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Change Detection for the Study of Object and Location Memory

L. Caitlin Elmore, Antony Passaro, and Anthony A. Wright

The University of Texas Health Science Center at Houston

Abstract

Six adult human participants were tested in change detection tasks for object and location memory with large and small sets of four different stimulus types. Blocked tests demonstrated that participants performed similarly in separate object and location tests with matched parameters and displays. In mixed tests, participants were informed that they would be tested with *either* object changes or location changes; surprisingly, they were nearly as accurate remembering both objects and locations as when either was tested alone. By contrast, in the large-set condition, performance was lower than baseline on surprise probe test trials in which participants were tested (on 13% of trials) with the change type opposite to the present block (e.g. location probe trials during the object change block). These probe-test results were further supported by the reduction in probe-baseline differences when tested with small sets (6) of these item types. Small sets required remembering locations and objects to resolve object-location confounds. Together these results show that humans can remember both objects and locations with little loss of accuracy when instructed to do so, but do not learn these contextual associations without instruction.

Keywords

change detection; visual short-term memory; object memory; location memory

1. Introduction

In recent years, visual short-term memory has been studied in both humans and animals using the change detection task (e.g., Wilken & Ma, 2004; Alvarez & Cavanagh, 2004; Eng, Chen, & Jiang, 2005, Wright et al., 2010, Elmore et al., 2011, Heyselaar, et al., 2011; Elmore et al., 2012). In this task, participants are presented with a display of visual objects, and after a brief retention delay are asked to report either the presence or absence of a change, or the specific item that has changed in a test display. The task has primarily been used to study object memory, and researchers frequently investigate the amount of information (number of objects) or precision of memory (ability to detect signal from noisy representations). However, the change detection task also lends itself to the study of spatial memory (memory for locations). The task allows multiple stimuli to be presented

Contact: L. Caitlin Elmore, Department of Neuroscience, Baylor College of Medicine, One Baylor Plaza, Houston, TX 77030, (713) 858-6753, lelmore@cns.bcm.edu.

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simultaneously in multiple locations for participants to remember. Instead of asking participants to identify a changed object, one can ask participants to identify changes in an object's location following a retention delay.

Using change detection to study memory for locations is also advantageous because location memory can be directly compared to object memory using exactly the same stimuli and task parameters. In addition, it is important to study memory for objects and locations concurrently because all objects necessarily occupy a location and locations are marked by the presence (or absence) of objects. In fact, research has indicated that objects and their locations are "bound" together in short-term memory under some conditions (Wheeler & Treisman, 2002). Participants can be asked to store both types of information on every trial. Also, probe tests can be conducted in which participants are instructed to attend to one type of information (e.g., object) and are then probed with unanticipated location change trials to see the extent to which they are storing location information as well, and vice versa.

Frequently, change detection studies are conducted using small sets of stimuli. Consequently a given stimulus will often repeat both within a single trial and across a series of trials. If a stimulus is presented more than once in a given trial, participants will be forced to also attend to the object's location in order to differentiate between identical objects and accurately perform the task. Repetition of stimuli across trials can lead to the buildup of proactive interference which is often detrimental to performance (e.g., Wright et al., 2012, Makovski & Jiang, 2008; Roberts & Grant, 1976) Thus it is also important to investigate the role of set size in short-term memory performance.

The goal of the present study was to directly compare object and location short-term memory using a change detection task. In addition, the study sought to further elucidate the cognitive processing used in a mixed condition, where objects and their locations had to be maintained in memory concurrently. The purpose of this condition was to assess whether memory performance would suffer when the memory load was effectively doubled by requiring participants to memorize both object and location information within the same trial. Next, in a probe condition, we assessed the role of conscious awareness in the tendency to bind objects and their locations in memory. The probe condition examined whether participants would remember both object and location information when they were instructed that it was only necessary to remember one type of information. Finally for all conditions (object, location, mixed, and probe) we assessed the role of large and small sets of stimuli in change detection memory performance.

2. Methods

2.1 Participants

Seven adult human participants were recruited to participate in this study. They ranged in age from 23 – 28 (mean age 25.6), and there were five females and two males. The participants visited the lab for a total of eight 1-hour sessions. The participants were compensated \$10 per 1-hour session. All procedures were approved by the University of Texas Health Science Center at Houston Committee for the Protection of Human Subjects.

2.2 Apparatus

The participants were tested in a room with a PC computer. The computer's monitor (17" EIZO) was equipped with an infrared touch-screen (17-inch Unitouch; ELO, Round Rock, TX). The participants were provided feedback by two 25 watt light bulbs that were mounted on the wall behind the participants. The green light was illuminated for 1 s following correct responses and the red light was illuminated for 1 s following incorrect responses. The lights were operated by a computer-controlled relay interface (Model PI0-12; Metrabyte, Taunton, MA). Microsoft Visual Basic 6.0 was used to create custom software which created, controlled, and recorded experimental sessions. The monitor was controlled by a video card (ATI graphics adaptor).

2.3 Stimuli

The stimuli were 976 color clip art images, 976 color kaleidoscope images, 256 black and white Kanji characters, and 256 black and white Snodgrass line drawings (Snodgrass & Vanderwart, 1980). A subset of the stimuli are depicted in Figure 1. The stimuli were randomly presented in 20 possible locations (defined by points on two invisible concentric circles). The stimuli subtended a visual angle of 1.3 degrees.

2.4 Test Procedures

The participants completed a total of eight 1-hour test sessions of the change detection task. In this task, participants first viewed a sample display of six, eight, or ten stimuli (all from the same category in an individual trial) for 1 s. A black display was then presented for a 1-s delay period. Following the delay participants were presented with the test display which contained two stimuli, one of which matched (object identity and location) a stimulus from the sample display, and one of which had changed (either in object identity or location). The participants' task was to touch the stimulus that had changed. The trial sequence is depicted in Figure 2. Individual trials were restricted to one stimulus category (e.g., Kanji characters), but stimulus categories were intermixed within the session. Each 1 h test session consisted of two blocks of 180 trials, in which stimulus categories and display sizes (6, 8, 10) were randomly intermixed.

2.5 Test Conditions

The eight test sessions were divided into two groups of four. One group of four sessions belonged to the large set condition, in which all stimuli in all trials were drawn from a large group of 976 (clip art and kaleidoscopes) or 256 (Kanji and Snodgrass) stimuli. The second group of four sessions belonged to the small set condition. In the small set condition, trials were drawn from sets of six stimuli from each category with no more than two repeats for each stimulus in a given sample display. For each condition (small and large set), the four test sessions were divided into eight blocks of 180 trials (two each of object change, location change, probe test, and mixed condition). The order of the blocks tested was counterbalanced. In the object change condition, participants were instructed to memorize the objects in the sample display and look for a change in the object's identity in the test display. In the location change condition, participants were instructed to memorize the objects' locations in the sample display and look for a change in location in the test display.

In the probe condition, for the object-change block of 180 trials, participants were instructed that the trials were in the object change condition and that they should look for changes in object identity. However, 24 probe trials were intermixed in which there was no object change, but rather a change in location of one object. Likewise, in the location block of 180 trials there were 24 probe object change trials intermixed. In both cases, participants were not informed of the probe trials. Lastly, in the mixed condition, object and location trials were randomly intermixed (90 of each per block), and participants were instructed that there could be a change in object identity or location, and that they should therefore try to memorize the objects' identities and locations during the sample display and look for either type of change during the test display.

3. Results

Mean accuracies and standard errors for each stimulus type in the large and small set condition are listed in Table 1.

Figure 3A displays mean accuracy in each of four trial types (blocked object and location and mixed object and location) for the large set condition. Performance was significantly greater than chance in all trial types (binomial tests, $p_s = 0.0001$). Figure 3B displays mean accuracy in the blocked object and location and mixed object and location trial types for the small set condition. Performance was once again significantly greater than chance in all conditions (binomial tests, $p_s = 0.0001$). A five-way factorial analysis of variance (display size $\times$ set size $\times$ trial type $\times$ stimulus type $\times$ condition) was conducted. The ANOVA showed highly significant effects of display size ($F(2,975) = 50.68, p = 1.15 \times 10^{-21}$), stimulus type ($F(3,975) = 37.79, p = 4.13 \times 10^{-23}$), trial type (object or location: $F(1, 975) = 15.91, p = 7.15 \times 10^{-5}$), and condition (blocked or mixed: $F(1,975) = 6.48, p = 0.01$). Participants had higher accuracy with smaller display sizes, and performed better with Clip Art and Snodgrass stimuli than with Kanji and Kaleidoscopes. See Table 1 for detailed accuracy results. In addition, participants performed more accurately in the location change trials (72.33% correct) than in the object change trials (69.77% correct). Participants were also slightly more accurate overall in the blocked condition (71.61% correct) than in the mixed condition (69.83% correct). There were also significant interactions of display size and stimulus type ($F(6,975) = 4.46, p = 0.0002$) and of trial type and stimulus type ($F(3,975) = 17.25, p = 6.39 \times 10^{-11}$).

Probe Condition

Figures 4A and 4B display mean performance in the probe condition. In Figure 4A the large set probe condition is shown and in Figure 4B the small set probe condition is shown. Participants performed well on baseline trials, both in the object and location conditions. Baseline refers to change type trials that the participants were instructed to perform (e.g. object or location change). Probe trials refer to the change types of which the participants were not instructed (probe trials of the other change type intermixed – e.g. location change trials in an object change block). A four-way factorial anova of display size $\times$ set size $\times$ trial type $\times$ probe condition (baseline or probe) showed a significant effect of display size ($F(2,153) = 3.77, p = 0.03$) and probe condition ($F(1,153) = 21.86, p = 6.4 \times 10^{-6}$). Thus in

both the large and small set conditions, participants performed better with smaller display sizes, and accuracy was greater in the baseline trials than in the unanticipated probe trials.

4. Discussion

In the blocked condition, participants performed accurately in both the object and location change trials, although location change performance was significantly higher (72.33% correct vs 69.77% correct for object change trials). There was also a small but significant difference in overall accuracy between the blocked (71.61% correct) and mixed conditions (69.83% correct). However, this 1.78% difference is much smaller than would be predicted based on the fact that the mixed condition required subjects to store twice as much information on every trial relative to the blocked condition. During the mixed condition, subjects needed to maintain both object and location information for each stimulus in the sample display, while in the blocked condition subjects were only required to maintain one piece of information (either object identity or location) about each stimulus in the sample display. The very small difference in performance between the blocked and mixed conditions suggests that object and location information is processed in parallel, with very little cost to overall performance. Such a small decrement in performance could be attributed to a constraint on attentional resources, rather than a limitation in memory storage, although the experiments conducted here do not allow that question to be directly addressed.

Wheeler & Treisman (2002) showed that focused attention is necessary for the maintenance of binding over time. While one might expect that the association of an object and its context (location) is automatic, both our results and the results of Wheeler & Treisman (2002) suggest that the parallel processing of object and location information may be under conscious control. Probe test trial performance was significantly worse than baseline object and location performance. Thus, when participants were unaware that object and location information should be stored concurrently, they failed to encode both pieces of information and instead stored what they had been instructed to remember (e.g., object or location alone). It is also possible that subjects stored object and location information in parallel but were biased by the experimenter's instructions to perform object or location change detection alone. Nevertheless, in interviews following the experimental session, none of the participants reported noticing any "unusual trials" during the probe condition.

The smaller baseline-probe difference in the small-set condition (8.58% difference between baseline and probe vs. 14.9% difference in the large set condition) may have been due to participants having to resolve the ambiguity between object and location when stimuli were repeated in the same display. In the small set condition, it was necessary for participants to attend to both object and location information in order to accurately perform the task. For example, in the object condition, using clip art stimuli as an example, the football helmet might appear as part of the sample display in location 1. After the delay, the dinosaur in location 2 could change to the football helmet. If the subject attended to object information alone, they would not accurately detect the change because the football helmet appears in both the sample and test display (see Figure 5). Although participants in the small set condition might have been biased toward the block type (e.g., object changes), the need to resolve the object-location confound described above likely facilitated good performance on

probe trials, as participants may have actively attended to both types of information. Thus, the results from the small set condition support the idea that the binding of object and location information is under conscious control.

A similar series of probe tests was conducted with both rhesus monkeys and pigeons trained to perform object change detection (see Elmore et al., 2012). These animals had no experience with location change trials and were tested to see if they would spontaneously transfer their change detection performance to location changes. Interestingly, in this case there was a species difference, as shown in Figure 6. Monkeys performed as well with the probe location change trials as they did with their baseline object change trials. Similar to the small set probe condition with human subjects, the monkeys were trained and tested with a small set of eight colored circle stimuli such that an optimal strategy would be to attend to both object and location information simultaneously, thereby facilitating their good performance with probe location change trials. Pigeons, however, performed at chance with location changes after being trained to perform object change. Although pigeons were also trained with a small set of stimuli they have been shown to be quite poor at transferring their performance to novel types of change (Elmore et al., 2012) so it is not surprising that they did not perform well with the novel probe location change trials. In addition, this is consistent with a species difference in bias. Pigeons are potentially more biased by their training with object changes than the rhesus monkeys, who appear to have stored object and location information concurrently, and readily identified both types of change.

In recent years, much emphasis has been placed on the notion of a slot-like storage system for visual short-term memory (e.g., Luck & Vogel, 1997, Cowan, 2000, Alvarez & Cavanagh, 2004, Eng et al., 2005, Buschman et al., 2011). This work supports the idea of a fixed capacity for visual information (e.g. magic number 4 ± 1). However, if visual memory is limited to specific number of stimuli, how can one explain the findings from comparing our blocked and mixed conditions? If a subject is only able to accurately store four stimuli in the blocked condition due to their limited-capacity slot-like storage system, how is it possible that the subject is able to perform nearly as well when they have twice as much information to store in the mixed condition? One could theorize that object and location information are bound together in memory and that the slots are filled by bound units (one object + its location).

Finite limitations in visual short-term memory have come under scrutiny in other recent work. These studies have supported the continuous-resource model using data from both humans (Wilken & Ma, 2004) and rhesus monkeys (Elmore et al., 2011). Rather than modeling memory as a discrete entity of a few slots, the continuous-resource model states that memory is a continuous resource that can be allocated to many stimuli. Instead of capacity, the model uses d' from signal detection theory as a measure of memory sensitivity. A reduction in resource per stimulus with increasing memory load results in increasing noise in those memory representations. If objects and locations are bound together in memory, perhaps the memory resource is allocated to each bound unit (one object + its location), or allocated globally across the scene as a whole instead of on a stimulus by stimulus basis.

Future experimental and theoretical work should seek to better understand the interplay of object and location memory. Is binding under conscious control? Or are participants simply biased by their expectations of the task? How do models of visual short-term memory account for our findings that participants actively maintain both object and location memory with similar accuracy, but only when instructed (mixed condition) or when it was advantageous (small set probe condition)? In our daily lives, our memory requirements are rarely restricted to the simple case of a small display of visual objects. We need to maintain vast stores of memories of scenes of information in order to navigate our environment. As a result, a cohesive understanding of the intersection of object and location memory is important. In addition, understanding the interplay between object and location memory also has implications for the “what” and “where” of episodic memory (what, when, & where) (e.g. Tulving, 2001, Tulving, 2002, Clayton & Dickinson, 1998, Clayton et al., 2001, Clayton et al., 2003).

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Highlights

- Humans perform object and location change detection with similar accuracy.
- Object and location information can be accurately stored concurrently.
- Binding of object and location information is under conscious control.

Figure 1.
Example stimuli. First row: clip art. Second row: kaleidoscope images. Third row: Kanji characters. Fourth row: Snodgrass line drawings.

Figure 2. Trial progression in the change detection task. The schematic presented here is representative of the mixed condition in which object and location trials are intermixed.

Figure 3.

A) Change Detection accuracy by trial type in the large set condition. B) Change Detection accuracy by trial type in the small set condition. Error bars represent standard error of the mean.

Figure 4.

A) Change Detection accuracy by trial type in the large set probe condition. Participants completed two 180-trial blocks, one each of object and location change detection in the large set probe condition. In each block, 24 probe trials of the opposite change type were randomly intermixed. B) Change Detection accuracy by trial type in the small set probe condition. Error bars represent standard error of the mean.

Figure 5.

Example object change trial with object-location confound. The dinosaur in the sample display changes to the football helmet in the test display. The football helmet was present in another position in the sample display, and the subject could be confused by this, thinking that the football helmet was not the changed item because it was present in the sample display.

Figure 6.

Performance by rhesus monkeys & pigeons trained in the object condition and tested with probe location change trials. Error bars represent standard error of the mean. Participants were tested over the course of seven 96-trial session with twelve probe trials randomly intermixed in each session.

Table 1

Percent Correct and S.E.M.s for Object and Location Changes with Large and Small Stimulus Sets

Stimulus Type	Large Stimulus Set			
	Blocked		Mixed	
	Object	Location	Object	Location
Clip Art	76.49 ± 1.61	76.82 ± 0.32	75.93 ± 5.31	74.35 ± 4.79
K-scopes	66.12 ± 4.75	71.99 ± 2.90	55.02 ± 3.06	68.75 ± 5.69
Kanji	63.55 ± 1.19	71.67 ± 3.75	65.85 ± 2.28	72.73 ± 0.89
Snodgrass	77.81 ± 3.58	72.50 ± 2.54	70.39 ± 3.72	73.35 ± 5.59
	Small Stimulus Set			
Clip Art	73.31 ± 4.48	73.09 ± 1.38	79.76 ± 4.62	72.78 ± 3.10
K-scopes	65.86 ± 5.44	72.98 ± 3.60	54.63 ± 1.88	68.87 ± 3.10
Kanji	64.69 ± 2.25	69.55 ± 1.39	70.15 ± 6.12	76.34 ± 1.86
Snodgrass	74.09 ± 1.20	71.10 ± 3.94	72.66 ± 2.78	72.49 ± 2.48