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Perseveration in attention: Inhibitory feature-based attentional sets automatically carry over to novel task contexts

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***Abstract*—** The question of how subjects manage to ignore irrelevant information has recently been a topic of keen interest. Previous research examined whether display-wide feature-based attention is accomplished by the enhancement of relevant features or the inhibition of irrelevant features. ERP data indicated that inhibition of irrelevant distractor features is the main component of the observed attentional effect. In the present study behavioral data confirms that the effect is inhibitory, and that such inhibition can carryover from one task to another.

***Index Terms*—feature-based inhibition, attention**

I. Introduction

Due to the limited information processing capacity of the central nervous system, engaging in appropriate behavioral responses to external stimuli depends on the ability to select the most relevant information. It is well known that humans can attend to specified features in the environment. For example, in a visual search task with a heterogeneous set of colored objects, a subject might be told that the target will be one of the red items. In this case, color can *guide* the search process [1]. That is, the subject can search just the red items. Thus, the time to find the target item will increase as the number of red items increases, but will not increase if the number of, say, blue items increases [2]-[3].

In the past few years investigators have inquired whether it is also the case that information about potential distractors (rather than targets) can guide information. For example, if subjects are told (correctly and reliably) that the target on a given trial will definitely *not* be green, can subjects avoid searching through green items? The results to date are not clear. Woodman and Luck [4] argue that subjects can indeed create what they call a "template for rejection" such that they can avoid examining items known not to be the target color.

However, Moher and Egeth [5] have found that identifying nontargets in this way prior to a trial may increase search time. They have suggested that subjects may actually first be drawn to such distractors for the purpose of suppressing them. They term this "search and destroy" and distinguish this mechanism from a "template for rejection."

What the preceding makes clear is that the potential role of inhibition in attention tasks is not well understood. Using a different approach, Zhang & Luck [6] had subjects attend to stimuli of a specific color, while ignoring stimuli of another specific color. Unlike the studies mentioned above, the roles of target and distractor did not vary on a trial-by-trial basis, but were kept consistent for an entire session. They measured the P1 component of the event-related potential (ERP) to assess early, feedforward processing (this measure assesses processing within the first ~100 ms after stimulus presentation). They found that this early component differed for the attended and unattended colors, and that this effect was not tied to a specific spatial location (i.e., this form of feature-based attention was display-wide). What this very interesting study could not determine is whether the difference between the attended and unattended color was due to enhancement of the former or inhibition of the latter. Moher, Lakshmanan, Egeth, and Ewen [7] adapted Zhang and Luck's paradigm to answer that very question. The stimuli and procedures were modeled closely on the methods of Zhang and Luck [6], which can be consulted for further details.

Observers maintained fixation on a central fixation mark continuously through a trial. On each 15-second trial an arrow indicated in which direction subjects should direct their attention (without moving their eyes, of course). The stimuli consisted of two small superimposed "clouds" of scintillating colored dots on one side of fixation. Three different colors were used, red, green, and blue. The roles of the colors were counterbalanced across subjects but for the sake of simplicity

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we will refer to the red as the target color, green as the distractor color, and blue as the neutral color. Thus, for a particular subject the red and green clouds would be superimposed. This subject's task was to respond whenever he or she detected the occasional dimming of the red dots; dimming of the green dots was to be ignored. From time to time a small cloud of dots, the probe, was presented in the opposite visual field for 100 ms. These were task irrelevant; subjects did not have to report anything about these dots. The cloud might be all red, all green, or all blue. (Zhang and Luck [6] used just red and green; the absence of a neutral probe like our blue is what prevented them from distinguishing enhancement from inhibition.)

Although subjects did not have to respond overtly to the probe dots in the unattended field, it is the contralateral evoked potential response to those dots that provides the main interest of the study.

There were two chief results. First, analysis of variance followed by pairwise comparisons showed that the P1 amplitude was significantly greater ($p < .01$) for probes that were the same color as the target probes than for probes that were the same color as the distractor. This replicates the result of Zhang and Luck (2009). Second, the mean P1 amplitude in response to distractor-colored probes was smaller than the mean P1 amplitude in response to neutral-colored probes ($p < .01$), but there was no significant difference between neutral-colored and target-colored probes ($p > .1$). In other words, the ERP data suggested the neutral probe was treated just like a target probe. Therefore, the difference between the target-colored and distractor-colored probes would seem to be due to inhibition of the latter.

It was interesting and important to observe evidence of display-wide inhibition of a to-be-ignored feature. It was surprising to see no corresponding evidence of enhancement of attended features. This is clearly a topic that deserves further intensive investigation.

II. Behavioral Experiment

Methods

Following the logic of Zhang and Luck [6], Moher et al. [7] took the finding that the mean P1 amplitude of the distractor-colored probes was lower than the mean amplitude of the neutral-colored probes to be evidence of inhibition. But this is something of a leap of faith. It would be valuable to show with a more direct observation that this difference can meaningfully be taken to indicate inhibition. In the present experiment we tried to do this by examining a possible transfer effect: If subjects who spend a half-hour ignoring, say, green stimuli, are presented with a search task in which the target might sometimes be green, would they be slower on such trials than on trials when the target is some other color? If so, this would be consistent with the idea that the representation of green was in some sense being inhibited.

To test this prediction, we presented observers with an identical task to the one described above (but without simultaneous electrophysiological recordings). This will be hereafter referred to as Task 1. Immediately following a session of Task 1, observers were presented with a new task (Task 2), in which they were required to identify whether a "z" or "n" target was present among 16 letters distributed randomly within a static display. One (and only one) of these two letters was present on every trial. Observers were required to press the key on the keyboard corresponding to whichever of those two letters was present, and instructed to respond as quickly as possible.

The target "z" or "n" could appear in one of four colors: red, green, blue, or yellow. Target color in Task 1 was counterbalanced in the same manner as in the electrophysiological experiment described above. That is, the target, distractor, and neutral colors were selected without replacement from among red, green, or blue for the entire session for each participant. As above, we will hereafter refer to the target as red, the distractor as green, and neutral as blue. In Task 2, yellow always represented a "novel" color. The purpose of including a novel color was to test whether the "neutral" blue color used in Task 1 was truly neutral (as we assumed), or whether there was some unexpected modulation of the neutral color occurring in Task 1. Critically, color in Task 2 was not task-relevant; that is, the target "z" or "n" was equally likely to appear in any of the four colors on any given trial. Thus, a main effect of target color in Task 2 would likely be due to a carryover of the attentional set from Task 1.

Results

Based on results from the Moher et al. [7] electrophysiological data, we predicted that response time in Task 2 would be slowed when the target "z" or "n" was rendered in green (i.e. the distractor color from Task 1). This result would suggest that not only was green actively inhibited in Task 1, but that this inhibitory attentional set was automatically carried over to a new task context. If activation of red (i.e. the target color from Task 1) also occurred in Task 1 (even though there was no electrophysiological evidence for target activation), we would expect faster response times when the target "z" or "n" was rendered in red.

Here we examined the first 100 trials from Task 2, as we presume any carryover effects will diminish over time as observers learn that color is not task-relevant in Task 2. Results in this set of trials matched our predictions. There was a main effect of color ($p < .05$). This main effect is best explained by contrasting green colored "z" or "n" targets against the remaining colors. When the target "z" or "n" was rendered in green, response times were significantly slower than if the target was rendered in any other color ($p < .05$). There was no benefit when the target "z" or "n" was rendered in red, nor any significant difference among any of the other colors ($p > .05$).

III. Discussion

These results are consistent with the electrophysiological results of Moher et al. [7]. They suggest that observers accomplish Task 1 using a feature-based inhibitory set to suppress the distractor color, with either no or weak target activation accompanying this distractor inhibition. Furthermore, this inhibitory set continues to influence behavior in a novel task context (Task 2) where it is no longer relevant, suggesting that the inhibitory set, once in place, is used as a default set for new behavioral goals. Taken together, these data suggest that when target and distractor feature are held consistent over a period of time, observers engage an inhibitory feature-based attentional set to suppress distractor items. Furthermore, the results of the current experiment suggest that inhibitory sets perseverate, influencing attention even when an observer's goals change and the set is no longer useful.

This type of carryover in attention sets has been noted before. For example, Bacon & Egeth [8] described two different types of attentional control settings that could be used to find a target when the target was defined both by its shape, and by its status as a singleton along a particular feature dimension. Observers could use a "singleton detection mode" to locate the most salient item in the display. Alternatively, they could use a "feature search mode" to locate a particular feature (e.g. shape). However, these modes were typically not under an observer's control. Instead, which mode was used typically depended upon the stimulus parameters and task demands. However, Leber and colleagues [9]-[10] discovered that one mode could be induced by providing trials where the use of that mode was the only way to accomplish the task, and that this mode would then continue to be used in new trials where either mode could be used, even transferring do a different type of task.

The inhibitory set detailed in the present results differs from previous examples in the literature where feature-based inhibition failed [5]. A simple explanation for this discrepancy may exist in the nature of the two tasks. In the present experiment, unlike Moher & Egeth [5], target and distractor features were held consistent for the entire experiment. This gave observers time to learn, perhaps at an implicit level, what the target and distractor features were, rather than relying on cues that were presented prior to each trial [4]-[5]. Thus, it may be the case that feature-based inhibition can only occur once some form of learning has taken place over a minimum period of time. If this is the case, inhibition may be the visual system's preferred method of accomplishing target selection in cases where the visual environment and task goals remain relatively stable over time. In dynamic environments where goals and relevant features rapidly change, the visual system might rely on a slower, target activation method [11]. Future studies are needed to confirm the existence of this dual-mode feature-based attention system.

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