	FRF	NREG	S1	S2
Associate	M	9.90	4.56	4.35	0.48	0.72
	N	192.00	192.00	192.00	192.00	192.00
	SD	3.17	3.67	1.99	0.30	0.37
Unassociated	M	9.74	4.58	4.22	0.48	0.70
	N	192.00	192.00	192.00	192.00	192.00
	SD	3.30	3.73	1.95	0.29	0.39

APPENDIX B

STIMULI LISTS

Stimuli List1. Experiment 1

Target Picture	Test Phase
Plane	Plane
Hose	Hose
Ball & Mitt	Ball & Mitt
Staple Gun	Staple Gun
Mailbox	Mailbox
Globe	Globe
Calculator	Calculator
Pot	Pot
Clock	Clock
Blender	Blender
Lantern	Lantern
Razor	Razor

Target Picture	Test Phase
Workbench	Bottle
Menorah	Briefcase
Toaster Oven	Candle
Speakers	Gas Can
Water Jug	Key
Typewriter	Measuring Cup
Vase	Wheelbarrow
Sunglasses	Q Tips
Soap Dispenser	Scale
Soccer Ball	Sewing Machine
Stethoscope	Shopping Cart
Basket	Drum

Stimuli List 2. Experiment 2

Target Picture	Associate Picture
Gun	Bullet
Trumpet	Trombone
Glove	Mitten
Car	Truck
Wine Bottle	Wine Glass
Screw	Screwdriver
Kettle	Tea Cup and Saucer
Camcorder	VCR Tape
Curling Iron	Hairdryer
Light bulb	Lamp
Broom	Dustpan
Bobber	Hook

Target Picture	Unassociated Picture
Guitar	Mousetrap
Purse	Fan
Hat	Padlock
Shoe	Platter
Faucet	Die
Pipe	Ring
Spatula	Paintbrush
Shovel	Day Planner
Tape Dispenser	Crib
Bell	Flower Pot
Sleigh	Grate
Balloons	Picture Frame

Adapted from Barry, Johnston and Scanlan, 1998.

APPENDIX C

VARIABLE DEFINITIONS

Variable Descriptions

Variable	Description
First Return Fixation	The first fixation on which the eye returns to a previous region from somewhere else.
Number of regions	The number of regions sampled on a given picture.
Number of Fixations	The number of fixations on a given picture.
S1	The first-order Entropy measure. It is a measure of first-order constraint in the transitions between regions.
S2	The second-order Entropy measure. It is a measure of second-order constraint in the transitions between regions.

For a complete description of other possible variable types and their calculation, see Cohen, N. J., Althoff, R. R., Webb, J. M., McConkie, G. W., Holden, J. A., and Noll, E. L. (1997). Eye movement monitoring as an indirect measure of memory. Unpublished manuscript.

EYE MOVEMENT MEASURES OF SEMANTIC PRIMING

Amy Elizabeth Alberts, 2000

The eye movement-based memory effect, manifest by changes in viewer eye behavior toward familiar versus novel images, is a mandatory outcome of prior exposure. An episodic eye movement-based memory effect for images of objects was demonstrated in one experiment. Episodic (Experiment 1) and semantic memory (Experiment 2) of object images were tested using 5 eye movement variables. Participants in Experiment 1 studied a group of images and were tested on recognition of images they were or were not exposed to in the study phase. Participants in Experiment 2 studied a group of images and were tested with images semantically related or unrelated to those in the study phase. ANOVA and Discriminant analyses indicated differences in Experiment 1 between novel and familiar images based on eye movement measures. Results suggest that image sampling behavior is mediated by only the episodic memory system. Conclusions surround the reliability and validity of using the eye movement-based memory effect as a measure of prior exposure.

Amy Elizabeth Alberts
Spring, 2000
Leann Stadtlander

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