Spatial probabilities as an attentional bias in visual search
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The characterization of attentional processes in psychological studies generally begin with the assumption that the outcome of selection is determined by either bottom-up (exogenous) or top-down (endogenous) sources of information. This dissertation investigated how a simple statistical regularity that is neither clearly bottom-up nor top-down in informational content, might bias visual processing. The impact of spatial regularities on visual processing is illustrated by the example of searching for a rabbit outside. When doing so, prior knowledge of rabbits and their habitats will automatically guide search towards grassy areas. If, however, one did happen to sight a rabbit in a tree, one might be inclined to search that location the next time with greater likelihood. The probability of an event occurring at a particular location can be a compelling guide for behavior and demonstrations of such regularities modulating behavior have been found in a variety of domains and species (e.g. Chun & Jiang, 1998; Fiser & Aslin, 2001; Greggers & Mauelshagen, 1997; Herrnstein, 1961; Hoffmann & Kunde, 1999; Miller, 1988; Peterson & Kramer, 2001).

To investigate the role of spatial probabilities in visual attentional processing, we manipulated the likelihood of a target appearing in a particular location in the context of a visual search task with normal undergraduate students and with neurological patients exhibiting spatial neglect. By adopting a standard psychological paradigm used to study visual attention, we hoped to understand probabilistic regularities as a specific example of an attentional cue that shapes visual perception.

All experiments involved a discrimination task in which subjects determined whether the target letter ‘T’ was rotated 90° to the right or left in a visual search array. A target was present on every trial and the manipulation of interest involved the probability of the target being in each location. All experiments consisted of uneven probability blocks in which high probability locations were more likely to contain the target than low probability locations (e.g. 75% in the high probability location, 25% distributed amongst the low probability locations), and random probability blocks (serving as baseline) in which the target was equally likely to appear in all locations. Importantly, the location manipulation was orthogonal to the dimension of response. The display duration was 150 ms in experiments with young participants and unlimited in those with patients with spatial neglect. No mention of the distribution of target locations was made at any stage of the experiment nor was feedback given.

Consistent with the hypothesis that spatial regularities produced an expectancy regarding the likely location of the target, young participant reaction times (RTs) to high probability targets were significantly faster than those to random or low probability targets, ($F(2,46) = 57.79$, $p < .001$, $MSE = 1807$) (Figure1). Although we attributed the speeded target identifications on the high probability trials to the aggregated probability, the facilitation may have also emerged from trial-to-trial repetition priming, which occurs for random sequences of stimuli (Hillstrom, 2000; Maljkovic & Nakayama, 1996). In order to assess the relative contribution of probability compared to repetition priming, we considered the effect of the 1-back trial and 2-back trial target being in either the same or a different location from the current Nth trial target. If our results were solely due to repetition priming, facilitation for targets in the same location as their 1-back and/or 2-back predecessors should be equivalent for high and random probability location targets. However, the only significant interaction was between the 1-back and the Nth trial location, ($F(2,23) = 7.81$, $p < .05$, $MSE = 1579$). Immediate repetition priming was present in all conditions, but the magnitude of facilitation for high probability targets was greater than that of spatial repetition priming in random probability targets alone.

The conditions that produce facilitation were investigated in a subsequent experiment using two distractor set sizes (four and eight) and two configurations of the four item displays (Figure 2). Interference from increased numbers of distractors was reduced significantly for high probability location targets producing an interaction between set size and probability, ($F(2,30) = 25.23$, $p < .001$, $MSE = 816.50$). Additionally, inhibition of low probability targets only occurred when a distractor was present in the high probability location, resulting in a main effect of probability within set size four displays, ($F(3,45) = 99.56$, $p < .001$). That is, on trials in which no distractor was in the high probability location, RTs were equivalent to those in the random probability block. This suggested that the spatial regularity facilitated object processing in the high probability location, rather than produced pure spatial priming per se.

Given that the location probability operated as an effective bias for information in the high probability location, we then tested the strength of the bias against well known attentional effects in two ways. First, we conducted experiments with patients with spatial neglect, a neuropsychological condition involving impaired processing of contralateral information, and second, we compared the strength of the probability bias against well known exogenous and endogenous attentional cues.

Spatial neglect is most often described as an attentional deficit and the pattern of impaired processing of contralateral information in visual search has been documented extensively (Aglioti, Smania, Barbieri, & Corbetta, 1997; Eglin, Robertson, & Knight, 1989; Esterman, McGlinchey-Berroth, & Milberg, 2000; Riddoch & Humphreys, 1987). We were interested in whether the deficit in visual search for contralateral information could be modulated by the probability manipulation. In one experiment, the target was always embedded within an array of six letters distributed in six columns across the screen (Figure 3a). In the uneven probability blocks, the target was more likely to be one of the left-sided elements. The characteristic gradient of response performance across the visual field was still present with the probability manipulation, but targets in the neglected field were detected significantly faster in the uneven probability block than in the random probability block. There was no difference for targets in the unimpaired visual field, ($F(5, 30) = 2.61$, $p < 0.05$) (Figure 3b). In another experiment, the target appeared either alone or with a single distractor and the high probability location was limited to the middle column in the left visual field. The design was chosen to test for the role of competition on cue effectiveness. The probability manipulation facilitated responses both when the target was alone and when it was with a distractor and there was a trend towards a larger magnitude of facilitation when a distractor was present compared to when the target appeared alone, ($F(5,10) = 3.81$, $p < .05$). These results suggested that the probability manipulation competed against the ipsilateral processing bias in neglect and as such functioned as an attentional cue that facilitated processing of items in likely locations.

Next, comparing the location probability cue against a salient exogenous and an explicit endogenous arrow cue provided a measure of its relative strength within the context of known attentional effects in normal participants. Results from several experiments indicated that spatial probability interacted with the salient exogenous event, but that spatial probability and the arrow cue produced independent effects. The interaction was produced by the compression of the exogenous cue validity effect in the high probability location (Figure 4). Additionally, increasing the predictive validity of the probability cue from 75% to 100% further compressed the effect of the exogenous event. These results were consistent with demonstrations that the relationship between the validity of explicit spatial cues and attentional capture by salient events operates on a continuum (e.g. Patel & Sathian, 2000; Yantis & Egeth, 1999; Yantis & Jonides, 1990).

The independent effects of the probability and arrow cue suggested dissociable underlying mechanisms, but we also found similarities between these two cues and their patterns of interaction with an exogenous event. Although the overall pattern was similar, each of the exogenous cue conditions in the high probability location were also significantly faster than their arrow cue counterparts, suggesting that under the conditions of these experiments, the probability cue was also a stronger bias than the explicit arrow (Figure 5).

The objective of these experiments was to explore the effect of probabilistic regularities in target location on attentional orientation within the context of traditional attentional methods and effects. Models of visual attention have typically only included provisions for an explicit endogenous subsystem and a separate subsystem sensitive to novel or salient information (Corbetta & Shulman, 2002; Hamker, 1999; Humphreys &

Mueller, 1993; Treisman & Gelade, 1980; Wolfe, 1994). Although speculative, we hypothesize that the probability cue operates within the endogenous attentional system, however, whereas the explicit cue produces a top-down signal that serves as a prime for a particular location, we suggest that the probability cue produces a change in the processing efficiency of objects in likely locations. In the case of the explicit cue, a particular spatial location is primed in advance of the stimulus display, which then results in inhibition of processing at other locations. In the case of the implicit spatial regularity, facilitation occurs via more efficient processing of objects in locations that are likely to contain the target. Instead of a spatial prime, this can be thought of as a change in the “weights” between the units that represent information in a particular location. Inhibition is produced by the act of processing the item in the high probability location rather than being a function of explicit expectations derived from a cue and prior to stimulus onset. As such spatial probabilities are another means by which visual processing may be biased towards some information at the cost of processing other information and is consistent with the ideas of attention formulated within a biased competition framework (Desimone & Duncan, 1995; Duncan, Humphreys, & Ward, 1997). Attentional effects can be determined by a number of properties in the external world and goals internal to the observer and spatial regularities are simply one of them.

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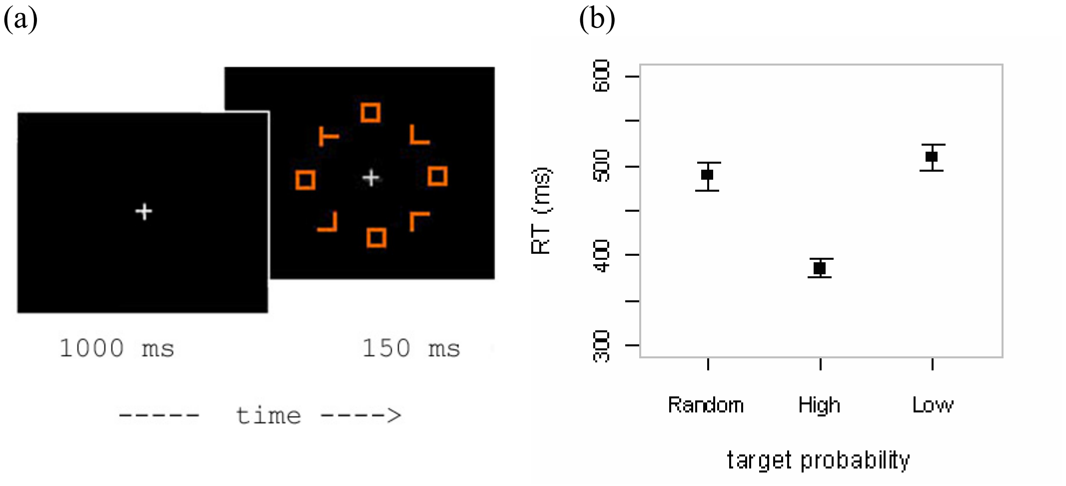

Figure 1: (a) Illustration of the trial procedure for young participants. (b) The basic effect of probability in which targets appearing in the high probability location were significantly faster than targets in either random or low probability locations.

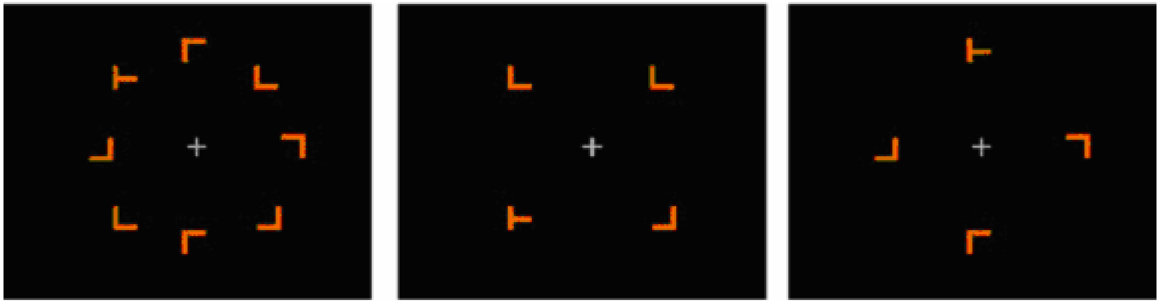

Figure 2: Examples of the three possible search display configurations (a) Set size eight display where the target is in the high probability location in the top left corner. (b) Set size four display in which the target was in a low probability location and a distractor was present in the high probability location. (c) Set size four display in which the target was in a low probability location and *no* distractor was present in the high probability location.

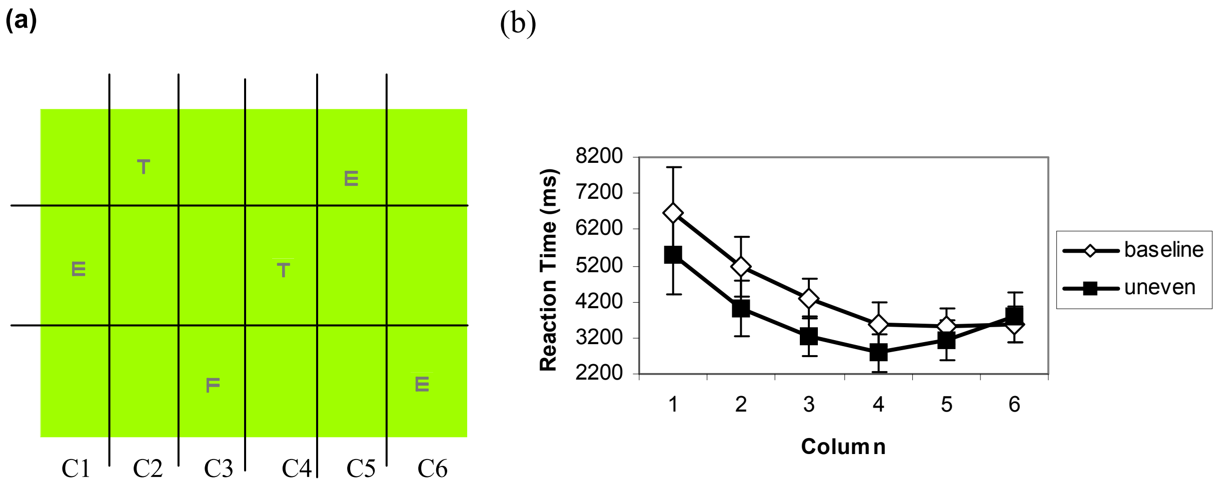

Figure 3: (a) Visual search stimulus display used in study with spatial neglect patients. A single letter appeared in each column. Within each column, there were three possible object locations. The task was to identify whether the letter 'F' or 'C' was present in the display. Gridlines are included here for exposition only. (b) Mean reaction time as a function of screen column in spatial neglect patients.

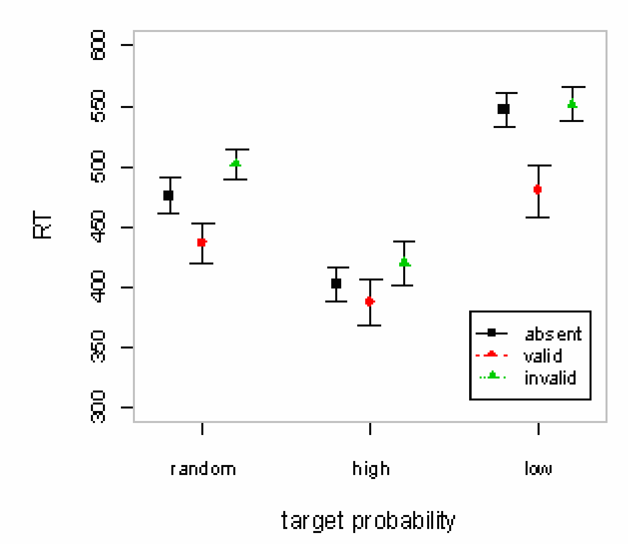

Figure 4: Interaction between probability and exogenous cue. The effect of the exogenous cue was compressed when in the high probability location, but emerged in the other locations suggesting that the effect of probability was relatively stronger than that of the exogenous event.

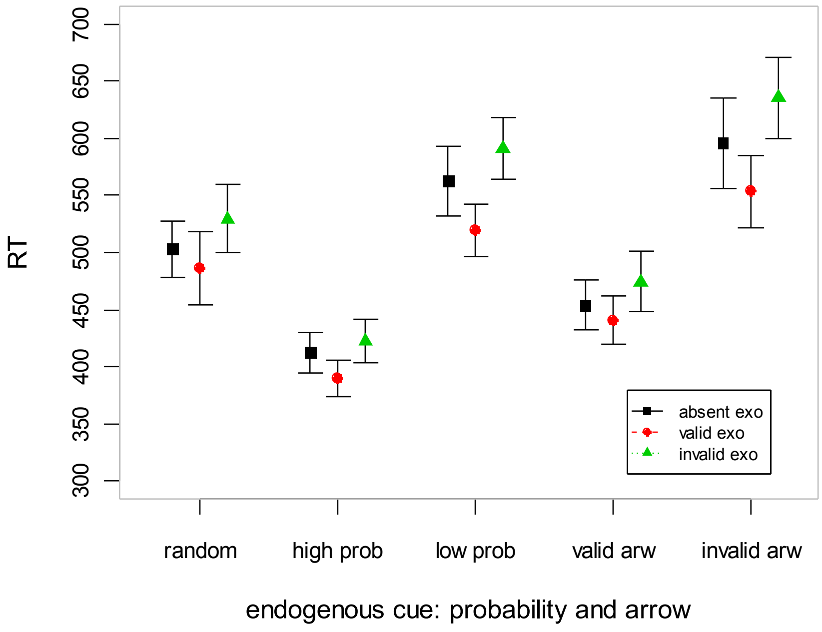

Figure 5: Interaction between endogenous and exogenous. Of greatest interest was the similar pattern of RT compression in the high and valid endogenous conditions and the fact that all three high probability means were faster than their valid arrow counterparts.