

EFFECTS OF ATTENTION AND WORKING MEMORY ON PERCEPTION

by

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Selective attention refers to perceptual selection and working memory refers to the active maintenance of mental representations. Selective attention and working memory are believed to be two of the most important functions in human cognition and have been intensively investigated in cognitive psychology. However, it is quite recent that the link between attention and working memory has been systematically researched. One question that remains controversial is the effect of working memory on attentional control with inconsistent results reported in the human psychophysical literature, despite clear and strong evidence from physiological studies with nonhuman primates that working memory is the main source of top-down attentional control. The main goal of the current study is to provide a plausible solution to the puzzle of attentional control by introducing the concept of *goal-specificity* and competition between working memory representations. I hypothesized that the strength of the biasing effect of working memory on attention depends on the specificity of representations in working memory, and developed an

experimental paradigm (the goal-specificity paradigm) to test this hypothesis using psychophysical and neuroimaging methods. One of the most important manipulations in the goal-specificity paradigm is how specifically targets in different tasks are defined. The results demonstrate that there is competition between items in working memory for attentional control that is influenced by the specificity of each representation as well as task relevancy. Also, it is shown that the effect of goal-specificity is present in both spatial and temporal domains as revealed by visual search and rapid serial visual presentation tasks. The results suggest the possibility that the negligible effect of working memory in some previous studies may be due to insufficient specificity of the objects in working memory or to the presence of other specifically-defined information in working memory. Furthermore, based on the implication from the current study that goal-specificity has a significant influence on attentional control, I expect that the experimental paradigm introduced in the current study can be utilized as an objective psychophysical measure of attentional control.

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To My Parents

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CHAPTER I

SELECTIVE ATTENTION AND WORKING MEMORY

Introduction

The information processing system of the brain has limited capacity such that we cannot process all the information around us at a given moment in time. Therefore, some kinds of selection processes have to be carried out continuously in order for us to select what is relevant and ignore what is irrelevant. Selective attention is believed to be one of the most important factors in understanding selective processes. The most common definition of selective attention is perceptual selectivity, and it is the meaning of attention intended in the current study.

As we have all experienced, it is sometimes easy to screen out irrelevant information and successfully find relevant information, but some other times it is very difficult. In order to illustrate this phenomenon and to characterize the function of attentional selection in the visual system, visual search paradigms have been used extensively from the initial stages of modern research on attention. In typical visual search tasks, participants are asked to report whether a given scene contains a predefined target among a set of nontargets (distractors) as quickly and/or accurately as possible. Performance is measured using reaction time and/or error rate, and search slope (the change in response time and/or error rate as a function of the number of items in the

search display) is considered as an index of search efficiency (search efficiency is higher when the search slope is smaller).

Based on the pattern of data from countless numbers of studies using visual search tasks, several accounts of visual attention have emerged, such as the Feature Integration Theory by Treisman and colleagues (Treisman, 1988; Treisman & Gelade, 1980; Treisman & Gormican, 1988; Treisman & Sato, 1990), the Guided Search Model by Wolfe and colleagues (Wolfe, 1994; Wolfe, Cave, & Franzel, 1989; Wolfe & Gancarz, 1996), and the Attentional Engagement Theory by Duncan and Humphreys (Duncan & Humphreys, 1989; Duncan & Humphreys, 1992). Earlier attempts to explain the search data and characterize the function of selective attention could not avoid a number of assumptions due to the limited information available at the time. Consequently, the earlier models seem to have more flaws in their original versions resulting in more modifications than relatively recent ones. After a number of revisions, each of the attention models mentioned above became successful at explaining most of the data in the visual search literature, even though there are still differences in structure, assumptions, and complications between them.

More importantly, each of the theories has moved toward a unified view that attentional selection is accomplished by facilitating relevant information and inhibiting irrelevant information, and that how selective attention is distributed depends on the complex interactions between bottom-up and top-down factors. When perceptual information is selected based on physical properties of sensory input, the selection is bottom-up or stimulus-driven, whereas when information is selected based on an

observer's behavioral goals, beliefs, and knowledge, the selection is top-down or goal-directed. In the following sections, influential accounts of selective attention will be summarized and contrasted with one another.

Feature Integration Theory

Feature Integration Theory (FIT) by Treisman and Gelade (1980) is one of the earliest models that describe the role of attention in a concrete way based on the pattern of data from visual search tasks. One of the main points in Feature Integration Theory is that the role of selective attention is to integrate or “glue” separate features together into an object (Figure 1). More specifically, Feature Integration Theory proposed that visual inputs are processed in two successive stages: (1) an early, parallel, preattentive stage, and (2) a late, serial, attentive stage.

In the first stage, visual inputs are analyzed into retinotopically organized feature maps, which are independent from each other. This process works in parallel across the visual field, so that the number of non-targets in a search display does not delay (i.e., the search slope is almost zero) the search for a target that can be discriminated from nontargets by at least one feature dimension. An example of a parallel preattentive feature search is the case of searching for a red X or blue O among blue Xs (the target is unique in its color or shape feature, respectively). In the second stage of processing, attention is allocated to one area at a time in a serial fashion within a master map, resulting in the conjoining of features that are registered at the corresponding area in the feature maps of the first stage. Therefore, if a target can be discriminated only by a conjunction of features, but not by any single feature, then attention needs to be focused on each item (or

each small area) in the display one by one in order to identify the conjunction target. Consequently, it takes longer to find a conjunction target as the number of non-targets increases (i.e., search slope is not close to zero). An example of a serial attentive conjunction search is the case of searching for a red X among red Os and black Xs (the target is not unique either in its color or shape feature, but unique in the conjunction of color and shape features).

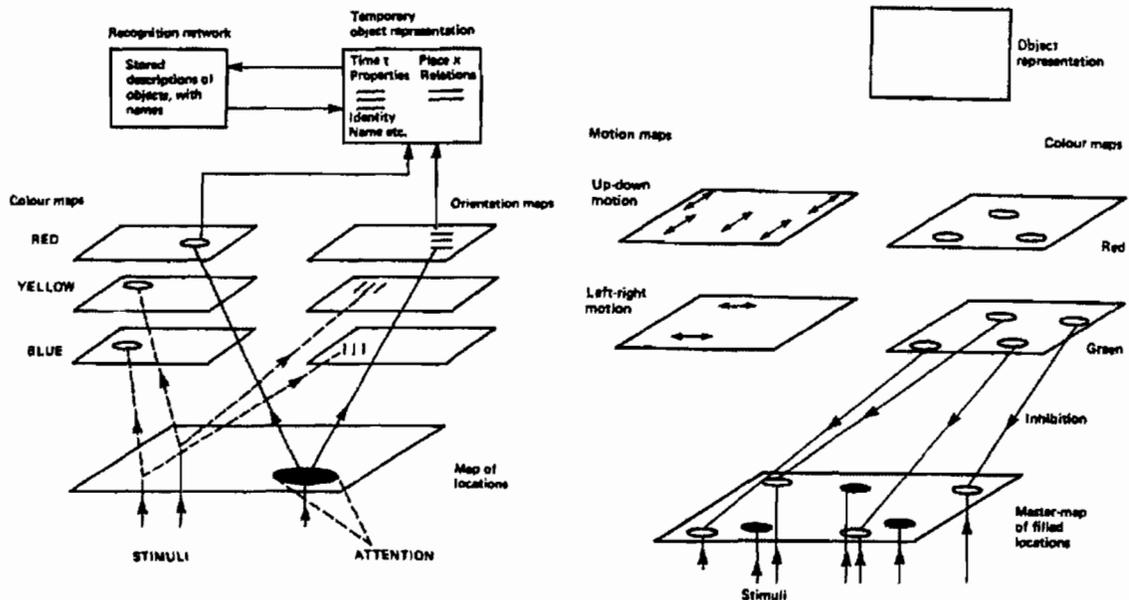


Figure 1. Model for the role of attention in feature integration (Treisman, 1988). Left: Attentional selection is controlled extrinsically by a spatial window; attention selects one area at a time within a master map of location thereby retrieving the features linked to the corresponding locations in a number of separable feature maps. Right: Model for modulating attention by inhibition from a feature map as well as from an attention window (Treisman, 1988). Attention can be achieved not only by an externally controlled window acting directly on the master map but also by changing the relative activation produced in the master map by one or another of the distractor feature maps.

Feature Integration Theory has been examined by a large number of studies and supported by converging evidence. However, there were also accumulating cases that

feature integration theory could not explain: feature search can be difficult when nontargets are very similar to the target but less like one another (e.g., Duncan, 1989); conjunction search can be easy when the target is very different from nontargets or nontargets are very similar to one another (e.g., Wolfe, Cave, & Franzel, 1989). The failure of Feature Integration Theory to account for these results has caused modifications of the original version of the theory (Treisman, 1988; Treisman & Gormican, 1988; Treisman & Sato, 1990; See Figure 1) and the emergence of alternative theories of visual search, including Guided Search Model (Wolfe, 1994; Wolfe, Cave, & Franzel, 1989; Wolfe & Gancarz, 1996) and Attentional Engagement Theory (Duncan & Humphreys, 1989; Duncan & Humphreys, 1992).

Guided Search Model

Wolf and colleagues (Wolfe, 1994; Wolfe, Cave, & Franzel, 1989; Wolfe & Gancarz, 1996) developed a theory of visual search that is called the Guided Search Model. The Guided Search Model differs from Feature Integration Theory in that the deployment of attention is not random, but in order of priority based on an activation map which is determined by a combination of two sources of activation, top-down activation and bottom-up activation (Figure 2): 1) Top-down activation is determined by how closely an object matches the current attentional set, and thus the more attributes an object shares with a target, the more activation the object receives; 2) Bottom-up activation is determined by how much an object differs from nearby objects in each feature dimension, and thus the more different the object is from nearby objects, the more bottom-up activation the object receives.

The Guided Search Model provides a better explanation of some cases, including why search for form and color conjunctions can be easy when discriminability of each conjunction's component features are high (Wolfe, 1994; Wolfe, Cave, & Franzel, 1989; Wolfe & Gancarz, 1996). However, since the Guided Search Model keeps the assumption that visual search is constrained by the need to bind independently processed features like Feature Integration Theory, it is considered to be a modification of Feature Integration Theory, rather than an independent theory of visual search.

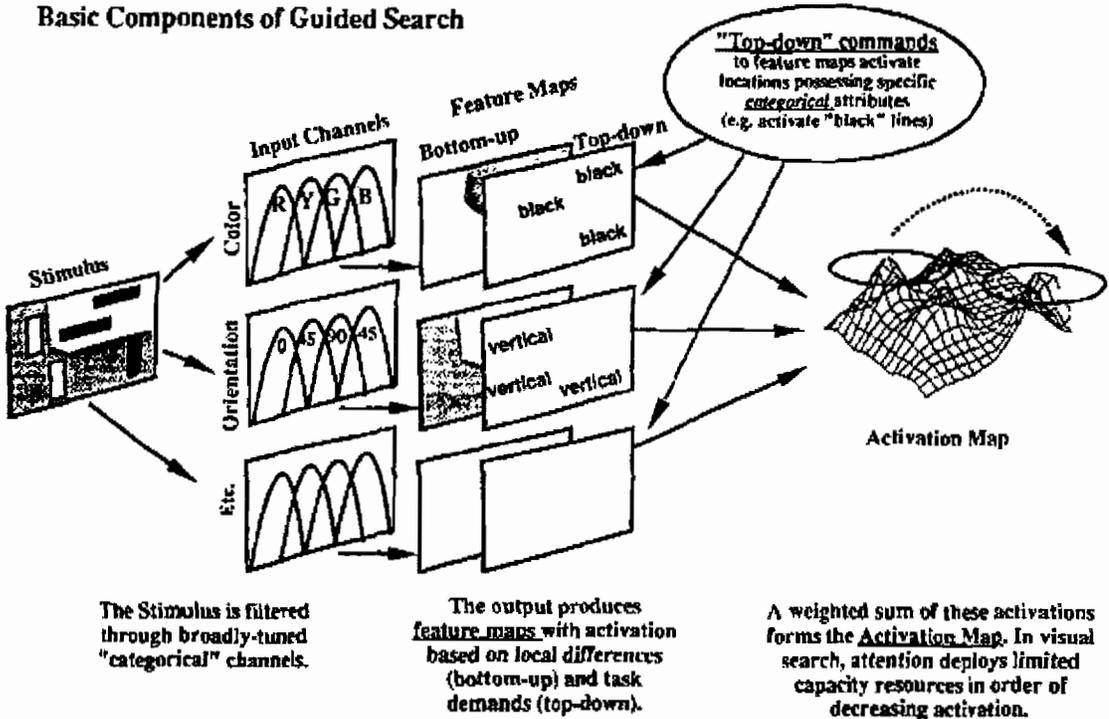


Figure 2. The architecture of Guided Search 2 (Wolfe, 1989).

Attentional Engagement Theory

Attentional Engagement Theory (Duncan & Humphreys, 1989; Duncan & Humphreys, 1992) is another alternative theory on visual search. A fundamental difference between Feature Integration Theory and Attentional Engagement Theory is that Attentional Engagement Theory does not assume the distinction between parallel and serial searches (or feature and conjunction searches). Instead, Attentional Engagement Theory considers stimulus relations as important factors in search efficiency: 1) the relationship between each nontarget and the target template (or input-template matching), and 2) the relationship between elements within each display (or perceptual grouping).

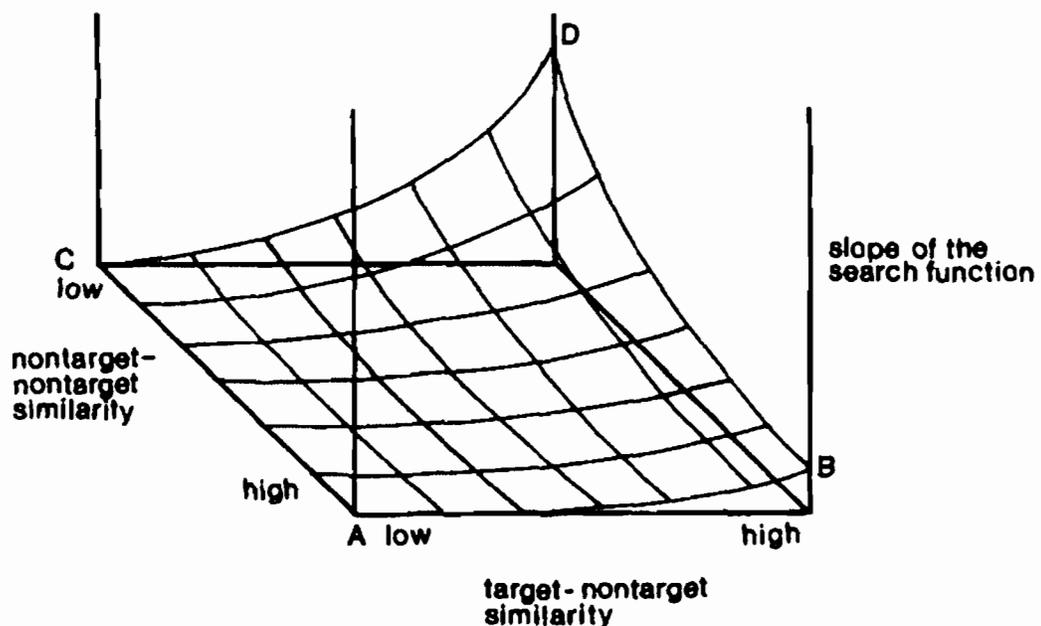


Figure 3. Summary of Attentional Engagement Theory (Duncan & Humphreys, 1989). (1) If target-nontarget similarity is low, search slope is flat, irrespective of nontarget-nontarget similarity. (2) If nontarget-nontarget similarity is high, search slope increases slowly as target-nontarget similarity is increased. (3) Search slope is highest when target-nontarget similarity is high and nontarget-nontarget similarity is low.

The general principles of Attentional Engagement Theory can be summarized as follows: (1) Search efficiency varies continuously across tasks and conditions and there is no clear implication of a dichotomy between serial and parallel search modes. (2) Search efficiency decreases with increasing target-nontarget similarity. (3) Search efficiency decreases with decreasing nontarget-nontarget similarity. (4) The preceding two factors interact to scale one another's effects (Figure 3).

The Attentional Engagement Theory explains the complicated patterns of visual search data most successfully and in the simplest way. The theory has become a base for an influential theory of selective attention, the Biased Competition Model (Desimone & Duncan, 1995), which is described in the following section.

The Role of Working Memory as a Source of Top-Down Attentional Bias

Biased Competition Model

One of the most influential theories on top-down attentional control is the Biased Competition Model by Desimone and Duncan (1995). According to the model, objects in the visual field compete for limited processing capacity and control of behavior. The competition is biased in part by 1) bottom-up neural mechanisms that separate figures from their background in both space and time, and, 2) top-down mechanisms that select objects of relevance to current behavior. The model also proposes that the main source of top-down influence derives from neural circuits mediating working memory, especially those in prefrontal cortex (Miller, Erickson, & Desimone, 1996; Rainer, Asaad, & Miller, 1998; Rao, Rainer, & Miller, 1997).

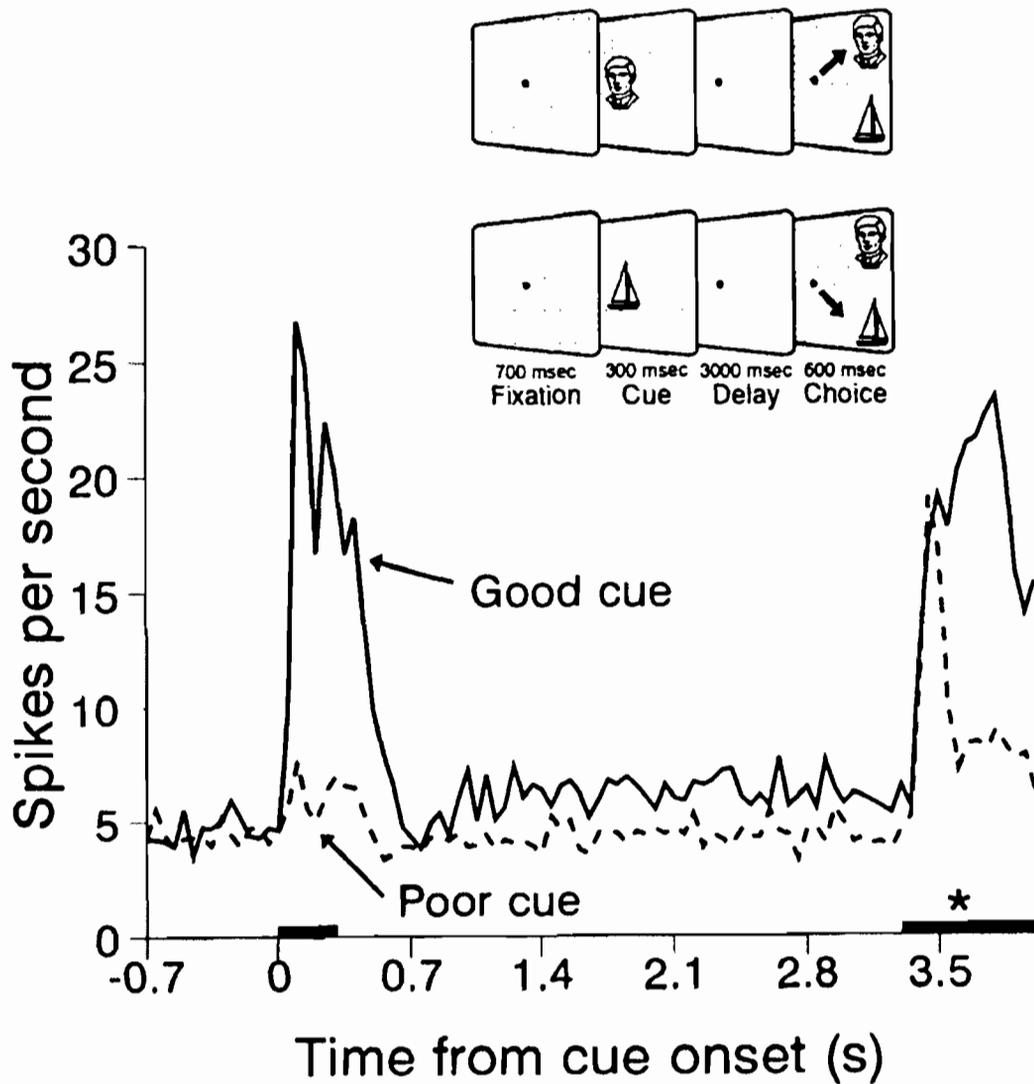


Figure 4. Effects of object selection on responses of cells in the IT cortex (Chelazzi et al, 1993). Graphs show the average response of 22 cells recorded while monkeys performed the task which procedure is depicted above. The cue was chosen to be either a good or a poor stimulus for the recorded cell. When the choice array was presented, the monkey made a saccadic eye movement to the stimulus that matched the previous cue. The saccadic latency was about 300 ms, indicated by the asterisk. Cell had a higher firing rate in the delay preceding the choice array when their preferred stimulus was the cue. Following the delay, cells were activated (on the average) by their preferred stimulus the array, regardless of whether it was the target. However, 100ms before the eye movement was made, responses diverged depending on whether the target was the good or the poor stimulus.

The Biased Competition Model has been supported by clear and strong evidence from single-cell recording studies with nonhuman primates using visual search tasks (Chelazzi, Miller, Duncan, & Desimone, 1993; Chelazzi, Duncan, Miller, & Desimone, 1998). In these studies, macaque monkeys were presented with a target stimulus and required to hold it in working memory during a subsequent delay period (Figure 4). The target stimulus initiated activity in neurons tuned to its features that persisted through the delay, indicating active maintenance of the target representation. The monkeys were then given a search array of multiple stimuli and were required to make an eye movement to the one that matched the target. Results showed that neuronal responses to the target and non-targets initially did not differ but, subsequently, responses to non-targets were suppressed (about 100 ms before the onset of the eye movement to the target) while responses to the target became dominant. The biased competition model suggested that this process reflected the resolution of a competition among stimuli, biased in favor of the target held in working memory during the delay.

Controversy on the Role of Working Memory

One of the most recent questions related to the Biased Competition Model is whether the contents of working memory bias selective attention even when the contents are not task-relevant. Despite the physiological evidence from non-human primates that working memory is the main source of top-down attentional control, the effect of task-irrelevant information in working memory on attentional control remains controversial with some studies showing significant attentional biasing effects of working memory

(Pashler & Shiu, 1999; Downing, 2000) and others reporting no effects (Downing & Dodd, 2004; Woodman & Luck, 2007).

For example, some human behavioral studies did show a biasing effect of working memory on attention using detection tasks as attention tasks (Pashler & Shiu, 1999; Downing, 2000). In Pashler and Shiu's study (1999), participants were given a word or phrase, such as "fish" or "swimming pool," and instructed to create a clear mental image of it. They then viewed a rapid serial visual presentation (RSVP) of 8 line drawings and a numeral with the goal of detecting and identifying the numeral that was always in position 5 of the stream. A critical factor of this task was that a line drawing of the imagined object was presented either shortly before (position 3) or after (position 7) the target numeral. The authors reasoned that if the line drawing that matched the mental image was "involuntarily" attended, then the accuracy of reporting the following target numeral would be impaired by the "attentional blink" effect – i.e., a reduction in the ability to report a subsequent target arriving close to the initially attended target in an RSVP stream (Chun, & Potter, 1995; Raymond, Shapiro, & Arnell, 1992; Shapiro, Raymond, & Arnell, 1994). The results showed that the detection accuracy of the target numeral was indeed significantly lower when the line drawing that matched the mental image was presented before the target numeral than after the target numeral, suggesting that attention was automatically drawn to the task-irrelevant line drawing that matched the image in mind.

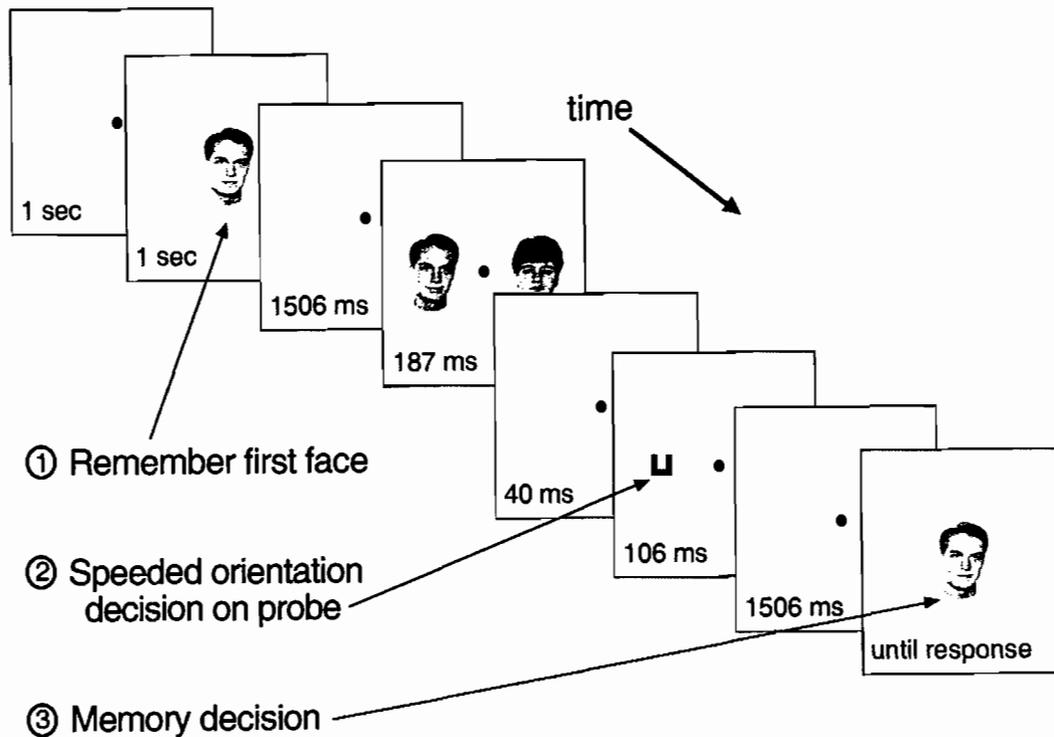


Figure 5. Schematic illustration of the experimental paradigm Downing (2000). In this example, a target for the discrimination task (a bracket) appeared on the side where a memory target has just flashed.

In an experiment by Downing (2000), a probe paradigm is used to measure attentional allocation (Figure 5). Participants were presented with a centrally positioned image of a face at the beginning of each trial and required to remember the face in order to correctly respond to a memory test at the end of each trial. They were then asked to detect the orientation or direction of a probe stimulus that was briefly presented to the left or right of fixation during the retention interval. Before the probe was presented, two faces were briefly flashed, one at each of the two possible probe locations. One of the faces matched the memory item held in working memory and the other did not. Downing reasoned that, if attention was automatically drawn to the task-irrelevant face that matched the face being held in working memory, participants would then be significantly

faster at processing the probe stimulus when it was presented at the location of the matching face. The results confirmed these predictions, supporting the idea that maintaining an object representation in visual working memory necessarily leads to the deployment of attention to similar items.

In contrast, some studies showed at most only a negligible biasing effect of working memory during visual search tasks by using dual-task paradigms in which visual search and visual working memory tasks are combined (Downing & Dodds, 2004; Woodman & Luck, 2007). In these studies, participants are presented with a memory item at the beginning of each trial and asked to remember it until probed at the end of the trial (Figure 6). During the retention interval, participants search for a predefined target among distractors, one of which matches the memory item on half of the trials. Participants are thus performing an attention-demanding visual search task for a predefined target while maintaining a similar item in working memory for a subsequent memory task. If attention is biased toward an item(s) in working memory, search performance for a target should be worse when the item in working memory matches one of the distractors in the search array. Results, however, demonstrated no biasing effect of working memory.

Rather than taking these results as evidence against the Biased Competition Model, Downing and Dodd (2004) propose that an additional mechanism is at play which either enables efficient switching between items held in a unitary visual working memory, or moves critical items between independent visual working memory buffers so that only those working memory items currently in the focus of attention can have a

direct impact on behavior. However, Woodman and Luck (2007) conclude that holding an object representation in visual working memory does not automatically bias attention to similar objects. They showed in some cases that matching distractors could be beneficial to visual search performance and propose that attention can be biased not only toward memory-matching distractors but also away from memory-matching distractors at different points during the trial.

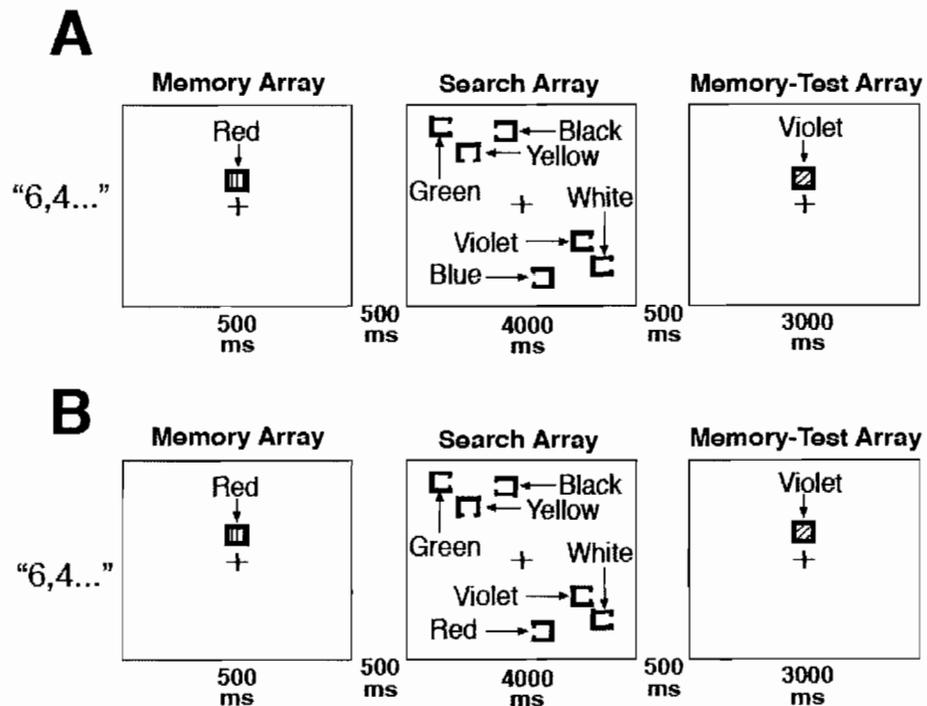


Figure 6. Examples of sequences used in Experiment 1 of Woodman & Luck (2007) are shown. A: Example of a stimulus sequence during a trial of the mismatching-distractor condition. B: Example of a stimulus sequence during a trial of the matching-distractor condition; note the matching distractor in the lower hemifield.

Specificity of Working Memory Representations

In view of the evidence from physiological studies with primates that representations in working memory are the main source of top-down influence on attentional control in visual search tasks, it is surprising that some previous studies with human participants show inconsistent results regarding the existence of a biasing effect of working memory on visual attention.

The main goal of the current study is to provide a plausible solution to the puzzle of attentional control by introducing the concepts of *specificity* of and competition between working memory representations. I hypothesize that working memory representations compete to bias attention and the strength of the biasing effect of working memory depends on the specificity of representations in working memory. Specifically, I propose that, when the target item for an attention task is well specified (e.g., an object with a specific shape), this item stored in working memory will bias attention toward its matching information while performing the attention task because of its task relevancy and specificity. As a result, the other item in working memory (i.e., the memory task item) will not bias attention significantly to its matching distractor during the attention task. However, when the target item for an attention task is more abstract (e.g., an object symmetric about the vertical axis), because it has lower specificity, it will allow the other specific item in working memory (i.e., the memory task item) to bias attention to a matching distractor in the search array. This hypothesis potentially helps to explain the pattern of conflicting results in the attentional literature, as items held in working memory in the various experiments varied in the specificity of task target representations.

To manipulate the level of specificity of working memory representations, targets for attention tasks were defined in two different ways: in the “specific target” task, the target was specified by its actual features (e.g., an object with a specific shape); in the “non-specific target” task, the target was described more abstractly (e.g., an object symmetric about the vertical axis). Memory task items were always specified with their actual features. In order to measure the possible biasing effect of task-irrelevant items in working memory, two different distractor conditions were compared: in the “matching distractor” condition, the memory item of the working memory task matched one of the distractors in the search array; in the “non-matching distractor” condition, the memory item did not match any of the distractors in the search array.

The current study tested the effect of goal-specificity in both spatial and temporal domains using visual search (Experiment 1) and RSVP (Experiment 2) paradigms. It is predicted that, in the specific target attention task, the search target item stored in working memory would be the most behaviorally relevant (heavily weighted) item because of its specificity and task relevancy. As a result, the search target item in working memory would bias attention to a search target in a search display while the other item in working memory (the memory task item) would be inhibited and not be able to effectively bias attention to its matching distractor during the attention task (Figure 7, left). However, in the non-specific target attention task, because the visual search target has lower specificity, it would be less heavily weighted which would allow the other specific item in working memory (the memory task item) to bias attention to a matching distractor in the search array. These results suggest that, when a matching distractor is the

only item in working memory with specified features, it dominates the biasing effect, thereby increasing the time required for finding a non-specified target item (Figure 7, right).

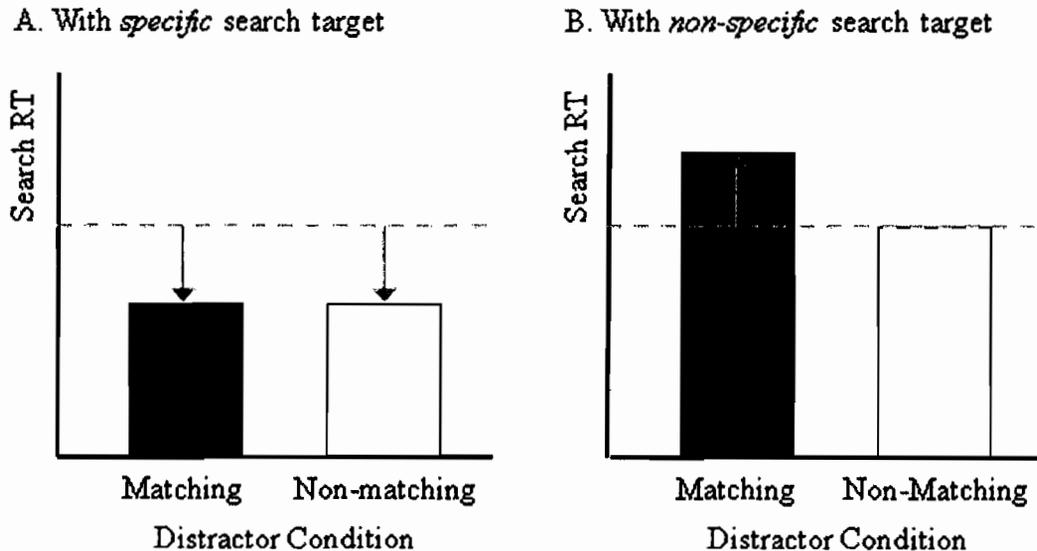


Figure 7. Predicted pattern of results based on the hypothesis of the current study. The dashed horizontal line represents a baseline search reaction time without top-down biases either from a search target template or from a matching distractor. A) The downward arrows represent the biasing effect from a specific target template in working memory that facilitates the search performance, leading to shorter reaction times. The effect from the specific target template overrides the possible effect from a matching distractor, so that search reaction times do not differ when there is a matching distractor in the visual field and there is not. B) In the absence of specific information about a search target template, a representation of the memory target in working memory can bias competition toward the matching distractor in the visual field. The arrow represents the biasing effect from the matching distractor that slows performance for the search target during the search task.

CHAPTER II

PSYCHOPHYSICAL MEASURES OF SPECIFICITY EFFECTS

Introduction

In this chapter, the role of goal-specificity in top-down control is investigated psychophysically. Participants perform an attention task and a working memory task concurrently. Each trial begins with the presentation of a memory item that participants have to remember for the length of the trial. While holding the memory item in working memory, participants search for a target appearing among a spatial array (Experiment 1) or temporal stream (Experiment 2) of distractors. After the spatial or temporal search target is detected, participants are probed for their memory of the memory item presented at the beginning of the trial.

The working memory task was used to have participants hold information irrelevant to the task at hand (the attention task) in working memory while performing the attention task, and the attention task was used to measure attentional allocation on visual displays either containing the task-irrelevant information in working memory or not. Non-meaningful stimuli are used in order to exclude any possible effects from past experience and other individual differences between participants.

Experiment 1A: Working Memory and Search Tasks

Methods

Participants

Two groups of eight undergraduate students with normal or corrected-to-normal vision participated for course credit, after informed consent was obtained. One group performed a dual task in which a working memory task was combined with a *specific* target search task, while the other group performed a dual task in which the same working memory task was combined with a *non-specific* target search task.

Working Memory Task

Stimuli and Design

The stimuli for the memory task were irregular polygons that were symmetric about non-vertical axes (30° , 60° , 120° , 150°) of orientation. The initial and test stimuli were the same on half of the trials and different on the other half. Both the initial and test stimuli for the memory task were presented at the center of the display.

Visual Search Task

Stimuli and Design

The stimuli were irregular polygons that were symmetric about the vertical (90°) or non-vertical axes (30° , 60° , 120° , 150°) of orientation. The search target stimuli were symmetric about the vertical axis while the search distractor stimuli were symmetric

about a non-vertical axis. The search array consisted of a target stimulus and 4 different distractor stimuli, positioned randomly within a 5x5 grid of 25 cells.

Specific vs. Non-specific Targets: Between-Subject Conditions

In order to manipulate specificity among working memory representations, targets for the attention tasks were defined in two different ways: in the *specific target* search task, the actual shape of the search target for each trial was shown to the participant. In the *non-specific target* search task, a vertical bar, indicating the axis of symmetry of the search target, is shown to the participants. (Note that memory task items are always specified with their actual shape.) Aside from the target presentation, everything else was same in the specific and non-specific target search tasks. Specific and non-specific target search tasks were tested in a between subjects design.

Matching vs. Non-matching Distractors: Within-Subject Conditions

In order to measure the possible biasing effect of task-irrelevant items in working memory, two different distractor conditions in visual search tasks were compared: in the *matching distractor* condition, the memory item of the working memory task matched one of the distractors in the search array; in the *non-matching distractor* condition, the memory item did not match any of the distractors in the search array. Matching and non-matching distractor conditions were tested in a within subjects design.

Procedure

Figure 8 shows an example of the experiment procedure (note that blank periods are not illustrated in the figure). Participants initiated each trial by pressing the space bar.

First, the memory item for the working memory task was presented for 1000 ms and participants were asked to remember the stimulus throughout the trial until probed at the end. After a 1000 ms blank period, a display for the search target was presented for 1000 ms, which was either the actual shape of the search target in the specific target search task blocks (top rectangle of the search target display in Figure 8) or a vertical line indicating the symmetry axis of the target in the non-specific target search blocks (bottom rectangle of the search target display in Figure 8). Following another 1000 ms blank period, the visual search array was presented for 3000 ms (note that the search display in Figure 8 is an example of a search display in the matching distractor condition, containing the memory item as a distractor). Participants were required to press the space bar once they found the search target. Response times (RTs) were based on the time elapsed from display onset to the space bar press. After a 500 ms blank period, an array of numerals was presented in the same positions as the items in the search display. Participants were required to type the number that occupied the location that the target object had appeared in. Correct performance on this un-speeded probe display ensured that the participants had correctly localized the target object. Once they responded to the probe display, the test item of the memory task appeared, and the participants were asked to report whether the test stimulus was the same as the memory item presented at the beginning of the trial. Accuracy on both visual search and working memory tasks was emphasized.

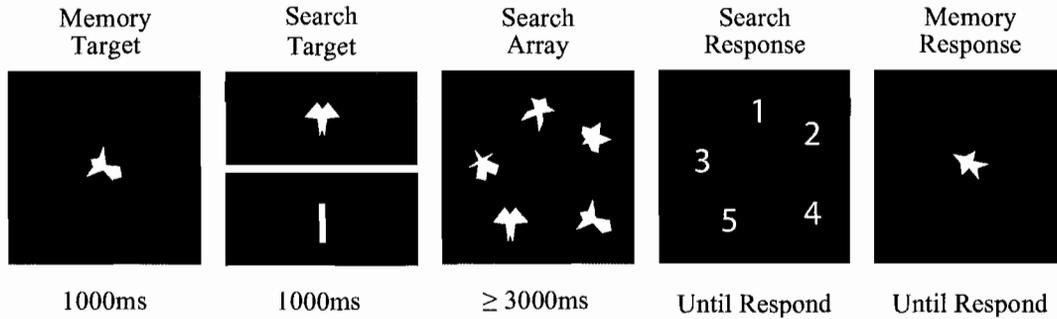


Figure 8. Procedure for Experiment 1 – spatial search task. Working memory task items are presented at the beginning and the end of each trial. During the working memory retention interval, spatial search task displays are presented. An example of a matching distractor condition is shown.

The experiment consisted of 6 practice trials and 2 blocks of 40 experimental trials. The practice trials consisted of only non-matching distractor trials. Each experimental block contained an equal number of matching and non-matching distractor search trials; consequently, both specific and nonspecific target search tasks contained equal numbers of *matching* and *non-matching* distractor search trials.

Results

Accuracy for the search task was above 90% correct, and accuracy for the memory task was above 80% correct. There were no significant differences in accuracy for the search and memory tasks based on search target type (specific target vs. non-specific target) or search distractor type (matching-distractor vs. non-matching distractor).

The mean correct RTs for the search task, plotted as a function of distractor type, are shown in Figure 9. In the specific target search task (Figure 9, left), RTs in the matching distractor [$M=1157$ ms, $SD=224$ ms] and non-matching distractor [$M=1164$ ms, $SD=214$ ms] conditions did not differ [$F(1, 14)=0.03$, $p=.87$]. More importantly, in the

non-specific target search task (Figure 9, middle), RT was greater [$F(1, 14)=5.30, p<.05$] in the matching distractor condition [$M=1563\text{ms}, SD=286\text{ms}$] compared to the non-matching distractor condition [$M=1465\text{ms}, SD=288\text{ms}$]. These results show that, when a matching distractor is the only item in working memory with specified features, it dominates the biasing effect, thereby increasing the time required for finding the non-specified target item.

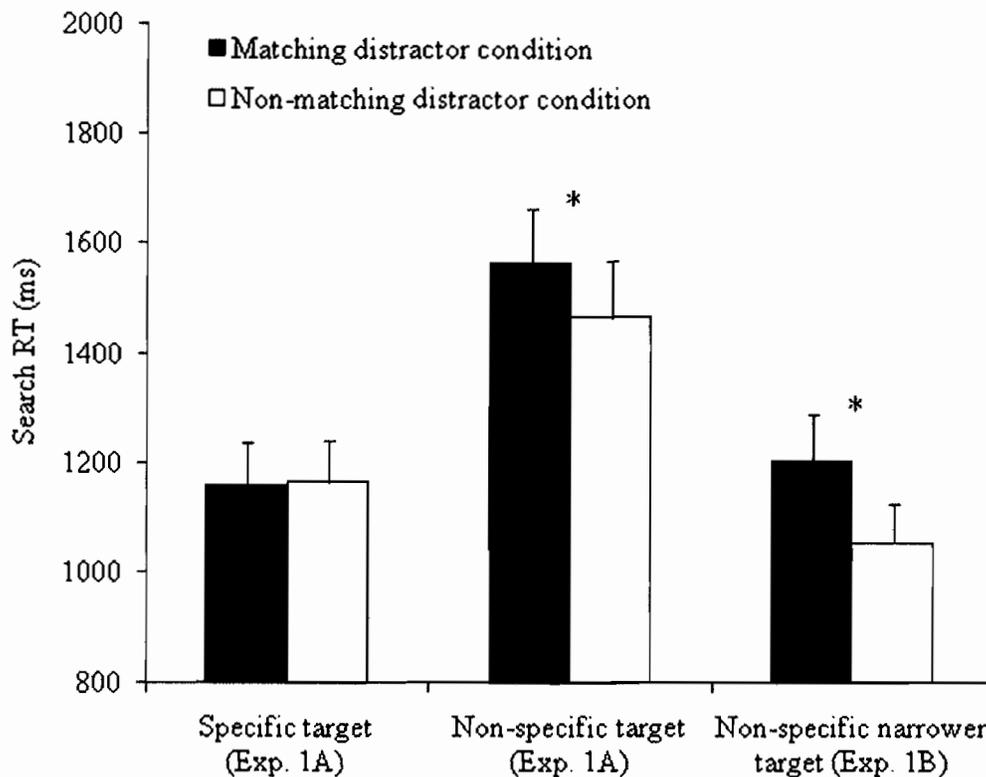


Figure 9. Results of Experiment 1 (1A and 1B). Filled bars represent the mean search reaction times in the matching distractor conditions. Open bars represent the mean reaction times in the non-matching distractor conditions.

In addition, the RT in the neutral, non-matching distractor condition was faster in the specific target search [$M=1164\text{ms}, SD=214\text{ms}$] than in the non-specific target search

[$M=1465\text{ms}$, $SD=288\text{ms}$] (Figures 9), suggesting that there is a difference between specific and not-specific target search tasks in addition to the biasing effect from matching distractors [$F(1, 14)=5.62$, $p<.05$]. The result can be explained as an enhancement in processing due to the biasing effect of specified targets in the specific target condition. Thus, the specified target representation guides selective attention to the search target in the specific target search task, thereby facilitating the search process.

Experiment 1B: Task Difficulty Control

A potential problem with the result in Experiment 1A is that such a basic difference in task difficulty between specific and non-specific search tasks might differentially affect the size of the biasing effect of matching distractors in these tasks. In order to rule out the possibility, the effect of task difficulty was controlled for in Experiment 1B by manipulating (decreasing) the difficulty of the non-specific search task to more closely match the task difficulty in the specific search task.

Methods

Eight undergraduate students with normal or corrected-to-normal vision participated for course credit, after informed consent was obtained. The task stimuli in Experiment 1B were 20% narrower about their axis of symmetry than those in Experiment 1A. This change made the search task less difficult because one feature of the target stimulus (its orientation) is easier to detect when the stimuli are narrower.

The goal of this experiment was to determine if a biasing effect would still be present in the non-specific target search task when the task difficulty of the neutral

condition (the non-matching distractor condition) is equivalent across specific and non-specific target search conditions. Therefore, participants only performed the dual task in which the non-specific target search and working memory tasks were combined. Otherwise, Experiment 1B was identical to Experiment 1A.

Results

Accuracy for the search task was above 95% correct, and accuracy for the memory task was above 85% correct. There were no systematic differences in mean accuracy for the search and memory tasks. The mean correct RTs for the search task, plotted as a function of distractor type, are shown in Figure 9, right. The RTs in the non-matching distractor conditions of the non-specific target search task in Experiment 1B [$M=1054\text{ms}$, $SD=206$] and specific target search task in Experiment 1A [$M=1164\text{ms}$, $SD=214\text{ms}$] were similar [$F(1, 14)=0.16$, $p=.70$], indicating that the manipulation of task difficulty for the purpose of matching performance levels between specific and non-specific target tasks was successful.

As in Experiment 1A, a significant biasing effect of matching distractors was found [$F(1, 14)=8.05$, $p<.05$] in the non-specific target search – RTs in the matching distractor condition [$M=1204\text{ms}$, $SD=224$] were significantly slower than in the non-matching distractor condition [$M=1054\text{ms}$, $SD=206$].

Experiment 2: Working Memory and Detection Tasks

Introduction

Previous work investigating the effect of working memory on attentional control not only differed in the specificity of working memory representations but also in the attention task design – using spatial (search task with a spatial search array) or temporal (detection task in an RSVP stream) paradigms. Experiment 2 was designed to test whether the specificity effect demonstrated in Experiment 1 using a spatial attention task design is also present in the temporal domain using an attention task design consisting of a detection task in an RSVP stimulus stream.

Methods

Participants

Two groups of seven undergraduate students with normal or corrected-to-normal vision participated for course credit, after informed consent was obtained. One group performed a dual task in which a working memory task was combined with a *specific* target detection task, while the other group performed a dual task in which the same working memory task was combined with a *non-specific* target detection task.

Task Design

The memory task was the same as in Experiment 1. The attention task was similar to that used in Experiment 1 except that task items were presented in an RSVP stream of 11 stimuli located at the center of the screen instead of as a spatial array as was done in

Experiment 1 (see Figure 10). The experiment consisted of 12 practice trials and 2 blocks of 128 experiment trials. Each block contained 96 detection target-present trials and 32 detection target-absent trials. The practice trials consisted only of non-matching distractor trials (detection target-present and absent conditions)

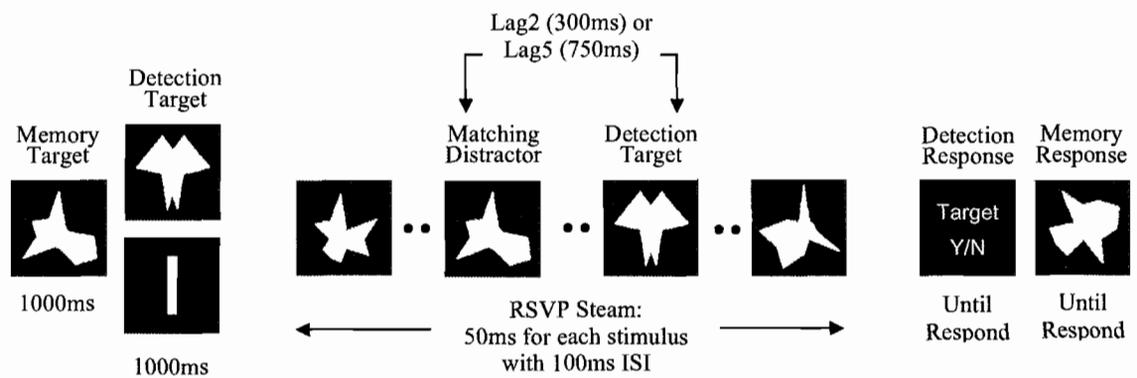


Figure 10. Procedure for Experiment 2 – temporal search task. During the memory retention interval (between memory target and memory response displays), detection task RSVP displays were presented. An example of a matching distractor condition is shown.

Lag 2 vs. Lag 5: Detection target-present trials consisted of 32 trials each of lag 2 and lag 5 matching distractor conditions and 32 trials of the non-matching distractor condition. In the lag 2 and lag 5 conditions, the memory item appeared in serial position 3 or 4 of the RSVP stream and the detection target appeared in serial position 5 or 6 (lag 2) or 8 or 9 (lag 5), respectively. In the non-matching distractor condition, the memory item did not match any stimulus in the RSVP stream and the possible RSVP search target positions were the same as in the matching distractor trials.

In the 32 detection target-absent trials (in which the detection target was not presented in the stream), the memory item matched a stimulus in either serial position 3 or 4 of the stream on half of the trials.

Procedure

Participants initiated each trial by pressing the space bar. First, the memory item was presented for 1000 ms. After a 1000 ms blank period, the search target was presented for 1000 ms. After another 1000 ms blank period, the RSVP stream began. Each of the 11 stimuli in the RSVP stream was presented for 50 ms with a 100 ms blank interval, yielding a 150 ms SOA. Participants were instructed to observe the stream of stimuli very carefully to detect the search target. After the RSVP stream ended, participants were asked if they had detected the target. Following this response, the test stimulus for the memory task was displayed and participants were asked to report whether the test stimulus was the same as the memory item presented at the beginning of the trial. Accuracy on both tasks was emphasized.

Results

Accuracy for the memory task was above 75% correct. There were no systematic changes in the accuracy of the memory task based on detection target type (specific target vs. non-specific target) and lag between matching distractor and target (lag 2 vs. lag 5).

The mean accuracy for the specific and non-specific target detection tasks, plotted as a function of the lag between matching distractor and target, is shown in Figure 10. In the specific target detection task (Figure 11, left), accuracy in the lag 2 [$M=80\%$,

$SD=12\%$] and lag 5 [$M=76\%$, $SD=10\%$] conditions did not differ [$F(1, 12)=1.18$, $p=.30$]. In contrast, for the non-specific target detection task (Figure 11, right), the detection accuracy was significantly lower [$F(1, 12)=7.30$, $p<.05$] in the lag 2 condition [$M=41\%$, $SD=12\%$] than in the lag 5 condition [$M=52\%$, $SD=10\%$]. These results suggest that, in the non-specific target detection task, attention is drawn to the matching distractor so that accuracy in reporting the following detection target, appearing soon after the matching distractor (lag 2), is decreased due to an "attentional blink" effect.

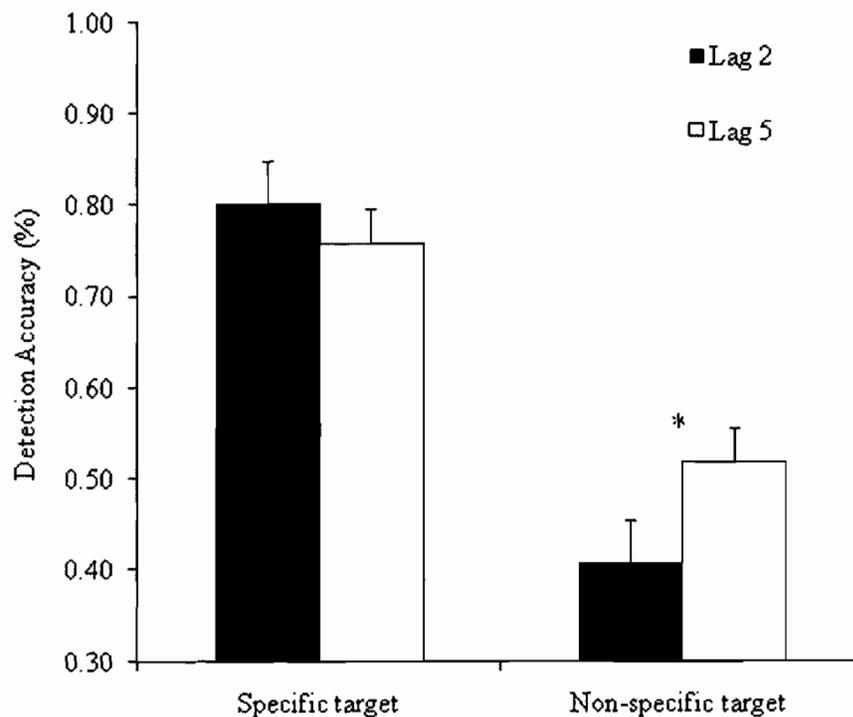


Figure 11. Results in Experiment 2 from the temporal search attention task. Filled and open bars represent the mean accuracy when the lag between matching distractor and detection target was 2 and 5.

In addition, accuracy in the lag 5 condition is greater in the specific target search task [$M=76\%$, $SD=10\%$] than in the non-specific target search task [$M=52\%$, $SD=10\%$], suggesting that additional factors beyond the biasing effect of matching distractors are at work in creating the differences between the results of the specific and not-specific target detection tasks [$F(1, 12)=19.88$, $p<.05$]. As in Experiment 1A, the difference in performance in the lag 5 conditions may be explained by enhanced processing (i.e., a biasing effect) that occurs with specified targets. The specified target representation guides selective attention to the detection target in the specific target detection task, thereby facilitating the detection process.

Discussion

The current study examined the hypothesis that the effectiveness of working memory in biasing selective attention depends on the *specificity* of working memory representations. Our results support this hypothesis by demonstrating that the biasing effect of working memory (as measured by the influence of matching distractors in an attention task) depends on the specificity of attention and memory task target representations in working memory, and is present in both spatial and temporal domains as revealed by visual search (Experiment 1A & 1B) and RSVP (Experiment 2A) tasks.

The fact that overall performance was significantly better in the specific vs. non-specific target attention tasks supports the specificity hypothesis. We propose that the presence of specific target features in working memory biases selective attention toward the target in the search display, thus facilitating the search process. The specificity

hypothesis is further supported by the fact that the biasing effect of matching distractors was found in the non-specific target search task, but not in the specific target search. In the specific target attention task, the attention target item stored in working memory is most behaviorally relevant (and therefore heavily weighted) because of its specificity and current task relevancy. As a result, the other item in working memory (the memory task target) is not effective in biasing attention to its matching distractor during the attention task. Conversely, in the non-specific target attention task, the attention target item is less heavily weighted because it is not well specified. As a result, the other item in working memory (the memory task target), which is well specified, is able to bias attention to its matching item (a distractor) in the attention task, slowing target detection.

The hypothesis in the current study suggests a possible explanation for some of the conflicting results reported in the literature regarding the influence of working memory representations on attentional control. For example, two studies (Downing, 2000; Pashler & Shiu, 1999) that reported an influence of an item held in working memory on a subsequent visual detection task used less well-specified attention targets and more well-specified memory targets. For example, the detection target was defined as any single digit (Pashler & Shiu, 1999) or a bracket oriented up or down (Downing, 2000) while the memory target was a specific object (Pashler & Shiu, 1999) or a face (Downing, 2000). Similar to those studies, the current study also found interference from an item held in working memory for a subsequent memory task on an attention task when the attention task target was not well-specified compared to the memory task targets. In contrast, other studies reported no interference by an item held in working memory on a

subsequent visual search task, which can also be explained by the specificity hypothesis. For example, Downing and Dodds (2004) used the same set of shapes for both attention and memory tasks, and the exact shape of the memory and attention targets were given to their participants at the beginning of each trial. They found no interference from the working memory target on a subsequent visual search task, which was consistent with the results from the specific target conditions of the current study. Another study that reported a similar pattern of results is one by Woodman and Luck (2007). In their multiple experiments, targets and distractors for the visual search tasks were squares with a gap on one side, and the only distinction between them was the location of the gap (on the top- or bottom-sides of the squares for targets, and left or right-sides for distractors). Since the targets and distractors were very similar to one another, perceptual grouping (Duncan & Humphreys, 1989; Duncan & Humphreys, 1992) between them was very likely which could prevent top-down effects from working memory for both the search and memory targets.

The overall goal of this research was to investigate important factors in top-down control – specifically, the conditions under which current contents of working memory influence attention. The current study significantly clarifies the top-down effects of working memory representations proposed in the biased competition model. In particular, this study suggests that there is competition between items in working memory for attentional control that is influenced by the specificity as well as task relevancy of each representation in working memory.

CHAPTER III

NEUROLOGICAL MEASURES OF SPECIFICITY EFFECTS

Introduction

In Chapter III, event-related fMRI techniques were employed to obtain more objective biological evidence for a biasing effect of working memory representation on attention for the condition where there is no other specific working memory representation present (i.e., the non-specific attention task).

Instead of the non-meaningful polygons used in Part 1 of the current proposal, visual stimuli of faces and places were used in the fMRI study. Brain areas known as the fusiform face area (FFA) and the parahippocampal place area (PPA) respond strongly to faces (but negligibly to places) and to scenes (but negligibly to faces), respectively (Epstein & Kanwisher, 1998; Kanwisher, McDermott, & Chun, 1997). Therefore, using faces and places as attention and memory targets respectively, it is possible to measure attentional allocation to attention and memory targets separately.

Functional Regions of Interest

One of the long-standing questions in high-level cognitive neuroscience is whether there are functional dissociations between discrete regions of the brain. Based on findings from numerous patient and behavioral studies, including a neurological deficit of face perception called prosopagnosia and a face-specific phenomenon called the face

inversion effect, face perception has been considered one of the leading candidates for a specialized processing-module in the brain. More recently, along with recent development of brain imaging techniques, the question of specialized processing in face perception has become heated again.

One well-controlled imaging study to address the question of face perception is work by Kanwisher, McDermott, and Chun (1997). In this study, a specific region of interest was defined for each subject by finding a brain area that responded more actively when participants viewed faces than when they viewed other common objects. Then, the region of interest was tested for further comparisons. The results showed that the lateral side of the mid-fusiform gyrus responded significantly more when participants viewed faces than common objects, and the same area responded more strongly to intact or front-view faces than scrambled or side-view faces. The authors named this area the ‘fusiform face area (FFA)’, and proposed that the area is specialized for face perception per se.

Similar to face perception, a brain region that is selectively active for scene perception has been reported (Epstein and Kanwisher, 1998). In the study, participants were presented a sequence of stimuli including faces, objects, scenes and scrambled images of those, and were asked to perform a one-back task. The results showed that a brain region around parahippocampal cortex was selectively sensitive to scene perception. Moreover, the parahippocampal area responded very actively to scenes but very weakly to common objects and not at all to faces. The authors named the brain area that was selectively sensitive to places the ‘parahippocampal place area (PPA)’.

Despite the strong evidence that different cortical areas are involved in processing faces and places significantly more than in processing other objects, the question as to whether there is any cortical module dedicated to any particular information seems to remain unresolved as it did after the discoveries of prosopagnosia and the face inversion effect a long time ago. This is because there is still a possibility to be ruled out that the brain regions engaged by faces or places are not selective for the particular stimulus category, but for some process that can be shared with other categories of stimulus.

Even though it could not lead us to the final answer to the question regarding domain-specificity, the recent findings establishing the existence of a fusiform face area and a parahippocampal place area provide a very useful tool to answer important questions in a different research area, such as *visual attention*, the topic of the current proposed study.

Experiment

Methods

Participants

8 participants were recruited. All participants had normal or corrected-to-normal vision because this research uses visual tasks. Participants were right-handed, between 18 and 35 years of age, and without known neurological deficits (e.g., hearing deficit, epilepsy and seizures, etc) because these factors increase between-subjects variability significantly. Participants passed the pre-screening procedure used in the Lewis Center

for Neuroimaging (LCNI) at the University of Oregon to ensure safety of participants and quality of imaging data.

Task Stimuli and Design

The stimuli were black and white pictures of faces and places. The stimuli for the memory task were pictures of places (i.e., landscapes) and the stimuli for the attention task were pictures of faces. All stimuli for both tasks were presented at the center of the display.

Participants performed a dual task in which a working memory task is combined with a *non-specific* target detection task. The detection task contained equal numbers of *matching* and *non-matching* mask trials. For the working memory task, the initial and test stimuli were the same on half of the trials and different on the other half.

Definition of Non-specific Detection Targets

In order to define the detection target non-specifically, the detection target was defined by its gender. Either the word “male” or “female” was presented right before the start of the detection task, and participants were asked to report if the word matched the gender of the detection target. Note that memory task items were always specified with the actual picture.

Matching vs. Non-matching Masks

In order to measure the possible biasing effect of task-irrelevant items in working memory on attention, two different mask conditions were compared: in the *matching mask* condition, the memory item of the working memory task matched the backward

mask of the detection task; in the *non-matching mask* condition, the memory item did not match the backward mask of the detection task. Matching and non-matching mask conditions were tested in a within subjects design. Each block contained an equal number of matching and non-matching mask trials.

Scan Procedure

Figure 12 shows an example task trial. Each trial began with the presentation of a memory item that participants had to remember for the length of the trial. While this item was held in working memory, participants were given a detection target cue (“male” or “female”), which they used to judge the gender of a subsequent, briefly appearing target face. At the end of the trial, the gender of the detection target was reported, and then participants were probed for their memory of the memory item presented at the beginning of the trial.

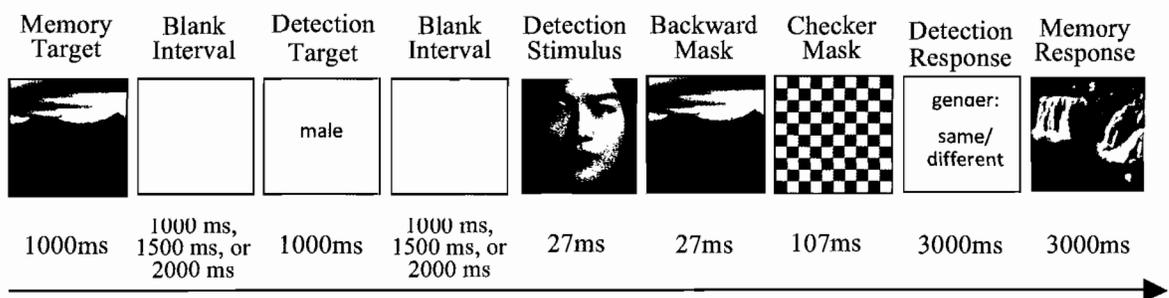


Figure 12. Procedure for fMRI Experiment. During the working memory retention interval, the detection target is presented very briefly, followed by masks. An example of a matching mask condition is shown.

At the beginning of each trial, a picture of a place (memory stimulus) was presented for 1000 ms and participants were required to remember the picture throughout

the trial until probed at the end. After a short blank period (1000, 1500, or 2000 ms), either a word “male” or “female” was presented for 1000 ms. Following another short blank period (1000, 1500, or 2000 ms), a picture of a face (detection stimulus) was briefly presented (27 ms), followed by a backward mask (27 ms) and then a checker mask (106 ms). Note that the backward mask in Figure 12 is an example of a mask in the matching mask condition – i.e., it matches the memory target item. Participants were asked to report whether the gender of the target matched the definition of the target, then report whether the memory test stimulus was the same as the memory item presented at the beginning of the trial. Accuracy on both detection and memory tasks was emphasized. Each participant performed six functional scans of 48 task trials. The order of trial types (matching and non-matching mask conditions) was randomized.

There were two localizer scans. Each scan consisted of four 30-second blocks of face or landscape pictures and 12-seconds of four blank fixation blocks. The face and landscape blocks were presented alternately and the fixation blocks appeared in between the face and landscape blocks. Participants were asked to look at the center of the screen where a fixation point was presented continuously.

fMRI Data Acquisition

A Siemens’ 3-Tesla Allegra MRI scanner was used for collecting BOLD echoplanar images (EPI) with a T2*-weighted gradient echo sequence with prospective acquisition correction (PACE).

Predicted Results

The mean detection accuracy is expected to be significantly lower in the matching mask condition than in the non-matching mask condition, suggesting that attention is drawn to the mask more in the matching mask condition since it is the only object whose features are specified in working memory. Accordingly, the FFA is expected to respond more strongly for the target followed by non-matching masks than by matching masks. This result will demonstrate at least one neural correlate of the effect of working memory on attention – when attention is drawn away from a stimulus by another item in working memory (an item that has greater specificity than the item currently attended), this is revealed as a decrease in the neural response to that attended stimulus.

Results

Behavioral Results

Data from two participants were excluded for statistical analysis due to low performance level (<50%) on the attention task (note that including those data do not change the pattern of statistical results). Accuracy for the memory task was above 85 % correct. Difference in accuracy for the memory task between matching mask [$M=93\%$, $SD=0.04\%$] and non-matching mask [$M=94\%$, $SD=0.04\%$] conditions was negligible. Accuracy for the face detection task was above 70% correct. The accuracy was significantly lower [$t(5)=3.16$, $p<.05$] in the matching mask condition [$M=71\%$, $SD=2.986\%$] compared to the non-matching mask condition [$M=76\%$, $SD=4.66\%$],

suggesting that matching masks competed for attention more effectively against detection targets.

fMRI Results

Data from two participants with low attention task performance were excluded. All data preprocessing (EPI de-warping, motion correction, brain extraction, spatial smoothing, registration, and normalization) and modeling were conducted with FEAT (fMRI Expert Analysis Tool) in the FSL image-processing tools (<http://fmrib.ox.ac.uk/fsl/>).

The FFA and PPA were localized in each participant by contrasting the averaged brain activity in face blocks with the averaged brain activity in landscape blocks of the localizer scans. A key contrast in the task scans was between the detection target events (detection target plus backward mask) in the matching mask versus non-matching mask conditions within the functional ROIs of the FFA and PPA. The detection target events for the matching and non-matching conditions were modeled as a series of square wave functions convolved by the hemodynamic response. The two detection target event types were contrasted with each other.

Neither of the two statistical contrasts between matching and non-matching mask conditions revealed activation in the PPA. More interestingly, right hemisphere FFA activation was found in a statistical contrast of matching greater than non-matching mask conditions, but not in the opposite contrast (Figure 13).

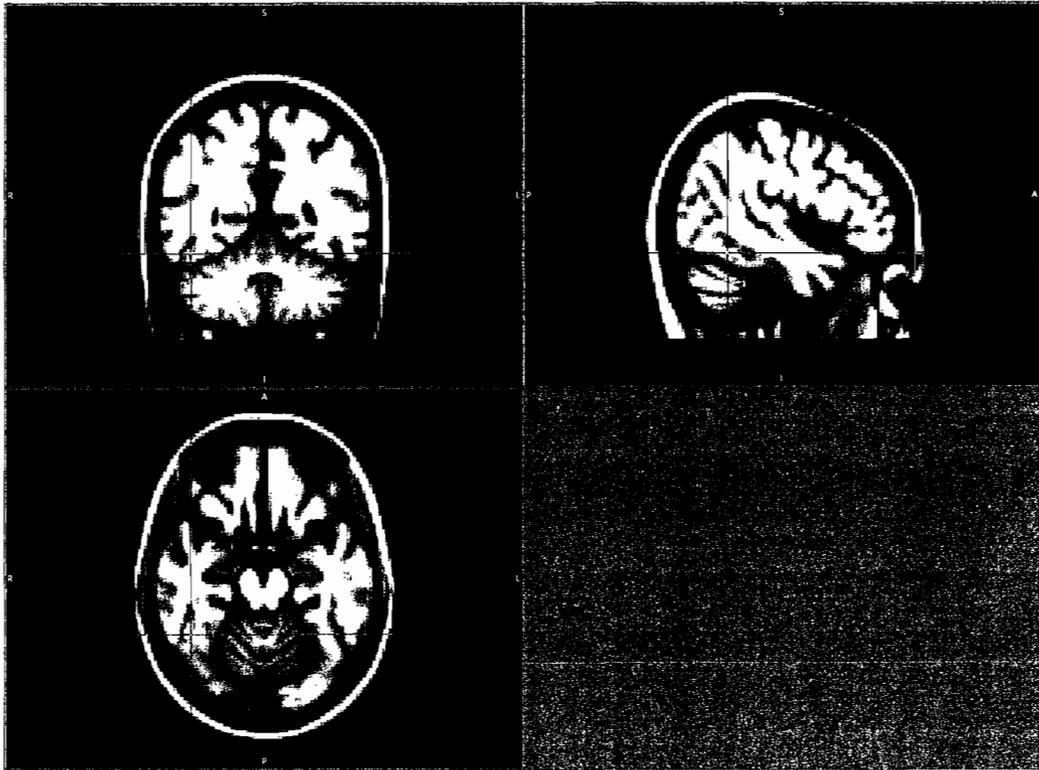


Figure 13. Group-Averaged Brain Activation: the contrast of matching versus non-matching mask conditions. The cross hairs pinpoint activation in the Fusiform gyrus of the right hemisphere.

Discussion

The prediction of the fMRI results was that FFA activation would be greater for the condition in which face targets are followed by non-matching masks than by matching masks. This prediction was based on the idea that a matching distractor would pull attention away from the face stimulus resulting in lower activation in the FFA than when attention was not distracted in the non-matching mask condition.

One possible reason that the current fMRI data did not reveal the hypothesized effect of specificity of working memory representations could be because presentation of

events of interest (a detection target and a backward mask) was too brief (57 ms, together) and there was a small number of participants ($n=6$). In order to compensate for these limitations, trial numbers were increased which resulted in having no rest-periods (e.g., presenting a blank screen with a fixation point to participants with no task) in the task scans. However, not obtaining rest-period activation as baseline activation became a limitation in itself. Without having baseline activation from rest-periods, each of the task-related activations (matching mask condition and non-matching mask condition) was contrasted with activation from all time periods not explicitly modeled, and, by doing so, it is possible that more task-related activation was contrasted out than if activation from rest periods was used as a baseline.

Another limitation in experimental design is a lack of trial order design efficiency. When scheduling events that are presented closely enough in time so that their hemodynamic responses overlap, the onset times of the events need to be jittered in order to remove the overlap from the estimate of the hemodynamic response. In the current study, stimuli for a memory target and a backward mask were landscape pictures that are hypothesized to activate the same brain region known as the PPA, and they were presented closely in time within each trial. Therefore, the SOAs between the two stimuli were jittered by randomly varying the duration of blank periods in between (either 1000 ms, 1500 ms or 2000 ms; see Figure 12) while the experiment was running. However, it could have been better if design efficiency of trial order was evaluated and maximized in advance, for example, by using `optseq2` (<http://surfer.nmr.mgh.harvard.edu/optseq/>) whose cost functions include: average efficiency, average variance reduction factor

(VRF), and a weighted combination of average and standard deviation of the VRF. In addition, 6 different efficient trial orders can be selected for the 6 task-scans presented to each participant, and the same 6 task-scans can be presented in counterbalanced order across participants.

A possible explanation for the results (observed FFA activation in the contrast of matching greater than non-matching mask conditions) is that the matching mask condition makes it more difficult to detect the face stimulus, perhaps requiring greater effort from the participants to complete the trials in this condition, resulting in greater activation in the FFA.

Finally, another factor to consider is repetition attenuation. Imaging studies on the neural basis of the priming effect have reported that neural activation is attenuated as an exposure to a certain stimulus is repeated (e.g, Grill-Spector and Malach, 2001). Thus, for example, the activation in the PPA was decreased when a certain landscape picture was exposed to participants a second time compared to the first time. Moreover, attention also has a significant influence on the magnitude of repetition attenuation, so that significantly greater repetition attenuation occurs when both the initial and repeated presentations were attended. In the fMRI design in the current study, in the matching condition, the same landscape pictures were repeated first as a memory target then as a backward mask. Also, the matching mask was assumed to be attended based on the behavioral data. Therefore, the smaller activation in the PPA in the matching mask condition can be explained by repetition attenuation.

CHAPTER IV

GENERAL DISCUSSION

Summary

The current study investigated the role of working memory as a source of top-down attentional bias. I hypothesized that representations in working memory compete for attentional control, and that this competition is influenced by the specificity as well as task relevancy of each representation in working memory.

The behavioral results from Chapters II and III supported these hypotheses, with converging evidence obtained using three different attentional paradigms: 1) visual search, 2) attentional blink, and 3) backward masking. In summary, the biasing effect is dominated by representations in working memory with high task relevancy and specificity. It was also demonstrated that, only when the representation with high task relevancy has much lower specificity, can attention be biased by task-irrelevant representations. The fMRI data in Chapter III, however, did not reveal the effect of specificity, which could be partly because rapid presentations of events of interest (a detection target and a backward mask) and spatial proximity of brain regions of interest (the FFA and PPA) could not overcome the spatiotemporal limitations of fMRI techniques.

Based on the implication from the current study with a normal population that goal-specificity has a significant influence on attentional control, I expect that the goal-specificity paradigm introduced in the current study can be expanded and utilized in research with clinical populations. The following section describes a proposal for research with clinical populations as one future direction of the current project.

Implications for Clinical Research

Top-Down Attentional Biases in Clinical Disorders

The biased competition model by Desimone and Duncan and many other studies have shown that information held in working memory automatically biases attention toward matching information available in the surrounding environment (Desimone & Duncan, 1995). Further, the current study has demonstrated that the more specific the working memory representations are, the stronger the biasing effect they have. This phenomenon is generally beneficial in human behavior. For example, it can facilitate search behavior and consciously or unconsciously guide one to relevant information (e.g., noticing food smells from nearby restaurants when you are hungry). However, it may also worsen attention-related symptoms in mental disorders such as anxiety and depression (e.g., noticing certain kinds of information more readily when one has an obsession or phobia about it) and, consequently, obstruct successful cognitive behavioral therapy for those symptoms (e.g., because of a lack of control over attentional biases toward a certain kind of information).

Indeed, a strong relationship between attention networks and symptoms of clinical disorders has been reported in clinical research studies. For example, a great deal of research suggests that depressed individuals tend to pay attention to negative information. Depression refers to a state of low mood and aversion to activity, and major depressive disorder is classified as a mood disorder in the DSM-IV (American Psychiatric Association, 2000). It has been reported that depressed individuals selectively attend to negative information over positive information (Matthews & Harley, 1996; Williams, Mathews, & MacLeod, 1996). In addition, they tend to remember negative information better than positive information (Blaney, 1986; Matt, Vazquez, & Campbell, 1992). Moreover, they tend to interpret information as negative that other people do not see as negative (Williams, Conner, Siegle, Ingram, & Cole, 1998). Brain imaging studies with depressed patients suggest that there is a relationship between attention networks and depression (Drevets, 1998). Increased blood flow in the frontal cortex as well as amygdala has been reported in depressed patients, suggesting a top-down bias for (negative) emotional information, and decreased blood flow has been found in brain systems that have been implicated in attention, such as the parietal and posterior temporal cortex, suggesting a dysfunction of attentional control with depressed patients.

Need for an Objective Measure of Top-Down Attentional Control

Considering the obviously harmful effects of heightened attentional biases toward negative information, one must agree that assessment of top-down attentional control is important in the diagnosis of mental disorders and in the prognosis of their treatment efficacy. Currently, the standard procedure of assessment is the one provided by the

Diagnostic and Statistical Manual of Mental Disorders, Forth Edition (DSM-IV, American Psychiatric Association, 2000). However, the procedure is based on subjective reports and discrete ratings on questionnaires so it has weaknesses in terms of reliability and validity. In addition, the questionnaires are not able to distinguish with sensitivity different aspects of attention. Therefore, the need for an experimental paradigm that can provide objective and continuous measures of top-down attentional control is clear.

Due to a clear need for objective and continuous measures of top-down attentional control, several experimental paradigms from attention research have been proposed and tested as diagnostic tools of attentional control. However, it has been argued that none of the paradigms can reliably distinguish individuals with attentional deficits from normal controls (Barkely, 1997; Huang-Pollock & Nigg, 2003). A similar issue is found in diagnosing other clinical disorders, such as major depression. Despite the fact that current diagnostic criteria for major depression based on the DSM-IV (American Psychiatric Association) represent a clinical and historical consensus about the most important symptoms and signs of depression, they are not sensitive enough to distinguish various forms of depression symptoms from each other.

Goal-Specificity Paradigm and Objective Measures of Attention

Individuals with depression or anxiety tend to ruminate about symptom-evoking information or negative past experiences, and have a hard time concentrating on tasks at hand. This situation is similar to the experimental procedure of the current study: participants need to use attentional resources to find a search target, but other information held in mind that is irrelevant to the search task hinders their performance in the search

task. An important implication from the current study for the diagnosis and treatment of depression and anxiety disorders is that it suggests a way for patients to be *less* hindered by task-irrelevant symptom-evoking information, by having more *specific* goals.

Given the strong evidence for the importance of goal-specificity in guiding attention from the studies presented in this dissertation, it is clear that further corroborating research could establish *goal-specificity* as an objective psychophysical measure of attentional control. Furthermore, the goal-specificity paradigm can be utilized not only to measure attentional bias in general but also to measure heightened attentional biases for particular types of information in individuals with clinical disorders by simply modifying the stimulus type. In the following sections, how the paradigm can be modified and tested is described in more detail with an example from major depression research.

A Diagnostic Tool for Attention-Related Symptoms

In the goal-specificity paradigm used in my previous studies with normal participants, stimuli that do not have special meaning to the participants were used as task-relevant and task-irrelevant information in order to exclude any possible effects from past experiences and other individual differences between participants. In contrast, in the proposed research, in order to measure the degree of attentional bias related to a certain kind of information for a special population, such information can be purposely used as a task-irrelevant distractor. For example, depressive information (e.g., faces with negative expressions) can be used as a task-irrelevant distractor when an individual with depressive symptoms is performing an attention task. If an individual with symptoms of

depression directs attention to a depressing distractor more than to a non-depressing distractor, then task performance will be lower when the depressing distractor is present in the task than when it is not. Thus, the goal-specificity paradigm can objectively test if one has heightened attentional biases toward depressing information, and it is predicted that participants with symptoms of depression will be distracted more by depressing distractors than participants without these symptoms.

Another interesting question that the goal-specificity paradigm can test is if development of symptoms of depression is related to the ineffective use of specific goal-relevant information. In other words, if one is sensitive to negative facial expressions, can one ignore such information better when a specific behavioral goal is given than when it is not? This question can be addressed by comparing task performances with and without specific target information. If patients cannot use goal-relevant information to inhibit depressing information, the same pattern of data will be obtained in the specific as well as non-specific target tasks. However, if patients can use specific goal-relevant information as effectively as the normal population in guiding their attention toward goal-relevant target information and to inhibit attentional allocation to task-irrelevant depressing information, then any difference in task performance with and without depressing distractors will be negligible in the specific target task.

At last, in order to evaluate the experimental measure as a severity measure of depressive symptoms, the results from experimental tasks and the levels of depressive symptoms of each participant can be analyzed with a correlation analysis. If a certain

measure from the experiment tasks has diagnostic power for depressive symptoms, there should be a significant correlation with the level of depression.

A Predictive Tool for Treatment Efficacy of CBT

The goal-specificity paradigm may be developed as a predictive tool for the treatment efficacy of Cognitive Behavioral Therapy (CBT). To do so, a test-retest method can be used. For example, patients newly diagnosed with major depression and starting CBT treatment for the first time receive clinical evaluations based on the DSM-IV (American Psychiatric Association, 2000) and perform a task using the goal-specificity paradigm with depressing information as distractors twice: before their first CBT sessions and after treated with CBT for a certain time period (e.g., after 10 weekly CBT sessions). In order to see which experimental measure has the strongest predictive power for CBT treatment efficacy, the amount of relief from depression (based on the clinical evaluation before and after the treatment) and value-changes in different components of dependant measures of the experiment task (based on experimental task performance before and after treatment) can be assessed by correlation analysis. If a certain measure from the experimental tasks has predictive power of CBT efficacy, it will show a correlation with relief from depressive symptoms. For example, if CBT treatment reduces attentional biases toward depressing information in patients with depression, negative effects from depressing distractors within the task will also be reduced. If the ability to use specific behavioral goals for attentional control is necessary in order to receive benefits from CBT treatment, performance in specific target tasks before the CBT treatment will show a

positive correlation with the amount of relief from depression and, if so, it will help to predict beforehand who will be responsive to CBT treatment.

Once we know which components have predictive power for treatment efficacy of CBT by the method described above, then it can be determined beforehand (by looking at the pattern of data from experimental task performance) whether CBT is likely to be an effective treatment for a patient before starting CBT treatment.

Closing

The goal of psychological studies is to describe and explain the human mind and behavior using scientific methods. By developing theories and models as well experimental paradigms and standardized measures, psychological studies further attempt to predict and influence the human mind and behavior. They are also the ultimate goal of the current study and its future direction.

The current study explored the link between attention and working memory. Considering that attention is what we constantly need to select relevant information and working memory is the storage of information that will be of use in the immediate future, it must be evolutionarily adaptive to pay attention to information that matches what we hold in mind. Duncan and colleagues (Desimone & Duncan, 1995; Duncan, Humphreys, & Ward, 1997) showed that this is true: the human brain is programmed in a way such that information matching the contents of working memory wins the competition for attention against other available information. However, this seemingly adaptive link between attention and working memory is not always beneficial. The current study

showed that the biasing effect from working memory is so strong that task irrelevant items held in working memory may bias attention to matching information, consequently interfering with the task at hand, but only when the goal of the task is not specific. Therefore, we conclude that while working memory is the main source of top-down control of attention, this control depends on the specificity of memory representations.

The currently study also provides a possible tool for attention research with clinical populations, for example, in measuring attentional bias toward certain kinds of stimuli or events, and predicting behavioral treatment efficacy for attention related symptoms. The goal-specificity paradigm developed in the current study is powerful because it measures both the positive guidance effect from the primary goal and the negative bias from the secondary content of memory at the same time (Figure 7). Another advantage of the paradigm is that modifications to measure attentional biases to particular types of information instead of general information can be easily done just by changing the kinds of task stimuli.

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