The Capacity of Visual Short Term Memory

Introduction

Because our experience of the visual world is rich and detailed, it is easy to assume that we are aware of virtually every object in view; we feel confident in the comprehensiveness of our perceptions. Changes to any object within our view should be easy to notice, especially large changes such as a jet engine disappearing off of the wing of a jet airplane. Surprisingly, though, change blindness studies (see Rensink, 1997) demonstrate that such changes must be repeatedly flickered on and off for several repetitions before they are noticed (for startling examples, see http://www.usd.edu/psyc301/ChangeBlindness.htm). Presumably, change detection depends upon a comparison operation between items contained within a memory store and those apparent in the visual field. If an item is contained within memory, and its appearance disagrees with the memory representation, then a change will be perceived. Change blindness suggests that the memory store may not contain sufficient information to perceive some changes, even ones affecting a large portion of the visual field. These rather startling results suggest a large disparity between one's detailed perception of the visual world and the amount of information that is actually available for change detection. Performance in tasks requiring change detection depends on the amount of information that is available from memory, and understanding the capacity of the memory store has applications to a multitude of situations. One particularly important human factors application is that of panel design. Flight controllers, 911 dispatchers, pilots, and even everyday drivers must notice changes in their panels quickly in order to avoid life-threatening disasters.

Which memory store is important in visual change detection tasks? First of all, the memory store under investigation has been shown to be different than that for auditory stimulation. Scarborough (1972) has demonstrated that short term memory of verbal and visual items do not interfere with each other, so we know that visual short term memory is different from auditory short term memory. Furthermore, visual memory is widely regarded to be composed of two separate stages. Sperling (1960) demonstrated that observers have access to a high amount of information within 300 ms of image offset, after which observers have access to a memory store with a much lower capacity. This latter memory store does not decay as quickly as iconic memory, the first stage, and is widely recognized as visual short term memory. Phillips (1974) demonstrated that the encoding of objects in visual short term memory does not depend on their spatial location. This aspect of visual short term memory demonstrates how useful it is in everyday applications: if items stored in visual short term memory were tied to the spatial locations where they were initially viewed, it would be impossible to identify actual changes in objects because movements of the observer would generate new spatial coordinates for unchanged objects.

Knowing these aspects of visual short term memory, the investigator must next inquire about the memory contents. Studies of visual short term memory suggest that a surprisingly small amount of information is stored after briefly viewing an image: Sperling (1960) found that observers could remember only 4.3 letters on average regardless of how long they viewed different sized letter matrices, and more recently, Luck & Vogel (1997) found that only four integrated objects, such as colored boxes, are available to the viewer in change detection tasks. Recently, however, Alvarez and Cavanagh (2004) have suggested that the capacity of visual short term memory is not limited by the number of objects, but rather by their informational load. The greater the informational load of the object, the fewer of its type may be contained in visual short term memory. Specifically, Alvarez and Cavanagh found a linear relationship between the informational load of a class of objects and the number of such objects that can be held reliably by visual short term memory. The objective of the current project is to investigate this linear relationship: first replicating it and, assuming it can be replicated, testing the generality of this formulation across different methods of varying the information load of sets of items.

Methodology & Approach

Alvarez and Cavanagh (2004) measured the capacity of visual short term memory separately for six stimuli classes (**Fig. 1** reproduces their stimuli sets) through the use of a standard change detection paradigm. In the change detection experiment, the observer views a 5×4 array containing a variable number of objects all drawn from a single object class for 500 ms, followed by a 900 ms blank interval, and then a second presentation of the object array. In the second presentation one of the objects might have been replaced by another item from the same class. After viewing the second presentation, the observer indicates whether or not the two presentations were the same (see **Fig. 2** for an example trial). The number of items in the array varies from 1 to 15 objects on different trials, so that a psychometric function relating the number of objects to the percentage of correct performance can be fitted to the data. With such a psychometric function it is possible to estimate the capacity of visual short term memory by using the 75% correct threshold. (Alvarez provides an explanation for this threshold choice in http://www.blackwellpublishing.com/products/journals/suppmat/alvarez/alvarez_appendix.html.) Alvarez and Cavanagh reported the memory capacity separately for the different stimulus types and found that the capacities ranged from 1.6 items (for cubes) to 4.4 items (for colors).

The informational load of each stimulus class was then evaluated functionally using a visual search task. In such a task, the observer is first presented a target item alone and then presented an array of objects from the same class as the target. When the array appears, the subject presses one of two buttons to indicate, as quickly as possible, whether or not the target is contained in the array whose size is 4, 8, or 12 objects. (See **Fig. 3** for an example visual search trial.) The time required to complete this search depends both on the number of items in the array and on the information load of each item. Search rate indicates the amount of time required to find the target item when it is present, so it is estimated as the slope of the line relating reaction time on target-present trials to the array size. Alvarez and Cavanagh reported search rates from approximately 125 msec/item (for cubes) to 10 msec/item (for colors).

The important relationship is that between a stimulus class' search rate and the corresponding number of items maintainable by visual short term memory during the change detection task. If the capacity of visual short term memory is limited by a maximum amount of information, fewer high-information items should fit in memory than low-information items. This relationship between a stimulus class' information load and the number of items from its class that visual short term memory can maintain is:

(amount of information per item) × (number of items) = memory capacity

where memory capacity can be thought of as the maximum amount of information storable by visual short term memory. This equation predicts that more low-information items can be stored (e.g., stimuli with color information only like the "colored squares" from **Fig. 1**) than high-information items. Recall that Alvarez and Cavanagh found 4.4 items could be maintained from the set of colored squares, but only 1.6 items could be maintained from the set of shaded cubes. The colored squares contained the least amount of information and had the quickest search rates, requiring only 10 msec of processing time for each item, but the shaded cubes contained much more information and required 125 msec of processing time for each item. In fact, the informational load of a stimulus set was inversely related to the number of items maintained in memory for each of the six stimulus sets Alvarez and Cavanagh evaluated. See **Fig. 4** for a graphical representation of this inverse relationship.

That the number of items storable by visual short term memory could depend on the information load of the items is an interesting theory. Unlike Luck and Vogel's (1997) finding that the capacity of visual short term memory maxes out at four items regardless of how much information each item contains, Alvarez and Cavanagh's findings suggest that visual short term memory capacity is defined by an informational maximum rather than an item number maximum. If the inverse relationship between number of items storable and informational load per item were an accurate description of visual short term memory's capacity, one would expect the relationship to hold for virtually any stimulus set.

The first objective of the current study is to replicate the linear relationship between informational load and number of items storable. We will measure visual search rates and memory capacities for three of the original study's stimulus sets that are different enough to define a line. For example, in **Fig. 4** we see that colors, Chinese characters, and shaded cubes are relatively evenly spaced along the line. If our data for these same three sets of stimuli replicate the linear relationship Alvarez and Cavanagh report, their experimental methods will gain reliability. If we do not find such a linear relationship, it could suggest that Alvarez and Cavanagh's method was not reliable. Namely, Alvarez and Cavanagh may have been incorrect in their functional definition of informational load or in their procedure for estimating memory capacity. The lack of a linear relationship could also suggest that visual short term memory is not defined by an informational maximum, in which case further support would be given to the results of studies like Luck and Vogel's (1997).

On the other hand, if we replicate this linear relationship for three stimulus sets duplicated from the original study, we could then evaluate the generality of the linear relationship. To show that the linear relationship is not just a product of the six specific stimulus sets Alvarez and Cavanagh used, we could create an entirely new stimulus set and evaluate whether or not it fell on the line. For instance, we could create a new set of items like six sketches of animals and then measure the search rate and number of items stored by visual short term memory. If search rate and number of items were inversely related in the same manner predicted by the linear relationship defined earlier, Alvarez and Cavanagh's theory would gain validity.

Another way to test the validity of Alvarez and Cavanagh's theory is to manipulate the visual search rate for a stimulus set by changing the items within the set. For example, we could choose our color set to create a 'pop-out' effect where the target color would be immediately found in a visual search task. Such effects are well documented (see Treisman, 1982; Treisman & Gelade, 1980) and should be easy to recreate with the right stimulus set. With such a 'pop-out' effect, the search rate should be virtually zero, in which case we could estimate the maximum number of items stored in visual short term memory. For such an informationally simple stimulus set, Alvarez and Cavanagh's linear relationship predicts approximately 4.7 items to be stored in visual short term memory. This suggests that the maximum number of items that could be stored in visual short term memory is approximately 5. In the opposite direction, it could be possible to find a stimulus set which maximized memory so that one item contained all the information storable by visual short term memory. The research of Duncan and Humphries (1989) suggests that visual search times can be increased by making the target item highly similar to the other items in the set; if we made a set of items which were quite similar, it should be possible to find a stimulus set for which only one or fewer items could be maintained by visual short term memory. This result would demonstrate the maximum amount of information one item can contain without overloading visual short term memory.

Timeline & Student Responsibilities

The goals of the present project are quite feasible and are expected to be met during the summer term. Because the experiment requires only a standalone PC, and the computer programming required is relatively simple, the creation of the experiment running software will be straightforward as will the data analysis. Data collection is expected to be the most time consuming portion of the project because sessions with hundreds of trials will be required in order to gather enough data to generate smooth psychometric curves.

The student's responsibilities in this research study include designing the stimuli and experiments, writing necessary computer programs, running subjects, analyzing data, and reporting the results in a professional quality paper. All of the above responsibilities will be overseen by my faculty mentor.

- June – July: Student creates the stimuli, writes the computer programs necessary for running the experiment and collecting the data, and conducts pilot testing of the experiments.
- August: Student runs subjects and collects data.

• September: Student analyzes data and reports results in a professional quality paper to be submitted for publication.

Figures

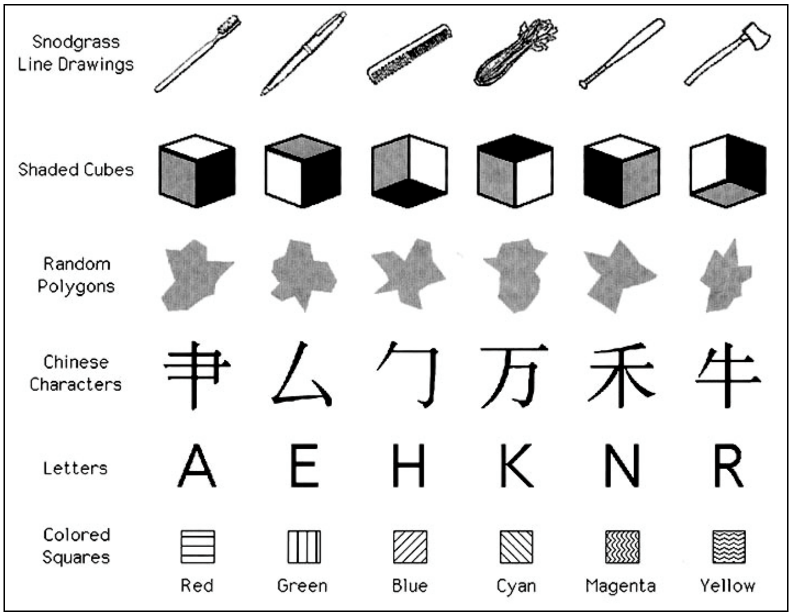

Figure 1. Reproduction of Alvarez and Cavanagh's (2004) six stimulus sets.

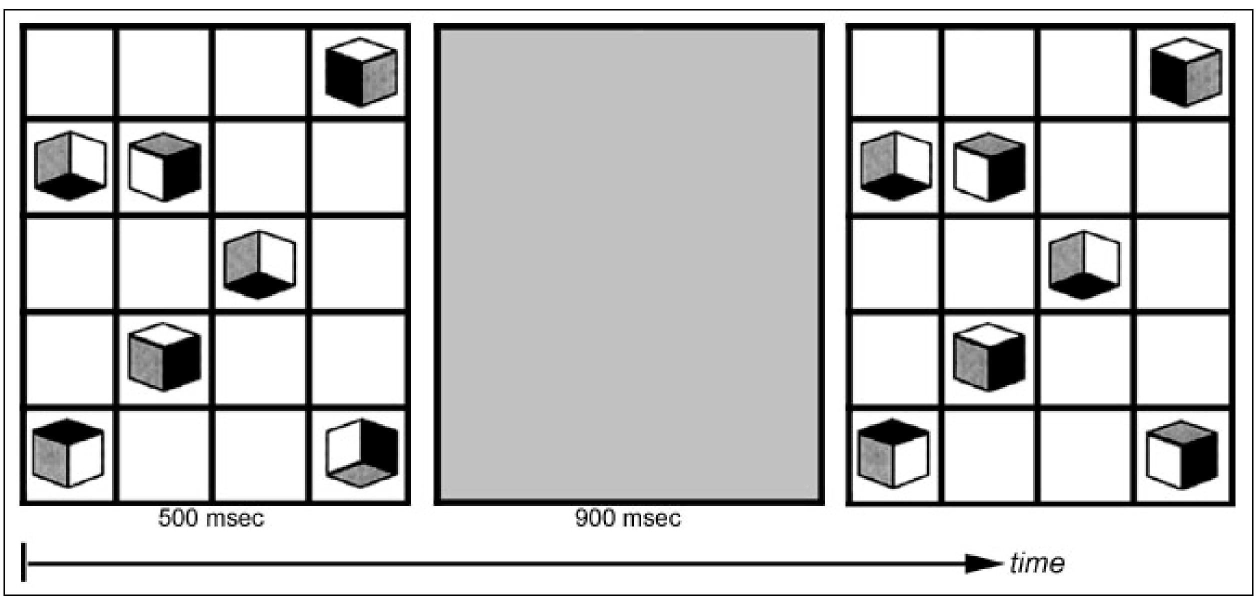

Figure 2. Example of a change detection trial. First the observer views the initial array of objects (N.B., all objects are from the same stimulus class), then a blank interval, and finally the second array of objects. The task is to indicate whether the second array is the same as the first. The correct response in this example is that the two arrays differ; the item in the bottom right-hand corner of the first array was replaced by a different one in the second array.

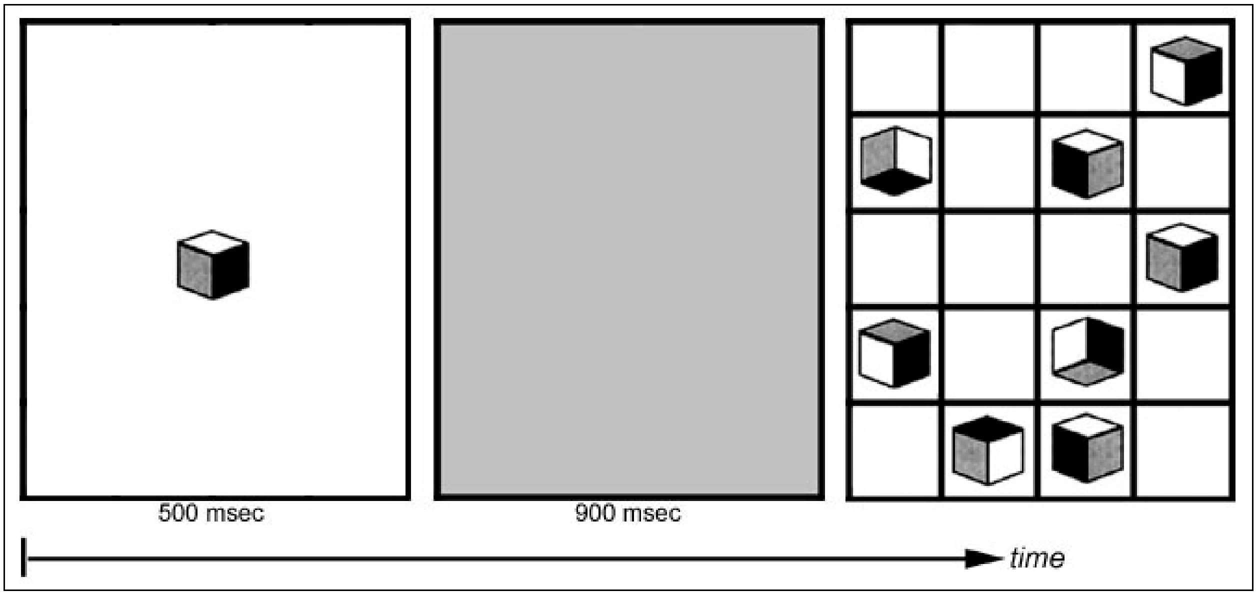

Figure 3. Example of a visual search trial. First the observer is presented with the target object, then a blank interval, and finally an array of items from the same class of stimuli as the target. The observer's task is to respond as quickly as possible whether the target is present or absent. In this example, the correct response is that the target item is present.

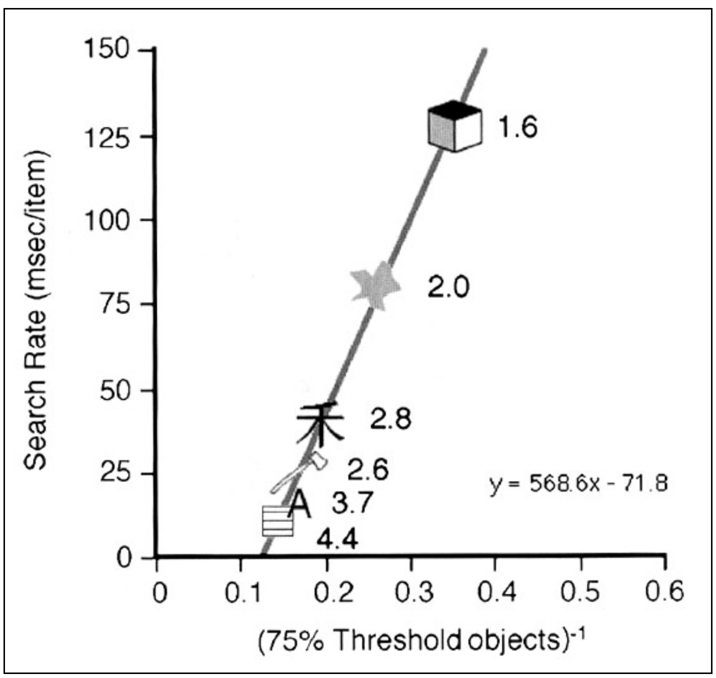

Figure 4. Search rate as a function of the inverse of the 75%-threshold number of objects in change detection for each stimulus class (from Alvarez and Cavanagh, 2004). This graph demonstrates the inverse relationship between a stimulus class' informational load (i.e. search rate) and the corresponding number of items maintainable by visual short term memory (the 75% threshold).

References

Alvarez, G.A., & Cavanagh, P. (2004). The capacity of visual short-term memory is set both by visual information load and by number of objects. *Psychological Science, 15(2),* 106-111.

Duncan, J., & Humphreys, G.W. (1989). Visual search and stimulus similarity. *Psychological Review, 96(3),* 433-458.

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

Phillips, W.A. (1974). On the distinction between sensory storage and short-term visual memory. *Perception & Psychophysics, 16(2)*, 283-290.

Rensink, R.A., O'Regan, J.K., & Clark, J.J. (1997). To see or not to see: the need for attention to perceive changes in scenes. *Psychological Science, 8(5),* 368-373.

Scarborough, D.L. (1972). Memory for brief visual displays of symbols. *Cognitive Psychology, 3,* 408-429.

Sperling, G. (1960). The information available in brief visual presentations. *Psychological Monographs, 74,* 1-29.

Treisman, A. (1982). Perceptual grouping and attention in visual search for features and for objects. *Journal of Experimental Psychology: Human Perception and Performance, 8,* 194-214.

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