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Stimulus representation underlying orthogonal stimulus-response compatibility effect

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When a stimulus set is vertically, and a response set is horizontally arranged, an up-right/down-left mapping has an advantage over the opposite mapping (orthogonal SRC effect). According to the categorical coding hypothesis, orthogonal SRC effect would appear only when the categorical spatial representation is used. The extreme point hypothesis assumes that the salient and non-salient sides are the most extreme points in each direction and predicts that orthogonal SRC effect would be obtained only with the stimuli set at the extreme points. The direct correspondence hypothesis assumes that down-to-up corresponds to left-to-right directly in mental representation. We tested these hypotheses in the experiments with four vertically arranged stimuli (two above and two below) and two horizontally arranged responses (one in each side). We obtained the orthogonal SRC effect not affected by the stimulus distance when we facilitated the categorical coding by grouping of the stimuli in each side. However, the orthogonal SRC effect disappeared when four stimuli separated by equal spaces. The orthogonal SRC effect appeared only when the stimuli were coded categorically. The categorical coding hypothesis was supported. Orthogonal SRC effect comes from the salient-features-based correspondence restricted to the categorical spatial representation.

Keywords: stimulus-response compatibility, orthogonal SRC, saliency, categorical coding, spatial representation.

Introduction

Performance is better when the stimulus and response locations correspond than when they do not. This is called a stimulus-response compatibility (SRC) effect. In this case, S-R translation is based on the stimulus and response codes, and reaction time is shorter when the codes correspond (e.g., Umilta & Nicoletti, 1990). However, SRC effects also occur when stimulus and response arrays are orthogonal, and there is no spatial correspondence between stimuli and responses. When a stimulus set is vertically, and a response set is horizontally arranged, an up-right/down-left S-R mapping has an advantage over the opposite mapping. This is termed an orthogonal SRC effect (Cho & Proctor, 2003).

There are three hypotheses that explain the orthogonal SRC effects, two based on salient-features coding, and one assumes the direct correspondence between the vertical and the horizontal representations. The formers are the categorical coding hypothesis (Kleinsorge, 1999) and the extreme point hypothesis, and the latter is the direct correspondence hypothesis (see Table 1).

According to the salient-features coding principle (Weeks & Proctor, 1990), S-R translation is more efficient when the S-R mapping maintains the structural correspondence of the salient features between the stimulus and response sets. In vertical dimension, “above” is more salient than “below” (Chase & Clark, 1971). In horizontal dimension, “right” is more salient than “left” for right-handers (Olson & Laxar, 1973). The categorical coding hypothesis and the extreme point hypothesis are different in terms of the spatial stimulus representations they assume. Kosslyn (1994) argued that there are two types of spatial representations, categorical and coordinate. The categorical

Table 1. Type of the correspondence and the spatial representation in each hypothesis

Hypothesis	Correspondence	Representation
Categorical coding	Salient-features	Categorical
Extreme point	Salient-features	Coordinate
Direct correspondence	Direct	Coordinate

representation specifies the general categorical relation between an object position and a referent position or between object positions, without intermediate value (e.g., right-left, up-down, and in front-back). On the other hand, the coordinate spatial representation specifies the metric spatial relations, such as precise distance, size, and orientation. According to the categorical coding hypothesis, inequality of the saliency is the property of the categorical spatial representation, and orthogonal SRC effect emerges only when the categorical coding of the stimuli was done. In contrast, the extreme point hypothesis assumes that the salient side and the non-salient side are the most extreme points of both directions. Because the categorical representation cannot distinguish the stimuli in one side, this hypothesis assumes the coordinate spatial representation as the stimulus representation.

The direct correspondence hypothesis assumes the direct correspondence between the vertical and the horizontal spatial representations. According to this hypothesis, down-to-up corresponds to left-to-right in mental representation. This hypothesis can be said to assume the coordinate spatial representation as the stimulus representation.

In this study, we investigated the property of the stimulus representation underlying orthogonal SRC effect. We tested these three hypotheses with four stimuli (two above and two below) and two responses (one in each side). In

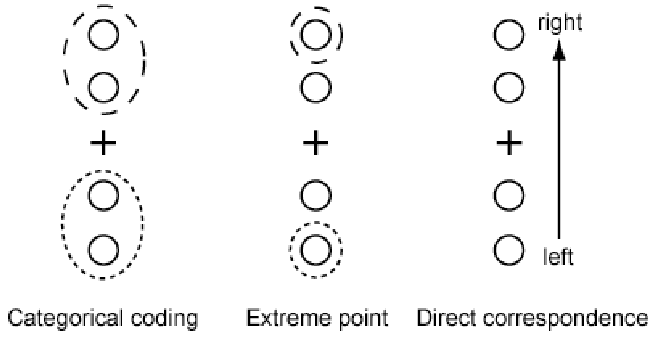

Figure 1. Stimulus representation in each hypothesis. Coarsely dashed circle = salient side; finely dashed circle = non-salient side.

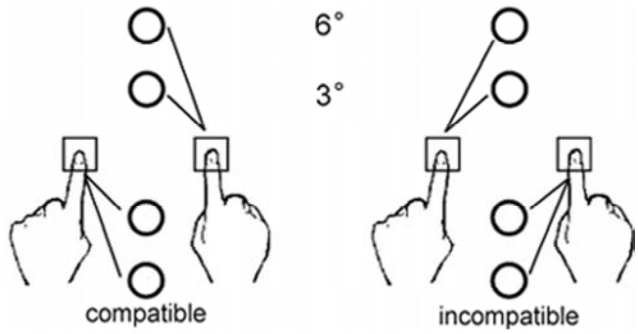

Figure 2. Experimental condition and the S-R arrangement of Experiment 1.

Experiment 1, the far stimuli were set at the locations of approximately 6° from the fixation, and the distance between the near stimuli was twice as long as the distance between the near stimulus and the far stimulus in each side. In this situation, the use of the categorical spatial representation is facilitated. In Experiment 2, the far stimuli were set at the location of approximately 9°, and the four stimuli separated by equal spaces. In this situation, the use of the coordinate spatial representation is facilitated. In these S-R arrangements, each hypothesis makes different prediction. The representations of the stimuli in three hypotheses were depicted in Figure 1.

The categorical coding hypothesis predicts that orthogonal SRC effect would be obtained only when the categorical spatial representation is used, in other words, only in Experiment 1. And this hypothesis predicts that the orthogonal SRC effect would not be affected by stimulus distance because the categorical representation does not distinguish the stimuli within the same side (or category). The extreme point hypothesis predicts that orthogonal SRC effect would be obtained only with far stimuli, because there is inequality of the saliency between the far stimuli but not between the near stimuli. And the orthogonal SRC effect with far stimuli may be more pronounced in Experiment 2. The direct correspondence hypothesis predicts that larger orthogonal SRC effect would be obtained with far stimuli than with near stimuli, because far stimuli are coded more “right” and more “left” than near stimuli, and this difference may be larger in Experiment 2 than in Experiment 1.

Experiment 1

In Experiment 1, the distance between the near stimuli was twice as long as the distance between the near stimulus and the far stimulus in the same side (Figure 2). By doing so, we facilitate the use of the categorical spatial representation by grouping of the stimuli in each side by the factor of proximity. The categorical coding hypothesis predicts the appearance of orthogonal SRC effect not affected by stimulus distance. The extreme point hypothesis predicts the appearance of orthogonal SRC effect only with far stimuli. The direct correspondence hypothesis predicts the appearance of larger orthogonal SRC effect with far stimuli than with near stimuli.

Method

Participants. Sixteen right-handers (8 males and 8 females), aged between 18 and 38 years (mean age = 23.3 years) participated. All had normal or corrected-to-normal vision. They were naive to the purpose of the experiment.

Apparatus and Stimuli. Stimulus presentation and data acquisition were controlled by an AV-tachistoscope system (Iwatsu ISEL IS-703). Response times were measured by means of a digital millisecond timer from the onset of target stimuli. Response time and the key pressed in each trial were recorded. Stimuli were a green LED as a fixation and 4 red LEDs (2 above and 2below the fixation) as targets. Target stimuli were set above and below the fixation at two different distances (near: approximately 3° of visual angle, far: approximately 6°) in each direction (Figure 2). Viewing distance was approximately 38cm. Response apparatus were the right and left key boxes, and were set in the same depth plane and at the same height of the fixation.

Task and Procedure. The task was to press the left or right key as quickly and accurately as possible in response to the stimuli above or below the fixation according to the current mapping regardless of the stimulus distance. Each experimental session consisted of 4blocks, and each block consisted of 120 trials. Half of the participants engaged in the compatible [up-right/down-left] mapping condition in the first two blocks and in the incompatible [up-left/down-right] mapping condition in the last two blocks. For the other half of the participants, the reverse order of the two mapping conditions was assigned. Before the first and the third blocks, participants engaged in the practice blocks consisted of 20 trials. Each trial began with the display of the fixation LED for 1000 ms. Following a delay of 100 ms, the target LED appeared above or below it until response was made. Inter-trial interval was 2000 ms. A 500 Hz tonal feedback for 100 ms was given for the errors.

Design. Mapping (compatible [up-right/down-left], incompatible [up-left/down-right]) x Stimulus Distance (near, far). Both were within-participant factors.

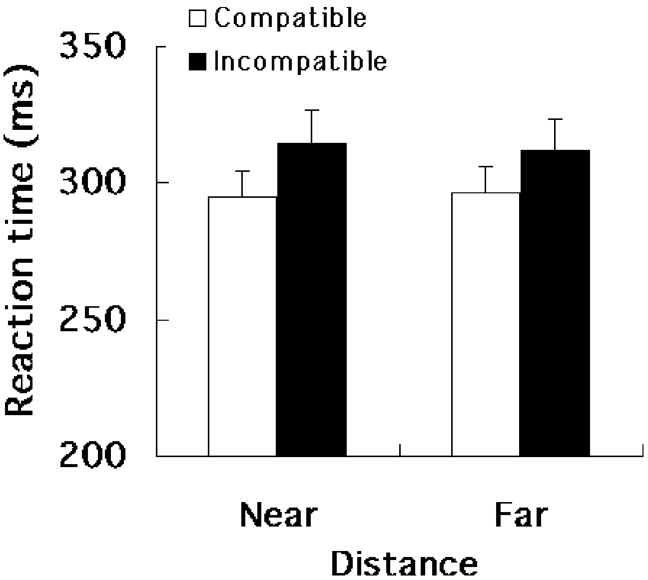

Figure 3. RTs for compatible and incompatible conditions in each stimulus distance condition in Experiment 1.

Results

Reaction times (RTs) shorter than 125 ms and longer than 1,250 ms were excluded from data (0.2% of the trials). Analysis of variance (ANOVA) was conducted on the mean RT for correct responses and error rate (ER) data, with mapping and stimulus distance as within-participant factors.

Reaction time. Figure 3 shows mean correct RTs for each condition. The main effect of mapping was significant, $F\,(1, 15) = 4.84$, $p < 0.05$. RTs for the incompatible mapping condition ($M = 313$ ms) were slower than those for the compatible mapping condition ($M = 296$ ms). The main effect of stimulus distance was not significant, $F\,(1, 15) < 1$. The two-way interaction between mapping and stimulus distance also was not significant, $F\,(1, 15) = 1.98$, $p = 0.18$. As can be seen in Figure 3, the orthogonal SRC effect didn't vary with stimulus distance.

Error rate. Overall ER was 2.3%. A main effect of mapping was significant, $F\,(1, 15) = 7.86$, $p < 0.05$. ER was higher for the incompatible mapping condition (2.9%) than for the compatible mapping condition (1.7%). The main effect of stimulus distance was not significant, $F\,(1, 15) < 1$. The two-way interaction between mapping and stimulus distance also was not significant, $F\,(1, 15) < 1$. The orthogonal SRC effect didn't vary with stimulus distance.

Discussion

With both RT and ER data, significant orthogonal SRC effects were obtained, and these effects were not affected by stimulus distance. These results were consistent with the prediction of the categorical coding hypothesis. The categorical coding hypothesis was supported.

The categorical coding hypothesis predicts that when the coordinate spatial representation is used, orthogonal SRC effect would not be obtained. However, there is another possibility. When the coordinate spatial representation is used, orthogonal SRC effect based on the coordinate spatial representation may emerges. In Experiment 2, we explored this possibility by facilitating the use of the coordinate spatial representation.

Experiment 2

In Experiment 2, the four stimuli separated by equal spaces. In this case, no grouping of the stimuli in each side would occur. Stimulus arrangement rather than the task plays an important role to select the type of the spatial representation used (Banich & Federmeier, 1999). So in this S-R arrangement, the use of the coordinate spatial representation would be facilitated. The categorical coding hypothesis predicts no appearance of orthogonal SRC effect regardless of the stimulus distance. The extreme point hypothesis predicts the appearance of orthogonal SRC effect only with far stimuli. The direct correspondence hypothesis predicts the appearance of larger orthogonal SRC effect with far stimuli than with near stimuli.

Method

Twelve right-handers (7 males and 5 females), aged between 20 and 24 years (mean age = 22.4 years) participated. One participant was replaced because of the high (over 10%) error rate. The information of the participants after the replacement was shown above. The stimulus distance of far stimuli was approximately 9°. Except for these points, the method of Experiment 2 was the same as that of Experiment 1.

Results

Of the trials, 0.2% were removed from analysis by using the exclusion criteria. ANOVA was conducted on the mean RT for correct responses and ER data, with mapping and stimulus distance as within-participant factors.

Reaction time. Figure 4 shows mean correct RTs for each condition. Neither the main effect of mapping nor that of stimulus distance was significant, Fs $(1, 11) < 1$. Their interaction also was not significant, $F\,(1, 11) < 1$. RTs for the incompatible mapping condition ($M = 302$ ms) were comparable to those for the compatible mapping condition ($M = 304$ ms). As can be seen in Figure 4, orthogonal SRC effect was not obtained in both stimulus distance conditions.

Error rate. Overall ER was 2.0%. Neither the main effect of mapping nor that of stimulus distance was significant, Fs $(1, 11) < 1$. Their interaction also was not significant, $F\,(1, 11) = 1.98$, $p = 0.19$. ER of the incompatible mapping condition (2.0%) was comparable to that of the compatible mapping condition (2.1%). Orthogonal SRC effect was not obtained in both stimulus distance conditions.

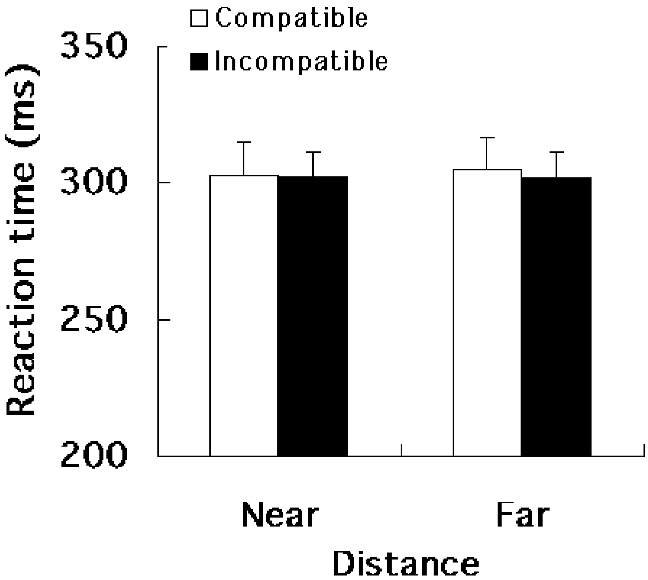

Figure 4. RTs for compatible and incompatible conditions in each stimulus distance condition in Experiment 2.

Discussion

With both RT and ER data, orthogonal SRC effect was not obtained regardless of the stimulus distance. The results of Experiment 2 did not support the extreme point hypothesis or the direct correspondence hypothesis.

General Discussion

In this study, we conducted two experiments with four stimuli (two above and two below) and two responses (one in each side) to investigate the property of the spatial stimulus representation underlying orthogonal SRC effect. The categorical coding hypothesis, the extreme point hypothesis, and the direct correspondence hypothesis were depicted and tested.

In Experiment 1, we facilitated the use of the categorical spatial representation by grouping the stimuli in each side. As a result, the orthogonal SRC effects not affected by the stimulus distance were obtained with RT and ER data. In Experiment 2, we facilitated the use of the coordinate spatial representation. As a result, no orthogonal SRC effects were obtained. These supported the categorical coding hypothesis. As for the representation underlying orthogonal SRC effect, there is no direct correspondence between the vertical and the horizontal representations. Orthogonal SRC effect comes from the structural correspondence of the salient features between the stimulus and response sets. And inequality of the saliency in each dimension was restricted to the categorical spatial representation.

Conclusion

The categorical coding hypothesis was supported. Orthogonal SRC effect emerges only when the locations of the stimuli were coded based on the categorical spatial representation.

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