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# Spatial S–R compatibility: Positional instruction vs. compatibility instruction

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**Abstract**

Subjects had to perform both in a classical spatial compatibility experiment where they were instructed to press a right or left button to a right or left stimulus ('positional instruction'), and in a variant, where they had to give a spatially compatible or incompatible response depending on the color of the stimulus ('compatibility instruction'). The result shows the normal advantage of compatible over incompatible responses for the experiment with positional instruction whereas the spatial compatibility effect completely disappeared for the experiment with compatibility instruction. This supports a translation hypothesis and speaks against an automatic activation hypothesis of spatial stimulus–response compatibility.

## 1. Introduction

By spatial 'stimulus–response compatibility' (SRC) one denotes that responses are quicker when stimulus and response side correspond than when they do not. Reaction times are for example faster when the right hand responds to a light in the right field than when it responds to a light in the left field and vice versa. The psychological research on spatial SRC goes back to Fitts and Seeger (1953). Later work on SRC was concerned with analysing and separating the effects of con-

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founding variables such as responding hand and response position (Simon et al., 1970a; Wallace, 1971), response position and response keys (Riggio et al., 1986), and apparent stimulus location and sensory organ stimulated (Craft and Simon, 1970; Simon et al., 1971; Simon et al., 1970b). The main result of these studies is that for spatial SRC basically the congruence between perceived stimulus position and the position of the response keys is essential (for a review see Proctor and Reeve, 1990).

The discovery that S–R compatibility effects are also obtained in experiments where the position of the stimulus is not relevant for the response, goes back to Simon (Simon and Rudell, 1967). This variant of the SRC effect is therefore called 'Simon effect' (due to Hedge and Marsh, 1975). It is of great practical relevance not only for man–machine interaction (display control arrangement), but also for all kind of research with lateral stimulation and lateral response. For example, divided visual field studies of cerebral lateralization may be affected by additional SRC effects (Heister and Schroeder-Heister, 1985, 1987), since the asymmetry of reaction times can express neural pathway effects, hemisphere effects and SRC effects at the same time. Also in electrophysiological or information processing studies with lateral stimulation the variable under consideration may be confounded with SRC.

One usually accepts that SRC effects are generated in the response selection stage rather than in the stimulus encoding stage (Sanders, 1980), but there is also some evidence for the importance of the stimulus side, e.g., the dependence of the size of the effect on the distance of stimuli (Ehrenstein et al., 1989; Gunia, 1987; Simon et al., 1971). The reasons for changes in size of the SRC effect have been investigated only sporadically up to now.

In a recent study of SRC Hasbroucq and Guiard (1991) have claimed that the Simon effect is not a distinct phenomenon by itself but a variant of the Stroop effect and therefore due to the encoding of stimulus features. They argue that it is not the S–R relationship between stimulus position and response position which is effective, but the S–S relationship between actual stimulus position and a positional cue associated with a stimulus feature (e.g., its color) by means of instruction. This approach has been challenged by Proctor et al. (1992), whose experiments using the precuing paradigm support again the response selection stage as responsible for the Simon effect. However, even by Hasbroucq and Guiard (1991), the independent character of spatial compatibility with *relevant* stimulus location, where the instruction immediately relates the position of the stimulus and the position of the response, has never been questioned.

Different explanations have been proposed for the spatial SRC effect. Simon (1969) assumed a 'natural tendency to react toward the source of stimulation'. Later he abandoned this position (which implies that the S–R effect is a kind of orienting reflex), since there was no habituation with practice (Simon, 1970; see also Faber et al., 1986). Eventually, Simon did not even claim that this tendency is 'natural'; he took into account that it might be learned.

Another explanation for the SRC effect is the so-called 'coding hypothesis' (Wallace, 1971). It says that SRC effects are due to a comparison of spatial codes for stimulus and response positions. Longer reaction times result when these codes do not coincide. This position resembles Fitts and Seeger's (1953) theory which presumes that SRC is related to the rate of information transfer in reaction tasks.

Although Wallace's original formulation of the coding hypothesis was rather vague, many other authors used it to explain their experimental results (e.g., Nicoletti et al., 1982; Nicoletti and Umiltà, 1984; Umiltà and Liotti, 1987; for an overview see Umiltà and Nicoletti, 1992). Also for the results of Heister et al. (1986), it was the best hypothesis available. In a study with unimanual two-finger choice reactions an SRC effect was obtained for two fingers of one hand held laterally, independent of whether hands were held in prone or in supine position.

In another study with irrelevant stimulus location (Heister et al., 1987), a two-fold SRC effect was found: When the responding hand was kept fixed throughout an experimental session, an SRC effect for hands was obtained as well as one for the responding fingers of one hand. That means, an SRC effect may occur even when the task requires no choice between hands (the choice was between fingers of one hand). Further research (for review see Heister et al., 1990) showed that even subordinate factors such as, e.g., the anatomical distinction of the arms as left or right may be influential in special cases such as orthogonal stimulus–response relations or responses with tilted head. Therefore, a hierarchical model of spatial SRC was suggested (Heister et al., 1990).

The present study is concerned with the precise meaning of the coding hypothesis as an explanation of SRC with relevant stimulus location. We distinguish two variants, one due to Umiltà and Nicoletti (1990, 1992) and the other one due to Kornblum et al. (1990). Umiltà and Nicoletti propose the following processing model: Upon encoding of the stimulus a spatial code (normally right/left) is formed. In the case of a compatible reaction, this code can be used to immediately trigger the response, whereas in the case of an incompatible reaction, this code has to be translated into an inverse code (normally right/left into left/right), from which then the response is initiated. Thus in a task requiring an incompatible reaction, an additional translation step is involved which prolongs processing and generates the SRC effect. Umiltà and Nicoletti (1992) call their approach the *translation hypothesis* of spatial SRC.

According to Kornblum et al. (1990), the formation of the stimulus code is followed by two independent processes: activation and confirmation. The activation function is automatic and triggers the compatible response if it is not inhibited by the confirmation function. Such inhibition happens in the case of an incompatible response. So spatial SRC is due to the difference between facilitation and inhibition of an automatically activated response in the presence of dimensional overlap between stimuli and responses. We call this approach the *automatic activation* hypothesis of spatial SRC. [1]

[1] We follow Umiltà and Nicoletti (1992) in considering Kornblum et al.'s approach to be a variant of the coding hypothesis since forming a stimulus code precedes and is essential for the initiation of the activation and confirmation processes, which are specific for that model.

In order to distinguish between the two hypotheses, we used a design where dimensional overlap between stimuli and responses was present, but where a translation step was needed for both compatible and incompatible responses. In our experiment, we presented a red or green stimulus in the right or left visual field and asked subjects to respond spatially compatibly (right key to right stimulus, left key to left stimulus) if the stimulus has a certain color (e.g., red), and to respond incompatibly (left key to right stimulus, right key to left stimulus), if the stimulus has the other color (e.g., green). We speak of a *compatibility instruction* as opposed to the usual *positional instruction*, since the instruction attaches a certain S–R mapping rather than a fixed position to a stimulus feature. In this way, we made the relevant S–R mapping itself dependent on the stimulus. [2] Since there was no fixed spatial S–R relationship for a whole block of trials, the right/left stimulus code could not even for compatible reactions be used to trigger the response directly. Rather, by processing the color of the stimulus and deciding about the correct mapping, the spatial stimulus code had to be translated into a code useful for initiating the correct response *in any case*. So according to the *translation hypothesis*, the SRC effect should disappear under the compatibility instruction, since, with respect to translating the stimulus code into the response code, the asymmetry between compatible and incompatible reactions was eliminated. According to the *automatic activation hypothesis*, however, the SRC effect should remain stable even with compatibility instruction, since the activation process based on the spatial stimulus code should be independent of the instruction ('the congruent response is automatically activated regardless of the mapping in the task', Kornblum et al., 1990, p. 262).

## 2. Method

### 2.1. Subjects

Eight male subjects, aged between 19 and 27 years, all righthanded students according to a handedness questionnaire took part in the two experimental sessions. They received 20 DM for their participation. All were naive with respect to the purpose of the study, and had normal vision and color vision according to self-report.

### 2.2. Apparatus and procedure

The stimuli were a green and a red square of 1.2° visual angle, presented 8° to the left or the right of a central black fixation cross on a VGA color monitor.

[2] To some extent, this also holds for Duncan's (1976) paradigm. Although in his experiments for each stimulus a certain response is fixed throughout, by grouping stimuli he can make sense of the idea of 'task-dependent mapping' which is related to what we are proposing. Apart from these conceptual similarities, his results are difficult to compare with ours since his design differs too strongly from ours.

Responses were given by two normal response buttons. Stimulus presentation and response recording was controlled by the software ERTS ('Experimental Run Time System', by J. Beringer). Subjects participated in two experimental conditions on two different days. Half of them started with Condition 1 and the other half with Condition 2.

Experimental Condition 1 (positional instruction) was a standard spatial compatibility paradigm, in which subjects had to ignore the color of the stimulus and just had to react to its position. In half of the trials subjects were instructed to press the right button in response to the right stimulus and the left button in response to the left stimulus (compatible subcondition); in the other half, vice versa (incompatible subcondition). Which half was the first one, was balanced between subjects. At the beginning of the session eight separate demonstration trials were presented. Each of the two subconditions consisted of a block of 24 practice trials, followed by three blocks of 64 experimental trials each.

In experimental Condition 2 (compatibility instruction) for half of the subjects the instruction was to give a spatially compatible response to a red stimulus, and a spatially incompatible response to a green one; for the other half of the subjects, the instruction was reversed (green: compatible, red: incompatible). As in experimental Condition 1, the session started with 8 demonstration trials followed by a block of 24 practice trials. Then 6 blocks of 64 experimental trials each followed.

A trial started with the presentation of a fixation cross in the middle of the screen. After 1400 msec, in addition a short warning tone was presented for 100 msec. After an interval of randomly varied duration (between 400 and 800 msec), the fixation cross disappeared and (at the same time) the stimulus was presented for 100 msec. A cutoff for response times was set at 1200 msec for experimental Condition 1 and at 1500 msec for the more complicated task in experimental Condition 2. There were 1.0% errors (incorrect or no response before cutoff) in Condition 1 and 2.5% in Condition 2. After a break of 2000 msec the next trial started.

The subject sat in a dimly lit room with his head in a chinrest and both arms resting on the table. Two response buttons were fixed on the table, one 15 cm to the right and one 15 cm to the left of the midline. In the first session, subjects received a written instruction stressing the importance of fixation and asking them not to move their eyes after the warning tone and to react as quickly and as correctly as possible.

## 3. Results

Mean medians of the correct reaction times were subjected to an analysis of variance with three within-subject factors: Experimental condition (positional instruction vs. compatibility instruction), visual field (left/right), and responding hand (left/right). (See Table 1.)

The analysis of response times showed a significant main effect for experimental condition ($F(1, 7) = 110.42$, $p < 0.001$), indicating that reactions were much slower

Table 1
Means of the median reaction times (in msec) and standard deviations (in parentheses)

| | Left field | | Right field | |
|---|---|---|---|---|
| | Left hand | Right hand | Left hand | Right hand |
| Experimental Condition 1 (positional instruction) | 312<br>(39) | 372<br>(45) | 369<br>(48) | 308<br>(28) |
| Experimental Condition 2 (compatibility instruction) | 540<br>(91) | 518<br>(46) | 528<br>(70) | 502<br>(63) |

in Condition 2 (ca. 181 msec). The main effect for field of stimulation just failed to reach the 5% level of significance ($F(1, 7) = 5.17$, $p = 0.056$); overall responses were 9 msec faster with right field than with left field stimulation. (See Fig. 1.)

The interaction between field of stimulation and responding hand, expressing the spatial SRC effect, was highly significant ($F(1, 7) = 18.85$, $p < 0.01$). Furthermore, the three-way interaction between experimental condition, field, and responding hand was significant ($F(1, 7) = 10.97$, $p = 0.01$). It shows that there was

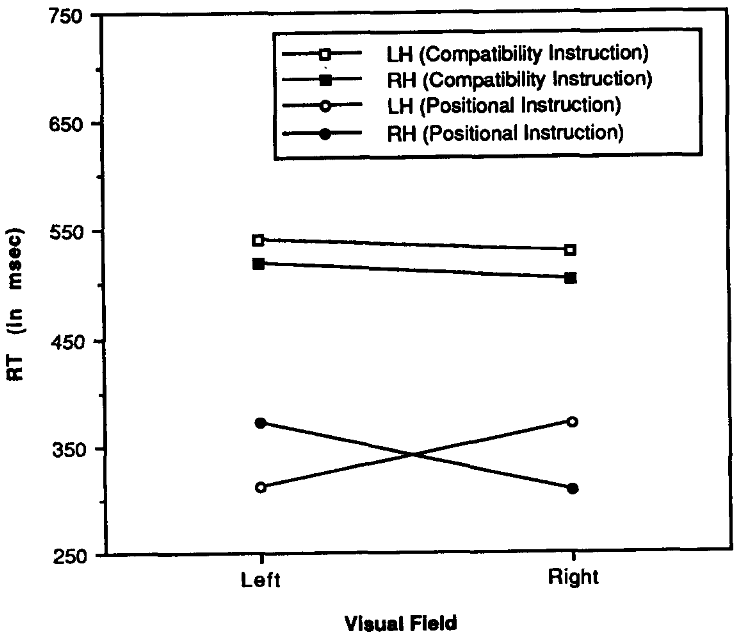


Fig. 1. Means of the median reaction times for left (LH) and right (RH) hands responding to stimuli in the left and right visual field in experimental Condition 1 (positional instruction, circles) and experimental Condition 2 (compatibility instruction, squares).

an SRC effect only for the normal S–R condition with positional instruction (about 60 msec) and no SRC effect for the condition with compatibility instruction.

A separate analysis of variance for experimental Condition 1 showed a highly significant field × hand interaction ($F(1, 7) = 66.11$, $p < 0.001$) while the analysis for experimental Condition 2 did not ($F(1, 7) = 0.03$, $p > 0.5$).

## 4. Discussion

This study compares the classical spatial SRC paradigm, in which the spatial S–R relationship is fixed by the usual *positional instruction* with a paradigm in which the S–R relationship is a trial-by-trial variable. This was achieved by means of a *compatibility instruction* based on a second feature of the stimulus: The stimulus color indicated whether the subject had to respond spatially compatibly or spatially incompatibly to the stimulus position. The aim of this design was to introduce an explicit translation step between the forming of stimulus and response codes even in the case of spatially compatible reactions. When the instruction of whether to react compatibly or not is not given in advance (e.g., for a whole block of trials), the spatial stimulus code cannot, in the compatible case, be used immediately as the code for response selection. Since the instruction of how to react is given together with the stimulus, there has to be a translation step in any case: Both in the compatible and incompatible case the spatial stimulus code has to be interpreted and transformed in the light of the stimulus-dependent task. Even if a compatible reaction is required, this explicit interpretation step is needed. Thus, according to the *translation hypothesis* (Umiltà and Nicoletti, 1992) of spatial S–R compatibility, the SRC effect should disappear in this condition, since the advantage of compatible over incompatible reactions in the usual positional instruction (stimulus code can immediately trigger the response) was eliminated.

Our result strongly confirms this hypothesis: As expected, for the normal spatial SRC paradigm with positional instruction and irrelevant stimulus color a highly significant SRC effect was obtained: Spatially compatible responses were about 60 msec faster than incompatible ones. This effect disappeared for the condition with compatibility instruction (see Fig. 1). This disappearance of the SRC effect is demonstrated by the significant three-way interaction between experimental condition, stimulus position and response position.

Our result disconfirms the *automatic activation hypothesis* (Kornblum et al., 1990), according to which the process leading to response selection is initiated independently of the task required, so that an SRC effect had to be expected for both experimental conditions. For the condition with the usual positional instruction, this hypothesis makes the same prediction as the translation hypothesis, since it assumes that in the compatible case the stimulus code activates the response without interference whereas in the incompatible case an additional step is required: the inhibition of the activation process by a parallel process of confirmation. The fundamental difference between the hypotheses is that according to the automatic activation hypothesis this activation process is spontaneous, just due to dimensional overlap between stimuli and responses, and therefore independent of instruction, whereas according to the translation hypothesis it depends on the global positional instruction: Only when it is known in advance that a compatible response is required, no recoding (translation) of the stimulus code is necessary to select the appropriate response.

A simpler explanation for the disappearance of the SRC effect under the compatibility instruction would be that, because of the more complicated decision, the response time slowed down so much that the spatial compatibility effect had already faded away until a decision was made. However, we doubt that such an explanation, which just refers to the time needed for a complicated decision, is applicable, since in other complicated tasks involving lexical decision we were able to demonstrate SRC effects with overall response times even longer than in the present case (Heister and Schroeder-Heister, 1987; Heister et al., 1990). Even if such an explanation were possible, it would speak against an automatic activation hypothesis, which would predict an advantage of compatible over incompatible responses independently of how much time a decision might take.

The disappearance of SRC in Simon et al.'s (1976) study with irrelevant stimulus location, where subjects were instructed to delay the execution of their response until an auditory go signal was presented (150, 250 or 350 msec after stimulus presentation), does not contradict our findings. One cannot conclude that in any case the SRC effect disappears after about 300 msec but simply that the SRC effect is no longer present, if one inhibits the reaction until the decision process (even in the incompatible case) is completed. This might be for example after 800 msec with complicated decisions.

Of course, there remains the theoretical possibility that the two experimental conditions do not differentiate between two competing explanations of basically the same process, but that different processes are responsible for the different results. One might argue that in the compatibility instruction the S–R relation is an intentional factor for the subjects. Subjects are instructed to react compatibly or incompatibly depending on the trial, while in other experiments in the SRC area they intentionally process only simple (non-relational) features of the stimulus and the response. The result would then show that, when the compatibility relation is intentionally processed, the SRC effect disappears, while in the classical spatial compatibility paradigm subjects unintentionally (and in most cases unconsciously), exhibit the advantage of compatible over incompatible responses. In this way, the present comparison may be seen as confirming some automaticity notion of spatial SRC effects for the normal case, but at the same time as restricting it to that case. One might perhaps speak of 'task-dependent' automaticity. However, then the translation hypothesis has at least the advantage of a wider range of application, since it covers both the normal case and the case of an intentional processing of the compatibility relation.

Our investigation intended to elucidate the coding hypothesis of spatial SRC with relevant stimulus location. The coding hypothesis has been used to explain the Simon effect as well. If the Simon effect is a phenomenon of SRC and nothing completely different, our results and theoretical conclusions should carry over to that domain, too. This will be investigated in further research.

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