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RESEARCH ARTICLE

Spatial coding for the Simon effect in visual search

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Abstract Two experiments were conducted to examine the Simon eVect (i.e., faster responding when irrelevant stimulus location corresponds with response location than when it does not) in visual search tasks. The search items were arranged in a 4 ˙ 4 grid, and grid locations were coded into sets of four, two involving inner columns and two involving outer columns. In experiment 1, three diVerent types of ineYcient search tasks were used. The Simon eVects were shown to be larger when the target appeared in one of the outer columns than in one of the inner columns ("laterality eVect"). This pattern of results was not observed when distractors were absent, suggesting that the laterality eVect depends on the operation of selective attention. In experiment 2, a pop-out search task was used, and no signiWcant eVect of target location on the Simon eVect was found. Interpretations of the results based on the attention-shift account and referential-coding account were discussed.

Keywords Simon eVect · Visual search · Spatial code · Laterality eVect · Attention-shift account · Referential-coding account

Introduction

In many situations, stimulus location in the visual Weld is automatically coded and it aV

is processed and what mechanisms are responsible for the impact of irrelevant spatial information upon task performance. Almost all of these studies, however, present a target in isolation, although its relation to Wxation, precue, or simple context could be manipulated (e.g., Hommel 1993b; Wascher and Wolber 2004; Zimba and Brito 1995). Even in a few studies with multiple-item arrays (e.g., van der Lubbe et al. 1999, 2004), the target is indicated by a cue and no active search is required to Wnd the target (but see Ward et al. 2005). In daily life, however, we often face more complex visual scenes and need to search for a target among a number of distractors. This target can appear randomly at a number of diVerent locations and its speciWc location can vary dynamically from scene to scene. It is not clear whether and how the Simon eVect would occur in this context.

The main purpose of this study was therefore to examine whether the Simon eVect could be observed in visual search tasks, and to what extent this Wnding can inform us about the mechanism underlying the activation of the spatial code of the target. As indicated above, it is widely accepted that a spatial code is automatically generated for a stimulus, even though this code is completely task-irrelevant. However, the origin of this spatial code remains controversial. Two major alternatives have been proposed: *the referential-coding account* and *the attention-shift account*. The referential-coding account (Hommel, 1993a) assumes that a spatial code is formed by relating the imperative stimulus (i.e., the stimulus that delivers the task-relevant information) to a reference frame or object. The attention-shift account (Proctor and Lu 1994; Rubichi et al. 1997; StoVer 1991; StoVer and Umilta 1997; StoVer and Yankin 1994), on the other hand, postulates that a spatial code is generated when there is a shift in spatial attention towards the location occupied by the imperative stimulus. Moreover, when multiple attention shifts take place over time and location, only the most recent shift is responsible for the generation of the spatial code for the target.

The attention-shift account is consistent with some previous evidences. For example, Nicoletti and Umilta (1989) instructed participants to respond, with a left or right keypress, to a rectangle or square that appeared inside one of six boxes arranged in a row. In their experiment 3, participants had to maintain Wxation on a plus sign located at one end of the row and to orient attention onto a small solid square that was shown for 500 ms in one of the Wve gaps between the boxes. At the oVset of the square the imperative target appeared in one of the immediately adjacent boxes. A Simon eVect was observed with respect to the location at which attention was initially oriented (i.e., the square), regardless of where the orienting square was placed. Thus a further attention shift from the square (the precue) to the target determined the spatial code of the target (see also Rubichi et al. 1997). Nicoletti and Umilta (1994) demonstrated that the Simon eVect was not obtained when attentional focus must remain at Wxation. The display was similar to their former study; except that participants had to keep attention at Wxation to detect a letter presented there, and could not voluntarily direct attention to the target. In addition to these studies with attentional focus shifting from Wxation to the periphery, recent studies suggest that attention shift from the periphery to a centrally presented target can also generate the Simon eVect. For example, Notebaert and Soetens (2003) asked participants to respond to the color of a centrally presented visual stimulus while presenting a sound to one of their ears. A Simon eVect in relation to the peripheral sound was observed.

Hommel (1993a), on the other hand, proposed a referential-coding account in which spatial codes are generated in relation to a referential frame. Hommel and Lippa (1995) demonstrated that the face of a famous

In a typical visual search experiment, participants are presented with a display containing a number of items. On each trial, participants must determine whether or not a speciWc target has appeared in the dis-

and the following. The other three within-participant factors were target location, search set size, and Simon congruency. As illustrated in Fig. 1, the 4 ˙ 4 grids were divided into 4 regions, according to the eccentricity of the grid to the central Wxation. A target could appear in any of the four regions in a particular trial. The factor of set size had three levels, which had 6, 11 or 16 displayed items. Target location could be either congruent or incongruent with the side of the responding hand. There were two potential targets, one requiring a left hand response, and the other a right hand response. The correspondence between target and responding hand was counterbalanced across participants in all the search tasks.

In addition, in types 1 and 2 search, there were trials in which a target was presented without distractors (target-only trials). The target-only conditions were not included in the type 3 search because we wanted to balance the total number of trials across the three search types. The main purpose of including target-only trials was to examine whether the potential laterality eVect was caused by the distance between the target and center Wxation i.e., the stimulus eccentricity. If the Simon eVect was observed in all regions of the search grid, we could conclude that the absence of the Simon eVect in the inner columns for the target with distractors could not be simply attributed to the target eccentricity per se.

In types 1 and 2 search, targets and distractors were created by removing segments of a Wgure-of-eight, which was composed of short bars, like those used in digital clock displays. A number or letter was 0.65°in width and 1.15°in height. In both search types, the target was either “2” or “5”. Distractors were uniformly “8” in type 1 search (Fig. 2

The congruency eVect for targets with distractors

For trials with distractors, mean RTs and percentages of error responses were then calculated for experimental conditions and are reported in Table 1.

RTs from the 3 search types were entered into a 3 (search type) × 3 (set size) × 4 (target location) × 2 (congruency) analysis of variance (ANOVA), with search type as a between-participant factor, and set size, target location and congruency as three within-participant factors. The main eVect of search type was signiWcant, $F(2, 43) = 278.94$, $P < 0.001$, with RTs fast-

location. These quintile data were entered into a 3 (search type) · 4 (location) · 2 (congruency) · 5 (quintile) ANOVA.

Not surprisingly, the main eVect of congruency was signiWcant, $F(1, 45) = 15.51$, $P < 0.001$, so the main eVect of quintile, $F(4, 180) = 1106.12$,

would predict that there should be equal Simon eVects for the inner columns (at least location 1) and outer columns, and for targets with or without accompanying distractors. This prediction was clearly refuted by the Wndings of this study.

On the other hand, the laterality of the Simon eVect is

account assumes that the absence of Simon eVects in inner columns is not due to the averaging of attention shifts over diVerent directions, but due to the ineYciency of the Wxation as a reference frame when there are multiple items presented in a search array. Compared with the display in which there are only a Wxation and a target, the Wxation in a crowded display with multiple items is perceptually less salient and its function as a spatial reference point may be reduced. This reduction has less inXuence on localizing the target appearing at the leftmost or rightmost periphery than on localizing the target near Wxation, because a leftmost target can use other items (distractors) as references to compensate for the reduction of the function of the Wxation. An inner target, on the other hand, cannot use this compensation mechanism because other items can be both on the left and on the right of the target, and no reliable references can be established.

In experiment 2, we still presented the Wxation in a crowed display but increased the possibility of the target capturing attention directly, i.e., the search eYciency in Wnding the target. According to the attention shift account of the Simon eVect, this pop-out target will cause the attentional focus to shift directly from Wxation to the target and a spatial code is generated automatically. Thus the Simon eVect should not be aVected by where the target appears. According to the referential coding account, however, the crowded display reduces the function of the Wxation as reference and this reduction should be invariant with respect to the perceptual saliency of the target. Thus the absence of the Simon eVect in inner columns should also be observed for the pop-out target.

Methods

Participants

Sixteen undergraduate students from Peking University participated in this experiment. None of them had been tested for experiment 1. As is in experiment 1, all participants were right handed, with normal or corrected-to-normal vision. All gave their informed con-

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out and captures attention directly, the laterality of the Simon eVect should not emerge. Indeed we observed equal Simon eVects at diVerent locations for the target-alone conditions in Experiment 1 and for the pop-out search in experiment 2.

Our results and arguments are consistent not only with many previous data concerning the Simon eVect when an isolated target is presented (see Lu and Proctor 1995 for a review), but also with a recent study which also used a visual search task (Ward et al. 2005) and showed the role of attention in generating and suppressing task-irrelevant spatial codes. In Ward et al's study, the search array consisted of two columns, one on the left and one on the right side of Wxation, and with an equal number of items in each column. Participants were asked to make speeded left or right key-presses to the color of a target letter O that appeared among varying numbers of distractor Qs. In their experiment 1, the time of target onset was separated from the time of target selection by using a diYcult search task with a variable number of distractors. Although reaction times increased as a function of the number of distractors, the Simon eVects were similar for both small and large set sizes, as in the present study. Thus, regardless of how long a target was on the screen, there was no suppression of involuntary response codes before the target was found and selected. Suppression of involuntary spatial response activation is not tied to object onset, but to the time of target selection. In Ward et al.'s experiment 2, the color information needed to determine response only appeared after a variable delay; however, participants could still select the target object based on its form. It was found that with delays long enough, target selection could occur before a response could be made and the Simon eVect was reduced as the delay between target selection and the availability of relevant response information increased. Suppression of irrelevant spatial response activation begins only after the target is attended.

Hommel (1994) proposed that the magnitude of the Simon eVect depends on stimulus complexity. In his experiment, participants were presented with two

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