Does Target Object Processing Affect Reaction Times in Simple Detection Spatial Cueing Tasks?

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Abstract
The current study tested the effect of varying target type and target set size during simple detection versions of Posner’s exogenous spatial cueing task. The four target conditions consisted of a single letter, a single number, one of four possible letters, or one of four possible numbers. Responses were faster for numbers than for letters, but only when the cue-target lag was short, the target set included more than one potential number, and the cue and target appeared in different locations. These findings suggest that even during detection tasks, responses are influenced by the object features of the target. Methodological implications for spatial cueing studies and other types of visual perception research were discussed.

Keywords
spatial cueing, detection, target object, target set size

Introduction
Spatial cueing tasks have long been used to study visual orienting (Posner, 1980). These tasks were initially developed to examine processes involved in shifting attention from one spatial location to another. However, spatial cueing tasks have also been employed in a variety of other psychological domains, including social, personality, and emotion research, as well as in clinical studies of anxiety,
attention deficit/hyperactivity disorder, and other psychopathologies (Bar-Haim, Lamy, & Glickman, 2005; Collings & Kwasman, 2006; Frischen, Bayliss, & Tipper, 2007; Vogt, De Houwer, Koster, Van Damme, & Crombez, 2008). In general, this paradigm involves the presentation of a visual cue followed by the target stimulus (Figure 1). In non-predictive exogenous versions of these tasks, cues and targets both appear in varying peripheral locations on the display. Cues and targets sometimes appear in the same spatial location (valid cues), and at other times, they appear in different locations (invalid cues), with a 50:50 ratio of valid to invalid cue presentations. Consequently, the cue’s effect is presumed to be a function of the spatial proximity of the cue to the target, and not an anticipation of where the target is likely to appear. To examine the temporal progression of spatial cueing, researchers vary the lag time between cue and target presentations (stimulus onset asynchronicity, SOA). Spatial cueing tasks have generated a tremendous body of knowledge about how responses are affected by visual cues appearing in the periphery, whether the visual stimuli involve boxes, faces, video game characters, or many other stimulus types employed by researchers.

Although several variants of spatial cueing tasks have been developed, most are either a detection task or a discrimination task. In simple detection versions of these tasks, participants are instructed to respond as quickly as possible when the target appears. Reaction time is measured and used as the dependent variable. In contrast, discrimination tasks involve making choices; that is, they involve making accurate discriminations between potential targets (e.g.,

![Figure 1. Example valid cue trial in exogenous spatial cueing task. Cue and target stimuli appear in same spatial location.](image-url)
consonants or vowels, odd or even numbers, red or blue colors, etc.). Responses in detection tasks occur as soon as the individual is aware of the target’s presence. Consequently, reaction times in detection tasks tend to be faster than in discrimination tasks. In detection tasks, attention is presumed to be constrained to the location of the cues and targets (where). In discrimination tasks, attention also must be given to features of the target stimuli (what and where). For this reason, detection tasks have been widely used when the focus of the study is supposedly limited to processes related to spatial cueing. It should be noted that both kinds of tasks, discrimination and detection, are widely used by researchers in many lines of research, for example, the perception of faces, emotions, colors, and features (Luck & Yard, 1995; Palermo & Rhodes, 2007; Williams et al., 2004). The current study examines the assumptions made about the processing that actually occurs during detection tasks.

**Processes involved in spatial cueing**

Early spatial cueing studies revealed that cues evoke both spatial effects (i.e., location *where* the target may appear) and temporal effects (i.e., *when* the target may appear; Posner, 1980; Posner & Petersen, 1990). The former effects are related to the spatial proximity of the cue to the target and are dependent on the SOA. When the cue-target lag is 100 ms or less, responses to validly cued targets tend to be shorter than responses to invalidly cued targets. When stimulus onset asynchronicities are increased to 300 ms (or more), the reaction time pattern is reversed. This phenomenon is referred to as inhibition of return (Posner & Cohen, 1984; Posner, Rafal, Choate, & Vaughan, 1985). Reaction times also are reduced by the phasic alertness generated by the sudden onset of the cue stimulus, irrespective of its spatial proximity to the target (Coull & Nobre, 1998; Fernandez-Duque & Posner, 1997).

Several recent quantitative reviews have been used to summarize research results and to draw general conclusions from the enormous number of spatial cueing studies conducted over the last four decades (e.g., Chica, Martín-Arévalo, Botta, & Lupiáñez, 2014; Losier & Klein, 2001; Samuel & Kat, 2003). These efforts have provided much insight about how reaction times are affected when conditions of the cue presentation (e.g., cue type, cue location, SOA, etc.) are varied. However, the effect for varying stimulus properties of the target (e.g., letters, numbers, symbols, etc.) has received little attention in the spatial cueing literature. This makes sense if one assumes that such target properties are irrelevant in simple detection tasks.

**Challenging the “simple detection” assumption**

Several disparate sets of research findings indicate that a closer look at this assumption about target processing is warranted. For example, Lupiáñez,
Ruz, Funes, and Milliken (2007) examined the effect of varying target set size (i.e., the number of potential targets that might be presented) during spatial cueing tasks. They found that inhibition of return was delayed when the target set size was increased from two to four potential targets. This phenomenon was attributed to cueing processes (i.e., attention capture, visual orienting, and cue-target integration). Lupiáñez et al. did not attribute this target set size effect to the processing of target object information. Rather, the authors inferred that in some cases participants adopted a “detection mode” because the pattern of reaction times they observed was “very similar to that observed in detection tasks” (p. 82). It is important to note, however, that their experimental tasks required participants to make discriminations between target stimuli (e.g., “X” vs. “O”). This question does not appear to have been explored with simple detection tasks.

Support for the notion that target object processing does influence reaction times can be found in the visual systems literature. Park, Hebrank, Polk, and Park (2012; also see Polk et al., 2002) found that letter recognition is processed in the left temporal-occipital area of the brain and number recognition is processed in the right temporal-occipital region. Furthermore, Park et al. (2012) observed shorter reaction times for letter strings than for number strings. Unfortunately, these findings from the visual systems literature have not received much attention by spatial cueing researchers. For this reason, it is not clear if the distinct processing for letter and non-letter stimuli would influence reaction times in spatial cueing tasks. This question challenges the assumption that reaction time variability is primarily a function of cueing, and not target processing in “simple detection” versions of these tasks. This question is especially important in light of the widespread use of this paradigm in other research domains.

The current study examined the effect of varying target type and target set size during simple detection exogenous spatial cueing tasks. The basic design (see Figure 2) included four cue validity conditions (i.e., valid, invalid, center, and no cue). In the valid and invalid cue conditions, the cue provided both temporal and spatial information. Since the target never appeared in the center of the display, center cues provided temporal cueing, but no spatial cueing. By definition, the no cue condition provided neither temporal nor spatial cueing. This design allowed us to examine how target object processing might be affected by the nature of the information provided by the cue (i.e., spatial and/or temporal).

To manipulate target type, participants were randomly assigned to either a number target or letter target condition. The target set size manipulation involved random assignment to either a single target set condition or a multiple target set condition. The aim of the study was to examine the effect of varying target stimulus properties during a simple detection paradigm, so it was crucial that participants were not explicitly or implicitly prompted to make discriminations between stimuli. Consequently, participants always responded to: (a) the
Figure 2. Example stimuli presentations during spatial cueing task trial (letter target). Cue validity conditions consist of same side as target (valid), opposite side from target (invalid), centered on fixation, or no cue (fixation only). Target appears either on left or right side of display. Target type conditions consist of letters (shown) or numbers. Target set size conditions consist of either a single letter or number, or one of four letters (W,X,Y,Z) or four numbers (4,5,6,7).
same target letter; (b) the same target number; (c) one of four target letters; or (d) one of four target numbers. Participants were instructed to respond as quickly as possible to the target. It was reasoned that if detection involved little or no target processing (other than the target’s temporal and spatial relation to the cue), reaction time patterns would be equivalent across the four conditions. On the other hand, if responses did involve processing unique object information about the target, it was hypothesized that varying either target type or target set size would affect the distribution of reaction times.

**Method**

**Participants**

An initial power analysis for a mixed factorial design was conducted, as part of the design of the current study. Effect sizes (Cohen’s $d$) for conventional spatial cueing effects observed in several published and non-published studies previously conducted in our lab were calculated and used in this power analysis. The mean and minimum sizes of these effects were both large ($d = 1.96$ and $d = 1.06$, respectfully). Based on the more conservative of these two, it was estimated that a minimum of seven to eight participants per group would be needed to detect any of these effects, if $\alpha$ was set to the accepted $p = .05$ standard and $1 - \beta$ was held to .80 at minimum (see Cohen, 1988, 1992). Accordingly, 32 volunteers ($M$ age $= 19.3$ year, $SD = 2.3$) were recruited from undergraduate introductory psychology courses to participate in this study. All participants were screened and had normal or corrected-normal visual acuity. No participant had a prior Attention Deficit/Hyperactivity Disorder (ADHD) diagnosis, and no participant exceeded the published age-appropriate diagnostic cutoffs for ADHD on a screening assessment (see Measures section). All participants were treated in accordance with APA ethical guidelines for human participants research.

**Measures**

The *Current Symptom Scale* (Barkley & Murphy, 1998) is a 26-item questionnaire assessing potential symptoms related to the diagnostic criterial for ADHD in the fourth edition of the *Diagnostic and Statistical Manual* (American Psychiatric Association, 1994). A factor score was calculated for each participant on the two ADHD symptom domains (i.e., inattention and hyperactivity/impulsivity) and compared to the authors’ published diagnostic criteria. An additional question about prior diagnoses for ADD or ADHD was included. These data were used for screening purposes only.

The spatial cueing tasks were performed on a Dell Optiplex GX240, (1.8-GHz Pentium 4 processor), with a Dell™ 20.1” Active Matrix TFT LCD display
E-Prime v1.1 (copyright 2002, Psychology Software Tools, Inc.) was used to develop and administer the spatial cueing assessments. A chin rest was used to maintain a stationary head position.

**Procedure**

All assessments were administered during a single session in our research laboratory. Instructions were given to participants for their randomly assigned spatial cueing task. In the multiple-number condition (see Figure 2), participants were informed that each trial would begin with the presentation of a “+” in the center of the display; followed by the presentation of a box in the center, to the right side, or to the left side of the display; and finally, the presentation of a number to the right or left side of the display. Participants were instructed that in some trials no box would appear. Participants were told that a number between four and seven might appear. Participants were instructed to remain focused on the “+,” to ignore the box, and to hit the response key as quickly as possible when a number appeared. In the instructions for the multiple-letter condition, the word “number” was replaced with the word “letter,” with letters ranging between “W” and “Z.” In the instructions for the single-number condition, participants were informed that the target would always be the same number (either “4” or “7,” counterbalanced across participants). Similarly, the participants in the single-letter condition were told that the target would always be the same letter (“W” or “Z,” also counterbalanced).

At the onset of each trial, a white “+” was presented as a fixation stimulus in the center of the display (see Figure 2). After 900 ms, a cue was presented for 50 ms, along with the center fixation stimulus. The cue consisted of a yellow box. The center of the box was presented either to the right or the left of the fixation (cued and invalidly cued conditions), or in the center of the display (center cue condition). During no-cue trials, the cue presentation consisted of a 50 ms presentation of the fixation “+” without the box. This created four cue validity conditions (valid, invalid, center, and no-cue). After the termination of the cue presentation, the fixation “+” was shown for 50 ms, 350 ms, 650 ms, or 950 ms. This design resulted in four SOA conditions (100 ms, 400 ms, 700 ms, and 1000 ms).

The white target stimulus was presented to the right or left of the fixation “+.” The target consisted of one of four numbers, one of four letters, the same number, or the same letter, depending on the condition. Between trials, a gray mask was presented for 600 ms. Participants performed two blocks of 128 experimental trials, with a rest break between blocks. Within each block, 32 of the trials were presented within each SOA condition. Of these, eight trials were presented within each cue validity condition. Consequently, an equivalent proportion of cues were presented in each condition, making them non-predictive, both spatially and temporally. An equal percentage of all conditions were
presented in each visual field (i.e., left and right), although these were collapsed for analyses. The order of conditions was randomized across participants. Participants took approximately 9 minutes to perform the actual experimental trials. Although the experiment involved a somewhat small number of trials, the task had strong reliability ($R_{SB} = .94$).¹

**Design and analyses**

The current experiment was a $2 \times 2 \times 4 \times 4 \times 2$ mixed factorial design. Target type and target set size were between-group measures, which each group being exposed to a single target type and set size (see Figure 3). All other measures were within subjects. To control for spurious responses, each participant’s median reaction times for each within-subjects condition (cf. Ratcliff, 1993) were used as the dependent variable. Reaction times less than 100 ms were omitted to control for anticipatory responses. Only 11 participants had a response that would be considered

![Figure 3](image-url)  
*Figure 3.* Within and between group independent variables and levels. All participants were administered the four cue validity and stimulus onset asynchronicity conditions. Participants were randomly assigned to target type (number vs. letter) and target set size (single target vs. multiple target) conditions.
anticipatory, and the percentage of omitted anticipatory responses for these participants was 1.2%. A preliminary mixed-design analysis of variance was conducted to test for significant main effects and interactions involving block, cue validity, SOA, target type, and target set size. Simple effects analyses were used to more closely examine any significant interaction effects.

Results

Preliminary analyses

The main effect for block was significant and moderately large, \( F(1, 28) = 4.77, p = .037, \eta^2_p = 0.15 \). Reaction times (ms) declined from the first block \( (M = 311, SD = 34) \) to the second block \( (M = 305, SD = 34) \). However, no significant interactions involving the block variable were observed. The main effect for SOA was significant and large, \( F(3, 84) = 110.87, p = .001, \eta^2_p = 0.80 \). A polynomial contrast revealed a significant and strong linear decline in reaction times as stimulus onset asynchronicities were increased, \( F(1, 28) = 181.93, p = .001, \eta^2_p = 0.87 \) (see Table 1). The main effect for cue validity was also significant and large, \( F(3, 84) = 43.12, p = .001, \eta^2_p = 0.61 \). A series of Bonferroni-corrected pairwise comparisons revealed that valid cue reaction times were significantly longer than invalid cue and center cue reaction times, \( F(1, 84) = 50.15, p = .001, \eta^2_p = 0.64 \) and \( F(1, 84) = 50.40, p = .001, \eta^2_p = 0.64 \), respectively. No significant difference was observed between reaction times in the valid and no cue conditions (corrected \( p \approx 1.000 \)).

Although a moderately large main effect was observed for target type \( (\eta^2_p = 0.11) \), neither it nor the target set size main effect was significant at traditional levels \( (p = .07 \) and \( p = .28 \), respectively). However, significant two-way interactions were observed for SOA \( \times \) cue validity, SOA \( \times \) target type, and SOA \( \times \) target set size, \( F(9, 252) = 13.49, p = .001, \eta^2_p = 0.33 \), \( F(3, 84) = 3.08, p = .032, \eta^2_p = 0.10 \), and \( F(3, 84) = 3.95, p = .011, \eta^2_p = 0.12 \), respectively. The three-way SOA \( \times \) target type \( \times \) target set size and SOA \( \times \) cue validity \( \times \) target type interactions were also significant, \( F(3, 84) = 5.03, p = .003, \eta^2_p = 0.15 \) and \( F(9, 252) = 3.47, p = .001, \eta^2_p = 0.11 \), respectively. Finally, the four-way SOA \( \times \) cue validity \( \times \) target type \( \times \) target set size interaction was significant, \( F(9, 252) = 2.28, p = .018, \eta^2_p = 0.08 \). These interactions are examined more closely in the following section. No other significant interactions were observed (all \( ps \) between \( .06 \) and \( .97 \)).

Simple effects analyses

The significant four-way interaction suggested that the target type and target set size effects were dependent on cue validity and SOA. A series of Bonferroni-corrected simple effects analyses was conducted to examine this interaction.
No significant differences were observed between the two cue types when only one target number or letter was used (all \( p \)s between .11 and .83). When the target set size was increased, reaction times for letters were significantly longer than were reaction times for numbers in the invalid cue 100 ms and 400 ms conditions, \( F(1, 14) = 16.43, \ p = .019, \ \eta_p^2 = 0.54 \) and \( F(1, 14) = 14.62, \ p = .03, \ \eta_p^2 = 0.51 \), respectively (see Table 1). A similar reaction time pattern was observed in both the center cue and no cue 100 ms conditions, \( F(1, 14) = 26.47, \ p = .002, \ \eta_p^2 = 0.65 \) and \( F(1, 14) = 43.32, \ p = .001, \ \eta_p^2 = 0.76 \), respectively. No significant differences were observed between multiple numbers and letters in the valid cue condition (all \( p \)s between .10 and .98).

Similar tests were conducted to examine the effect of varying target set size within each SOA, cue validity, and target type condition. Single-number reaction times were significantly longer than multiple-number reaction times only for the 100 ms invalid cue condition, \( F(1, 14) = 12.35, \ p = .048, \ \eta_p^2 = 0.47 \)

### Table 1. Mean reaction times and standard deviations for stimulus onset asynchronicity, validity, target type and set size.

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Large but non-significant trends for the center and no cue reaction times also were observed in the 100 ms SOA condition, $F(1,14) = 11.45, p = .053$, $\eta^2_p = 0.45$ and $F(1,14) = 10.56, p = .07, \eta^2_p = 0.43$, respectively. No other significant effects for set size were found with target numbers (all $p$s between .31 and .96). Nor were any significant differences found between the single or multiple target conditions when letters were used as targets (all $p$s between .14 and .96).

**Discussion**

The current study tested the hypothesis that responses in simple detection spatial cueing tasks involve processing information about both the cue (i.e., validity and SOA) and the target (i.e., type and set size). The justification for this hypothesis comes from findings in visual systems research that suggest that differential visual processing occurs for different types of visual stimulus (i.e., letters and numbers; Park et al., 2012; Polk et al., 2002). This phenomenon, however, has been largely ignored in spatial cueing research. The data provided support for the hypothesis, but with two important caveats. First, the effects for varying target type and target set size were both short-lived (less than 400 ms). Second, these effects were absent when the target appeared in the cued location. The current findings are relevant not only to spatial cueing studies but to any research that involves detection of cued targets. They suggest that reaction times are dependent on where attention is directed, on when the target appears (in relation to the cue), and on the object properties of the target. This appears to be true even when no purposeful discriminations are expected.

The current results do seem to conflict with Park et al. (2012), who observed faster responses for letters than for numbers. In the current study, no differences in reaction times to single letters and numbers were observed. Furthermore, when target set size was increased, number processing was actually faster than was letter processing. Park et al. attributed efficient letter processing to reading experience. It seems plausible that such reading biases may affect the processing of letter strings, as were used in the Park et al. study, but not letter singletons, as were used in the current study. On the surface, the current findings would also appear to conflict with Lupiáñez et al.’s (2007) findings of a delayed inhibition of return when target set size was increased. The current findings revealed no evidence of delayed inhibition of return, as set size had no effect on valid cue reaction times or invalid cue reaction times at longer SOAs. It must be reiterated, however, that Lupiáñez et al. used a target discrimination paradigm, whereas the current study involved simple target detection. In any event, interpreting cueing effects without considering target object processing in the context of task demands would seem to be risky.

The interaction between spatial cuing and target object processing observed in this study leads to an obvious question: What role does attention play in target object processing during detection tasks? One possibility is that attention
capture by a cue limits the processing of target information. When participants visually orient to “where” and “when,” it inhibits the processing of “what.” This explanation is reminiscent of Desimone and Duncan’s (1995) spatial vs. feature competition hypothesis. They proposed that visual processing is subject to a competition between the ventral stream associated with object recognition and the dorsal stream associated with spatial perception. In tasks like those used in this study, attention to spatial location may take precedence over attention to feature. This might explain the apparent absence of target object processing in the valid cue condition. When attention is not focused on the target location, as would be the case in the invalid, center, and no cue-conditions, target processing would not be constrained. This would explain the observation of target object processing in those conditions. Admittedly, this explanation is speculative. If true, however, the current findings suggest two important things: first, a considerable amount of object recognition occurs even in detection tasks, unless competing demands by spatial processing interfere, and second, this object recognition seems to be relatively short-lived when it is not relevant to the task. A potentially fruitful direction for future research would be to compare neural activation in both of these systems (i.e., object recognition and spatial perception) during detection and discrimination tasks.

Findings from non-spatial cueing studies in other research domains suggest that both behavioral and neurological responses are affected by unintentional processing of target information. In a recent study of the effect of same-race bias on face recognition, Zhou et al. (2015) presented arrays containing human and non-human faces. Participants were asked simply to determine if a human face was present in an array of faces. They found that response times were faster when the racial features of the displayed faces matched the race of the participant (i.e., Chinese participant viewed Chinese face or non-Chinese participant viewed non-Chinese face) than when the racial features of the participant and displayed face were different (i.e., Chinese participant viewed non-Chinese face or non-Chinese participant viewed Chinese face). This suggested that although the task involved explicit discriminations between human and non-human faces, the race of the displayed face was processed implicitly. Whether or not such implicit processing would occur in a simple detection task is an open question, although the current findings suggest that it might.

The current findings imply that object processing is differentially affected by spatial and temporal cueing. If true, this point would be relevant to several domains of psychological research. For example, there is a disparity in research related to emotion perception that may be explained by this phenomenon. Holmes, Vuilleumier, and Eimer (2003) found evidence of stronger behavioral responses and event-related potentials to emotional facial expressions appearing in a spatially cued location than to facial expressions appearing in the periphery. However, their findings conflicted with earlier brain imaging studies (Vuilleumier, Armony, Driver, & Dolan, 2001). The current findings support
Holmes, et al. attribution of this disparity to differences in temporal resolution between the two research paradigms.

Similarly, the current findings suggest that methodological differences may explain disparate findings in clinical research. Spatial cueing studies have been used to study a wide range of phenomena, including pain-related bias, disengagement from threat-related stimuli with individuals with anxiety disorders, and deficits in visual orienting among individuals with ADHD (Cisler & Koster, 2010; Crombez, Van Ryckeghem, Eccleston, & Van Damme, 2013; Huang-Pollock, Nigg, & Halperin, 2006). The current findings suggest that researchers should consider spatial and temporal parameters when they design new experiments and when they make cross-study comparisons. Furthermore, researchers should be aware that some processing of object features occurs, even when no explicit discriminations about those features are required in the task.

Limitations and conclusion

The current study's relatively small sample size does represent a limitation. The fact that the expected effects typically found in spatial cueing tasks were replicated here suggests that the sample provided sufficient statistical power. The generalizability of these results is a separate issue. However, the best evaluation of the external validity of the current findings would come from independent replications, so it is hoped that this report will spark such examinations.

The results of the current study suggest that during traditional spatial cueing tasks with simple detection, responses are affected by information provided by both the cue and the target. Varying target stimulus type and target stimulus set size affected reaction times. However, these effects only occurred when attention was not focused on the target location, and they were relatively short lived. The current results seem to concur with findings from visual systems research that distinct processing occurs for different types of stimuli. These findings have both methodological and theoretical implications for spatial cueing studies, as well as other research involving “simple detection” cueing paradigms.

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Note
1. Split-half reliability coefficients were calculated for each of the validity and stimulus onset asynchronicity conditions, comparing the trials from blocks one and two (see Rosenthal & Rosnow, 2008). The Spearman-Brown adjusted mean of these coefficients ($R_{SB}$) was calculated as an index of reliability.

References


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