Psychol Res (1993) 55: 270–279

Psychological Research
Psychologische Forschung

Inverting the Simon effect by intention

Determinants of direction and extent of effects of irrelevant spatial information

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Received August 13, 1992/Accepted March 8, 1993

Summary. The Simon effect indicates that choice reactions can be performed more quickly if the response corresponds spatially to the stimulus – even when stimulus location is irrelevant to the task. Two experiments tested an *intentional* approach to the Simon effect that assigns a critical role to the cognitively represented action goal (i. e., the intended action effect). It was assumed that the direction of the Simon effect depends on stimulus-goal correspondence, that is, that responses are faster with spatial correspondence of stimulus and intended action effect. Experiment 1 confirmed that the direction of the Simon effect was determined by spatial correspondence of stimulus and intended action effect, the latter having been manipulated by different instructions. Experiment 2 indicated that effects of correspondences unrelated to the action goal (i. e., stimulus to hand location or to anatomical mapping of the hand), contributed additively to the resulting Simon effect. It is discussed how current approaches to the Simon effect can be elaborated to account for these results.

Introduction

The Simon effect is observed in reaction-time tasks in which the locations of stimuli and responses vary on a common spatial dimension. Suppose, for example, that high- and low-pitched tones (Simon & Small, 1969) or red and green lights (Hedge & Marsh, 1975) are presented randomly as imperative stimuli at a left-hand or at a right-hand location, and binary choices have to be made by pressing a left or a right response key. Even though stimulus location is completely irrelevant to this task, performance will be facilitated by spatial correspondence between stimulus and response; that is, responses will be faster when there is spatial correspondence between stimulus and response, and slower when there is correspondence between stimulus and alternative response.

Usually, studies of the Simon effect focus on the stimulus and try to explain how, why, or under which circumstances the stimulus is coded spatially, or why stimulus location cannot be ignored in a Simon task (e.g., Hasbroucq & Guiard, 1991; Hommel, 1993; Michaels, 1988; Nicoletti & Umiltà, 1989; Simon, 1969; Stoffer, 1991; Umiltà & Nicoletti, 1985). However, a further issue of considerable theoretical relevance that is commonly ignored is the meaning of the term *response*. Each response has various features and can be described, and possibly coded, in different ways. For example, even a simple key press requires a particular movement of a specific finger of a specific hand, which, in turn, is placed at a certain location. Pressing the key may also evoke a (spatially or temporally) more remote effect, which the actor or the experimenter may or may not consider important, such as a visual feedback event or an auditory key click. In the standard Simon task, all these features are localized at the same relative location and hence confounded. This raises the question: To what kind of response feature must a stimulus correspond in order to speed up a response?

Empirical evidence suggests that neither the anatomical mapping of the active effector nor the effector location is necessarily critical for response coding in the Simon task. Wallace (1971, 1972) has shown that the Simon effect does not depend on correspondence between stimulus and anatomical mapping of the active effector, but on correspondence between stimulus and hand or key location. His subjects performed a Simon task with either parallel or crossed hands. Like responses with parallel hands, responses with crossed hands were also speeded up by spatial correspondence between stimulus and response key (or hand).

Guiard (1983) has even demonstrated that effector location is not important when the locations of the active hand and the action goal differ. His subjects first placed their hands on a steering wheel in a 9:15 starting position, and then turned the wheel either to the right (clockwise) or to the left (anticlockwise). Therefore, each wheel rotation to the right (i.e., clockwise) required simultaneous movements of the right hand to the (bottom) left and of the left hand to the (top) right. Left or right rotation was signaled by a high- or low-pitched tone from one of two loudspeakers located to the left and right of the subject. As in a standard Simon task, reaction time (RT) was shorter when there was a correspondence between direction of rotation and loudspeaker location; thus demonstrating that response initiation is facilitated by spatial correspondence between the *intended* action effect (direction of wheel rotation) and the stimulus, regardless of the location of the hands or the direction in which they moved.

Riggio, Gawryszewski, and Umiltà (1986) reported similar results when trying to disentangle the effects of hand location and the location of the action goal in a spatial-compatibility task. Their subjects had to manipulate reaction keys with sticks that were either parallel or crossed. Responses were faster when there was a spatial correspondence between the stimulus and the location of the end of the stick, irrespective of the anatomical mapping or location of the active hand.

Finally, Merz, Kalveram, and Huber (1981) found effects of the spatial compatibility induced by the task context. Their subjects had to track a horizontally moving cursor with a second cursor that was moved to the left by pushing a knob to the right and vice versa. Actually, the knob was mounted to the bottom of a (covered) steering wheel, which was revealed to the experimental group, but not to a control group. It was hypothesized that wheel knowledge would induce spatial compatibility between knob and the cursor to be controlled, because the steering direction (defined as in car driving) was perfectly compatible with the movement of the cursor to be controlled. And, indeed, tracking performance was much better with wheel knowledge than without.

Altogether, these results permit an interesting hypothesis. The response feature that is critical for the Simon effect to occur is possibly not invariant, but dependent on the action intention – that is, on the cognitively represented action goal. An intention to act might refer to any feature of an action that can be discriminated, be it one of its more remote effects on the environment, the active effector's location, or its anatomical mapping. Which feature finally represents the action (i.e., defines the action goal) is assumed to be the subject's choice. Once a feature is chosen, it will represent the entire action in a categorical manner, and its relation to the stimulus (i.e., the coded stimulus location) will determine the direction of the Simon effect.

Guiard's steering-wheel study mentioned above (1983, Exp. 3), has provided some support for this *intentional* interpretation of the Simon effect. Subjects in a darkened room rotated the wheel with their hands starting from the 6:30 position; that is, a rotation to the right (clockwise) required both hands to be moved to the left, and vice versa. The expected Simon effect occurred in a group that received visual feedback on wheel rotation; however, subjects in a second group with no feedback behaved inconsistently: some exhibited a Simon effect, while others exhibited an equally strong, inverse effect. This indicates that some subjects benefitted from a correspondence between stimulus location and wheel direction, while others benefitted from the correspondence between stimulus location and the direction of hand movement. Guiard's post-hoc interpretation of these results was based on the assumption of two different response-coding strategies in the no-feedback group. He suggested that some subjects might have specified their action goals in terms of the direction of wheel rotation, resulting in faster responses when stimulus location and rotation direction corresponded. The other subjects might have specified their action goals in terms of hand movements, leading to faster responses when stimulus location corresponded to the direction of hand movement. Both Guiard's data and his interpretation fit an intentional approach and support the assumption that the direction of the Simon effect possibly does not depend on invariant features of the specific task, but on the subjective definition and, thus, the cognitive representation of the action goal.

The two experiments presented here were designed to test this assumption alongside further implications of an intentional approach to the Simon effect. Experiment 1 varied instructions systematically in an attempt to manipulate the subjects' intentions. This was aimed at determining whether the spatial relationship between stimulus and intended-action effect is actually the strongest determinant of the Simon effect. Experiment 2 performed orthogonal variations of different correspondence relations to determine whether non-goal-related response features also contribute to the effect.

Experiment 1

The first experiment took advantage of the possibility of describing an identical action in different ways. Imagine a key that is located to the left of a given reference and a light to the right that lights up each time the key is pressed down. In observing a person pressing the key, we would not know whether he or she intended to switch on the light, to press the key, or simply to exercise the fingers a little, because the same action can be performed for different reasons.

However, if we told a person to perform such an action, we could refer to only one of the possible goals in describing the same movement as either a light-switching or a key-pressing action. In the first case, we assume that a compliant actor would intend to switch on the light and, therefore, be likely to code the action as *right*, according to the location of the light, while, in the second case, his or her intention would refer to the key, so that the action would be coded as *left*. Our intentional hypothesis would then predict that the light-switching action (coded as *right*) would be initiated faster when signaled by a right-side stimulus, while the key-pressing action (coded as *left*) would be speeded up by presentation of the stimulus on the left side. In other words, an identical action should give rise to different kinds of effects of irrelevant stimulus location only by varying the way the task is described to the subjects.

In Experiment 1, all of the participants performed a Simon task with acoustic imperative stimuli. High- or low-pitched tones were presented randomly via either a left- or right-hand loudspeaker or simultaneously by both

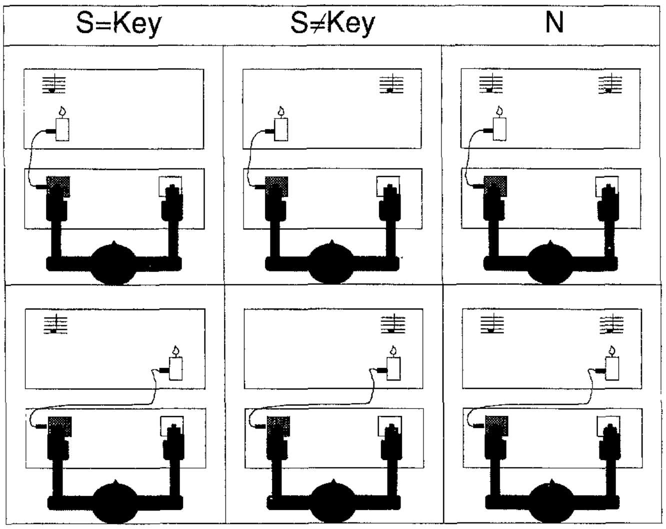

Fig. 1. Diagram of spatial relations in Experiment 1 between stimulus (symbolized by the note), anatomical mapping of active effector and positions of hand, key, and light (symbolized by the candle) for parallel mapping (left-hand key connected to left-hand light; see upper row) and inverse mapping (left-hand key connected to right-hand light; see lower row). Examples are given for left-hand responses only

speakers. Simultaneous presentation of tones[1] was chosen as a control condition, so that correspondence effects could be interpreted in terms of facilitation and interference. For all subjects, the mapping of responses to stimuli was identical. Low tones were responded to with a left key and high tones were responded to by pressing a right key. This yielded three correspondence conditions: the stimulus either did (S = Key) or did not (S ≠ Key) spatially correspond to the correct response key, or, with simultaneous tone presentation, it was neutral (N).

Each of the two response keys was connected to a red light located on the left- or right-hand side in front of the subject. A light went on when the key was pressed, staying on as long as the key was held down. Hence, the lighting up of the lights served as an additional action effect, apart from key press and finger movement. The first experimental manipulation concerned the mapping of lights to keys. In Group 1, each key was connected to the lights in parallel – that is, the right-hand key switched on the right-hand light, and the left key switched on the left light (parallel mapping: PM). In Groups 2 and 3, key-light mapping was inverted, with the right key switching on the left light, and the left-hand key switching on the right-hand light (inverse mapping: IM). Figure 1 shows the relations that result for the PM group (upper row) and the IM groups (lower row).

The second experimental manipulation concerned the instructions given to the subjects and, in particular, how the necessary actions and their goals were described. Subjects in Groups 1 and 2 received the instruction to "press the left-hand key" after hearing the low-pitched tone and to "press the right-hand key" in response to the high-pitched tone (key instruction: KI). In contrast to this, subjects in Group 3 were instructed to "produce the right-hand light" following the low-pitched tone and to "produce the left-hand light" in response to the high-pitched tone (light instruction: LI). Therefore, although the same assignment of response key to pitch applied to all groups, subjects in Groups 1 and 2 were assumed to have the goal of pressing keys, while subjects in Group 3, instead, should have defined their action goal in terms of producing lights. (This, of course, could not be distinguished by an external observer.)

From an intentional approach, the crucial test is between the two groups that received different instructions under identical light-key mapping conditions (Groups 2 and 3); whereas a comparison of groups that received the same instruction under different mapping conditions (Groups 1 and 2) speaks to the question whether the mapping manipulation as such has any effect. The predictions are straightforward. If the instruction were to prove effective and to change the action goals of the subjects, there should be no mapping effect, but an effect of instruction. That is, Groups 1 (KI-PM) and 2 (KI-IM) should not differ and should exhibit a standard Simon effect with the shortest RTs in Condition S = Key and the longest RTs in S ≠ Key; whereas in Group 3 (LI-IM), RTs should be shortest in Condition S ≠ Key and longest in S = Key, reflecting a kind of inverted Simon effect.

Method

Subjects. Twenty female and 22 male subjects aged between 14 and 34 were paid to participate in the experiment. They reported having normal or corrected-to-normal vision and audition and were not familiar with the purpose of the experiment. Fourteen subjects were assigned randomly to each of the three groups[2].

Apparatus. Sessions were run individually. Subjects were seated at a table in a dimly lit cubicle. Their heads were fixated with an adjustable chin-rest. Stimulus sources were hidden behind a fabric-covered semi-circular wooden screen placed 93 cm from the chin-rest. A green LED (Telefunken CQX 95; 5 mm diameter, approximately 3 cd/m^2) served as a fixation light in the center of the array. Two red LEDs of the same type were attached at 20° to the left and right of the fixation light. Two small loudspeakers were attached directly below the red LEDs behind holes of 2.5 cm diameter. The acoustical stimuli were a 200-Hz and a 500-Hz sinus tone, presented with 55 dB (as measured at chinrest position). Response keys were two microswitches (Schadow-Digitast), with a surface area of 1.5 × 1.5 cm, mounted on a wooden board at a distance of 30 cm. Subjects were allowed to adjust the position of the board so that it was at a comfortable distance: that is, they could shift it backwards and

[1] This was preferred to presentation via a single central speaker in order to copy the approved binaural control condition as used in studies with earphone presentation (e.g., Callan, Klisz, & Parsons, 1974; Simon & Acosta, 1982; Stoffels, Van der Molen, & Keuss, 1989). Subjectively, the fusion was perfect, giving the illusion of a single central tone.

[2] Data from eight additional members of Group 3 (LI-IM) were dropped from analysis for the following reasons: after completing the task, two subjects reported that they had not followed the instruction and defined their action goal in reference to the response keys instead; one subject was unable to discriminate between the two stimuli, and five subjects made more than 30 errors in sequence, through a misunderstanding of the instructions. In Experiment 2 we tried to prevent this by presenting an even more detailed instruction, including everyday examples of actions with alternative goal definitions, despite identical movements (such as stopping the car rather than stepping on the brake).

forwards, but not to the left or to the right. This guaranteed that both keys had the same defined distance from the median plane. Stimulus presentation and tone generation, as well as the recording of RTs and error data, were controlled by an Atari Mega ST4 computer.

Procedure. Verbal instruction was followed by a demonstration of the tones that were labeled *high* or *low*. Then subjects were given the opportunity to memorize the pitch-key mapping rules and to become familiar with the key-light mapping. At this stage, keys and lights were already connected, although tones were not presented. When subjects considered themselves sufficiently prepared for the task, the experimenter left the room and the experimental phase began. After an intertrial interval of 1,500 ms, each trial began with a 5-ms presentation of the green fixation light. The acoustic stimulus was presented after 1,000 ms and remained until either a response was given or 1,000 ms had passed. The parallel or inverse-mapped red LED lit up simultaneously with the key press and stayed on until the key was re-released. No error feedback was given. If subjects felt confused or inattentive, they could delay the following stimulus presentation by keeping the key pressed down. Each session lasted about 30 min.

Design. The Correspondence condition (i.e., the spatial relationship between tone and response key: S = Key, S ≠ Key, or N) varied within groups. Light-Key Mapping was varied between Groups 1 (KI-PM) and 2 (KI-IM) while Instruction was held constant. Mapping was parallel in Group 1 (KI-PM; i.e., light location = key location), and inverted in Group 2 (KI-IM, right-hand key connected to left-hand light; left-hand key connected to right-hand light). Instruction was varied between Groups 2 (KI-IM) and 3 (LI-IM) while Mapping was held constant (Group 2 was instructed to "press the key;" Group 3, to "produce the light").

The subjects familiarized themselves with the task by first completing 12 practice trials that were not subjected to analysis. The following 240 experimental trials consisted of 40 six-trial blocks (3 correspondence conditions ×2 reaction alternatives, randomly intermixed). Pressing the wrong key counted as an error, and trials with latencies longer than 1 s were considered as missing. Both kinds of trials were recorded and then repeated at a random position in the remainder of the block.

Results

Missing trials accounted for 2.1% (KI-PM), 2.2% (KI-IM), and 1.3% (LI-IM) of the data. Mean RTs and error percentages per subject, correspondence condition, and group were calculated (see Table 1). Between groups, ANOVAs on RT and error data were performed to compare Group 1 to Group 2, and Group 2 to Group 3. Within groups, Newman-Keuls tests were carried out to estimate the reliability of mean differences between correspondence conditions.

Mapping effects. In a 2×3-factorial ANOVA of RTs over Groups 1 and 2 (KI-PM, KI-IM) with Mapping (parallel vs. inverse) as between-groups and Correspondence (S = Key, S ≠ Key, N) as within-groups factors, the main effect of Correspondence was highly significant, $F(2, 52) = 85.06$, $p < .001$. Responses under S = Key were 37 ms faster and responses under S ≠ Key were 22 ms slower than in the neutral condition, and both facilitation and interference were significant ($p < .01$). The main effect of Mapping failed to reach significance ($p > .6$) as well as the Mapping × Correspondence interaction ($p > .09$). The same pattern was found in the error data. As was indicated by a highly significant Correspondence effect, $F(2, 52) = 27.54$, $p < .001$, errors were more frequent in condition S ≠ Key than in N and S = Key ($p < .01$), while the latter two conditions yielded rates that were not statistically different. Neither the main effect of Mapping ($p > .1$) nor the Mapping × Correspondence interaction ($p > .07$) reached significance.

Table 1. Mean correct RTs (ms) and error percentages (in parentheses) for the three correspondence conditions in the three experimental groups of Experiment 1

Instruction	Light-key mapping	S = Key	S ≠ Key	N
Key	Parallel	382 (1.4)	455 (8.4)	422 (3.9)
Key	Inverse	406 (1.8)	458 (5.4)	440 (2.8)
Light	Inverse	429 (4.9)	399 (4.5)	409 (4.1)

Instruction effects. A 2×3-factorial ANOVA of the RT data over Groups 2 and 3 (KI-IM, LI-IM) with Instruction (key- vs. light-related) as between-groups and Correspondence (S = Key, S ≠ Key, N) as within-groups factors yielded two effects. The marginally significant main effect of Correspondence, $F(2, 52) = 3.16$, $p < .06$, was modified by a highly significant Instruction × Correspondence interaction, $F(2, 52) = 43.22$, $p < .001$, indicating an inversion of the Correspondence effect from Group 2 (KI-IM) to 3 (LI-IM). Under key instruction, responses were fastest in the S = Key condition and slowest in the S ≠ Key condition. Both facilitation (34 ms) and interference (18 ms) as compared to N was significant ($p < .01$). Under light instruction the result pattern was turned around. Here, responses were slowest in the S = Key condition and fastest in the S ≠ Key condition. While there was significant interference of 20 ms ($p < .05$), the facilitation of 10 ms was not reliable. The Correspondence effect proper (S = Key vs. S ≠ Key) was, however, clearly significant ($p < .01$). For error rates, the highly significant main effect of Correspondence, $F(2, 52) = 6.21$, $p < .005$, was modified by a highly significant interaction of Instruction and Correspondence, $F(2, 52) = 6.74$, $p < .005$. While Group 2 (KI-IM) made comparably more errors in Condition S ≠ Key ($p < .01$) with rates in N and S = Key statistically equal, the rates of Group 3 (LI-IM) were very much the same in all three Correspondence conditions.

Discussion

The first prediction of the intentional approach under discussion was that comparable Simon effects should have appeared in both of the key instruction groups (Groups 1 and 2). On the one hand, this prediction seems to be confirmed, as a correspondence effect emerged in both groups with a structure and extent comparable to the common Simon effect. This means that the light-key mapping manipulation, which was a prerequisite for the crucial instruction manipulation, was obviously far from sufficient to invert the Simon effect. On the other hand, mapping was apparently not completely ineffective either. Although not statistically reliable, the Simon effect seems to be somewhat reduced in RTs, as well as in error rates, under inverse mapping. A tentative explanation of this result is presented below and then tested in Experiment 2.

The second prediction of the intentional approach is a great deal more interesting. Because manipulating the instruction should have changed the cognitively represented action goal (i.e., the intended action effect), an inversion of the Simon effect should be obtained between Groups 2 (KI-IM) and 3 (LI-IM). Indeed, in contrast to mapping, manipulating the instruction proved very effective. RT data offer clear evidence of an inversion of the Simon effect by instruction (i.e., by intention), as predicted by the intentional approach. Simon-type effects appeared in both groups, but while a standard Simon effect was found in Group 2, an inversion occurred in Group 3. However, the inversion is far from being perfect and distinct:

First, no correspondence effect is evident in the error data for Group 3 (LI-IM). A closer look at the data showed why. While 9 out of the 14 subjects in Group 3 made most errors in Condition S = Key and 1 subject showed equal error rates in S = Key and S ≠ Key, 4 subjects made more errors in S ≠ Key than in S = Key. Unlike the remaining members, 2 of these 4 subjects did not show an inverted, but a standard, Simon effect in the RTs. Thus, although in the postexperimental interview none of them reported problems in following the instruction, intentional or unintentional ignoring of the instruction could have led to a considerable increase in error variance and a distortion of the error data. If this assumption were true, the results would reflect individual problems with an unfamiliar instruction rather than a dissociation of RT and error data.

Second, and this is more important, the reaction-time data indicate a smaller correspondence effect under light-related (30 ms) than under key-related instruction (52 ms). This difference might be explained as follows. In the case of noncorrespondence between goal and key, each laterally presented stimulus corresponds either to the goal or to the key, but never to both. Correspondence between stimulus location and action goal necessarily implies noncorrespondence between stimulus location and key location and vice versa. Although the direction of the Simon effect may primarily depend on stimulus-goal correspondence, other correspondence relations may contribute additively to the overall effect, diminishing or extending the effect of stimulus-goal correspondence. For example, diminishing may have occurred in Group 3 (LI-IM), in which goal location differed from key location and from anatomical mapping, but did not occur – or not in the same way – in Group 2 (KI-IM), in which only the location of a task-irrelevant light differed from the other action features.

By the application of the logic of this explanation to the results of experiments on hand-crossing, some degree of independent support is obtained. Crossing hands in a standard Simon task changes the usually congruent relation between anatomical mapping and hand location into an incongruent relation. Thus, if stimulus location corresponds to hand location or key location, which is usually the instructed goal-defining response feature, stimulus and anatomical mapping do not correspond, and vice versa. According to our hypothesis, this should lead to a reduced Simon effect with crossed compared to uncrossed hands. Indeed, a reduced effect can be found in most studies in which both conditions, hands crossed and uncrossed, were investigated. The reduction (i.e., size of the Simon effect with parallel hands minus size of the Simon effect with crossed hands) has not always been tested statistically, and when tested, it did not always prove significant. However, it showed up more often than not (Callan, Klisz, & Parsons, 1974, b-reaction: 13 ms, c-reaction: 12 ms; Simon, Hinrichs, & Craft, 1970: 11 ms; Umiltà & Nicoletti, 1985, Exp. 3: 8 ms; Wallace, 1971, Exp. 1: 3 ms; 1972, Exp. 1, nonkinesthetic condition: 4 ms, Exp. 2: 12 ms). Only Wallace (1972, kinesthetic condition) and Umiltà and Nicoletti (1985, Exp. 1) found a small increase in the extent of the Simon effect in a crossed-hands condition. Thus, all in all, the effect of correspondence between stimulus and goal may indeed be modified by the spatial relationship between the stimulus and non-goal-defining response features.

If goal-defining response features (i.e., their relation to stimulus location) are responsible for the direction of the Simon effect, while correspondence relations between stimulus and the remaining response features are responsible for its extent, then we have an explanation for the (unreliable) mapping effect between Groups 1 and 2. Since the feedback light was certainly a disregarded and unimportant, but still objective, response feature, just like the active effector's location or its anatomical mapping, it may also have modified the correspondence effect in Group 2. Whereas under parallel mapping all response features were located on the same side and, thus, they all either did or did not correspond to stimulus location, stimulus and light differed spatially in S = Key and corresponded in S ≠ Key for Group 2, and this may have reduced the extent of the effect.

In summary, Experiment 1 provides evidence in favor of an intentional approach to the problem of response or action coding. The relevant factor in determining the direction of the Simon effect obviously consists of the intended action effect, that is, the goal-defining response feature and its correspondence to stimulus location. Independently of anatomical mapping and the location of the active effector, action initiation is subject to interference due to noncorrespondence of stimulus and intended action effect. But this is not the whole story: other forms of correspondence, such as between stimulus and hand location, or between stimulus and anatomical mapping, may contribute to the resulting effect.

Experiment 2

To test for the presumably different roles of goal-defining and irrelevant response features, it is necessary not only to demonstrate an inversion of the Simon effect by instruction but also to isolate effects of correspondence between stimulus location and the goal-defining response feature on the one hand, and between stimulus location and the remaining features on the other. This was achieved by the use of a design similar to that in Experiment 1, but with independent variations of correspondences of stimulus to light (or goal), stimulus to hand location (or key location), and stimulus to hand (or anatomical mapping). Thus, Experiment 2 consisted of four slightly differing tasks with hands parallel or crossed and light-key mapping either parallel, as in the PM group in Experiment 1, or inverted, as in the IM groups. This resulted in an independent variation of the three correspondence relations in question. Table 2 (see columns under the headings Correspondence, Task, and Condition) and Figure 2 (Examples 1–2, 4–5, 7–8, 10–11) provide an overview.

However, different independently varying correspondences in the Simon task lead to a methodological problem. If more than one response feature exists, we have to consider not only correspondence (i. e., S-R) relations, but also relations of congruence between response features, that is, R-R relations. In the following, the term *congruence* is used to describe similarity relations between different features of an action in a given task; for example, between the locations of an environmental action effect, the active effector, and its anatomical mapping. If, in a Simon task or compatibility task, the effector, its location, and the location of the action goal are independently varied, at least three relevant relations of congruence have to be distinguished.

1. The location of the goal (i.e., the intended action effect) and that of the active effector may be congruent or incongruent. Goal and effector locations are always congruent if the intended effect appears on the same side as the response key, independent of any crossing of effectors that might occur (see Figure 2, Examples 1–6). This is the case in the standard Simon task, but not, for example, in most of the conditions in Guiard's (1983) experiment, in which intended directions of wheel movements and hand locations differed from each other.

2. The location of the goal and the anatomical mapping of the active effector may be congruent or incongruent. Goal location and anatomical mapping are always congruent if a parallel mapped action effect has to be produced with uncrossed effectors, or an inversely mapped effect with crossed effectors (see Figure 2, Examples 1–3, and 10–12). This is also the case in the standard Simon task, where the action goal consists in pressing a key, but not in similar tasks like those in Wallace's (1971) experiment, in which hands were crossed.

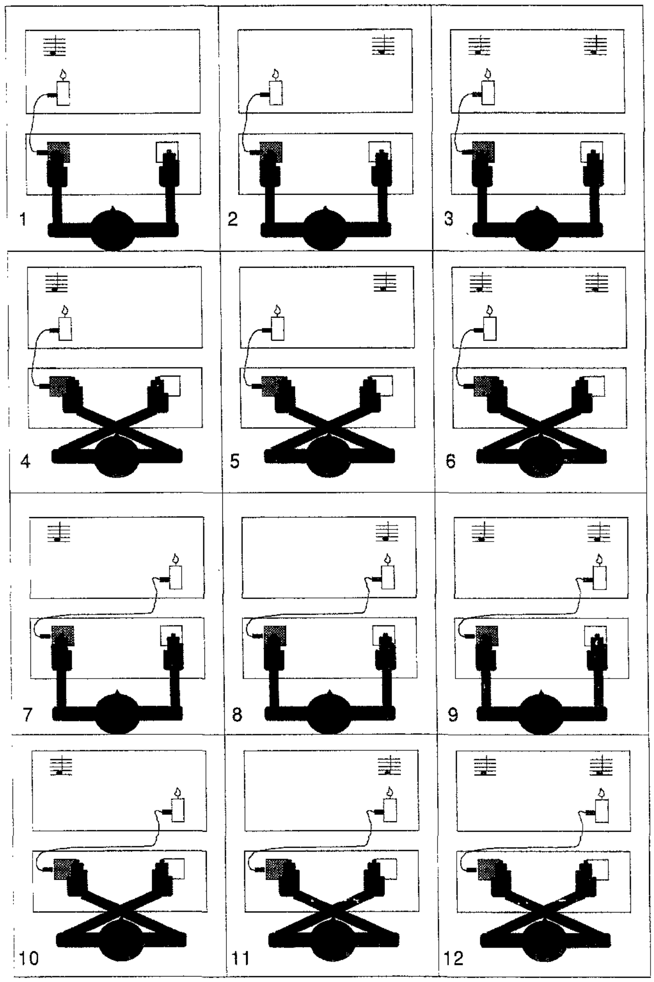

Fig. 2. Diagram of spatial relations in Experiment 2. Examples are given for left-hand responses only. Example numbering refers to Table 2 (Condition and Control columns). Columns show conditions of stimulus-key correspondence, noncorrespondence, and neutral conditions (from left to right). Rows show conditions from the four tasks (parallel mapping/uncrossed hands, parallel mapping/crossed hands, inverse mapping/uncrossed hands, inverse mapping/crossed hands; from top to bottom)

Table 2. Relations between task variables (Light-Key Mapping, Hands Uncrossed/Crossed; see Task Columns) and resulting types of correspondence (Correspondence columns) in Experiment 2. Mean RT (in ms) and error rates (%) for each correspondence condition (Condition columns) and control condition (Control columns) (example numbering refers to Fig. 2). Signed RT differences (in ms) between correspondence conditions and appropriate control conditions (Effect column).

Correspondence			Task		Condition			Control			Effect
-Light	Stimulus -Key	-Hand	Light-key mapping	Hand crossing	Example	RT	Errors	Example	RT	Errors	RT
+	+	+	Parallel	Uncrossed	1	365	(0.4)	3	395	(0.6)	–30
+	+	–	Parallel	Crossed	4	379	(0.7)	6	408	(1.8)	–29
+	–	+	Inverse	Crossed	11	430	(3.4)	12	446	(3.5)	–16
+	–	–	Inverse	Uncrossed	8	394	(1.0)	9	405	(2.1)	–11
–	+	+	Inverse	Uncrossed	7	430	(2.8)	9	405	(2.1)	+25
–	+	–	Inverse	Crossed	10	479	(4.7)	12	446	(3.5)	+33
–	–	+	Parallel	Crossed	5	442	(3.1)	6	408	(1.8)	+34
–	–	–	Parallel	Uncrossed	2	437	(3.8)	3	395	(0.6)	+42

3. The location of the active effector and its anatomical mapping may be congruent or incongruent. Effector location-mapping relations are congruent only if effectors are uncrossed, independent of the goal-defining response feature (see Figure 2, Examples 1–3, and 7–9).

The relation between correspondence and congruence of S–R and R–R relations is asymmetric. Whether two features of a given action are congruent or incongruent depends by no means on the location of the stimulus. While the variation of correspondence depends on the varying of stimulus locations, congruence is a task-specific relation and is therefore independent of the stimulus location in a given trial. On the other hand, the correspondence relation in a given trial is subject not only to stimulus location, but also to congruence relations. If, for example, key and anatomical mapping are congruent, spatial correspondence of key and/or hand location always means correspondence of stimulus and anatomical mapping, and vice versa. On the other hand, an incongruence between key-hand location and anatomical mapping always brings about different correspondence relations between stimulus-key and stimulus-anatomical mapping.

Thus, while congruence can be examined without the varying of correspondences, variations of different correspondences necessarily result in variations of congruence. The fact that congruence relations may indeed be an important factor was suggested by the finding of higher overall RT levels with crossed hands in Simon-type tasks (Simon, Hinrichs, & Craft, 1970, Exp. 1; Wallace, 1971, Exp. 1, 1972) and spatial compatibility tasks (Anzola, Bertolini, Buchtel, & Rizzolatti, 1977; Bradshaw, Bradshaw, Pierson-Savage, & Nettleton, 1988; Exp. 2; Brebner, 1973; Brebner, Shephard, & Cairney, 1972; Nicoletti, Anzola, Luppino, Rizzolatti, & Umiltà, 1986; Schroeder-Heister, Heister, & Ehrenstein, 1988; Simon, 1967). Elevations of RTs have even been found when only artificial extensions of effectors were crossed (Riggio et al., 1986).

Because congruence is specific to the task, but not to stimulus location, the emerging problem of confounding correspondence and congruence can be solved by the inclusion into each task of a control condition with a neutral stimulus location that serves as a reference to the remaining RTs. Each control condition thus reflects the congruence-dependent RT level, in relation to which correspondence effects can be estimated. Therefore, an N condition with spatially neutral stimulus presentation was included in each task of Experiment 2 (see Table 2, Control columns, and Figure 2, Examples 3, 6, 9, and 12) and used as a control variable in statistical analyses.

Two effects are predictable, if we follow an intentional action coding approach and consider additional contributions of effects of correspondence relations that are not goal-related. (a) The effect of stimulus-goal correspondence should be strong enough to determine the direction of the Simon effect. Therefore, correspondence of stimulus and light location should result in decreased RTs – independent of remaining correspondences – and noncorrespondence should result in increased RTs compared to a control condition. (b) Every correspondence that is not goal-related (i. e., stimulus-hand and stimulus-hand or key location) should combine additively with the effect of stimulus-goal correspondence.

Method

Subjects. Four female and 12 male subjects aged between 21 and 35, with normal or corrected-to-normal vision and normal hearing, were paid for their participation. All were naive to the purpose of the experiment.

Apparatus. The same apparatus was used as in Experiment 1. Only the LEDs (3 mm in diameter, 1.6 to 2.0 cd/m^2) were exchanged for technical reasons.

Procedure. Subjects were informed that they would run through four tasks with uncrossed or crossed hands and parallel or inverse key-light mappings. They were instructed to "produce the left-hand or right-hand light" depending on the pitch of the stimulus tone, ignoring their hands or the response keys. They were told that this was the most effective strategy to prevent being irritated by the changing hand-key relations and key-light mappings. So, following this instruction would be for their own benefit. Further procedural steps were identical to those in Experiment 1. Each subject participated in two sessions on two days with a maximum interval of two days in between. Each session lasted 40–60 min, including instructions.

Design. The task variables, as well as correspondence (i. e., stimulus location and response location), were varied within groups. Mapping of light to key never varied within, but only between, sessions in balanced order of mapping conditions. Within each session, the order of conditions with uncrossed and crossed hands was balanced. Crossing the left hand over the right hand, or vice versa, was varied from session to session, again in balanced order. Each of the four tasks (2 crossing conditions × 2 light-key mappings) consisted of 3 initial practice blocks and 40 experimental blocks. Blocks were composed of 6 randomly mixed trials, whose type resulted from the factorial combination of the 3 stimulus locations (left, right, or both speakers) and 2 response alternatives (left or right key). Pressing the wrong key was counted as error, and trials with latencies longer than 1 s were counted as missing. Both kinds of trials were recorded and repeated at a random position in the remainder of the block.

Results

Missing trials (1.5%), as well as errors, which accounted for only 2.2% of the trials, were dropped from the analysis. Mean RTs were calculated for each subject according to the coding schema presented in Table 2 (Correspondence columns) – that is, for each combination of correspondence/noncorrespondence between stimulus and light, stimulus and key location, as well as stimulus and anatomical mapping of the hand. The results are given in Table 2 (Condition columns). Mean RTs for the N conditions of the four tasks (parallel vs. inverse mapping, uncrossed vs. crossed hands) served as concomitant variables (Hays, 1988) for statistical analyses. Means and error rates of control conditions are given in Table 2 (Control columns), as well as signed differences between correspondence conditions and appropriate control conditions (Effect column).

A 2×2×2-factorial ANOVA, with Stimulus-Light (goal) Correspondence, Stimulus-Key (hand location) Correspondence, and Stimulus-Hand (anatomical mapping) Correspondence as within-groups factors and the N data as concomitant variables, yielded three significant main effects. First, responses were about 55 ms faster with Correspondence between Stimulus and Light (goal) than with Noncorrespondence, $F(1, 15) = 80.61$, $p < .001$. Second, responses were faster by 12 ms with Correspondence between Stimulus and Key (hand location) than with Noncorrespondence, $F(1, 15) = 12.16$, $p < .005$. Third, responses were faster by 5 ms with Correspondence between Stimulus and Hand (anatomical mapping) than with Noncorrespondence, $F(1, 15) = 7.32$, $p < .02$. All of the remaining effects were far from significant ($p > .5$).

Discussion

Experiment 2 had two aims. On the one hand, we wanted to know whether the goal-related effect found in Experiment 1 can be replicated and generalized. On the other hand, we wanted to gather empirical evidence supporting our interpretation of Experiment 1, that the correspondence effect was reduced under light instruction as compared with key instruction.

The first aim is clearly met, as the results of Experiment 2 again show that the direction of the Simon effect is solely determined by goal location. As was proposed in our intentionality hypothesis, the spatial relationship between the stimulus and the intended action effect is responsible for the direction of the Simon effect, irrespective of the kind of correspondence relations that remain. Further, the RT results of the light-instruction group in Experiment 1 are fully replicated. As Table 2 shows, inverse mapping and uncrossed hands (i.e., the conditions replicating those of the LI-IM group) yielded 11 ms facilitation under stimulus-key noncorrespondence and 25 ms interference under stimulus-key correspondence. These effects are very similar to the 10-ms facilitation and 20-ms interference obtained in Experiment 1. Note that, this time, the pattern of the error rates mirrors that of the RTs.

Our second hypothesis, based on the results of Experiment 1, has also gained some plausibility. As the results clearly show, the extent of the Simon effect in a given task not only is determined by correspondence between stimulus and goal, but is also influenced markedly by the relation between stimulus and hand location, and between stimulus and the anatomical mapping of the hand. As was expected, both non-goal-related effects combine additively with the goal-related effect, consequently extending or diminishing the resulting Simon effect[3]. Thus, it seems true that the Simon effect does not consist of the one-and-only (goal-related) correspondence effect, but of the sum of effects of various correspondence relations.

General discussion

Two experiments were conducted to investigate how actions are coded and how the Simon effect depends on changing coding strategies. Both yield results supporting the assumption that: (a) simple actions can be coded in different ways, and (b) the way in which they are coded can be influenced to some extent by the subject's intention. For a general theory of the Simon effect, three empirical constraints arise from the present results. First, the inversion of the effect as a result of instruction has to be accounted for. That is, how an actor interprets the experimental task and defines his or her action goal must be considered to play a major role in a successful theory. Second, the finding has to be acknowledged that effects of more than one correspondence relation contribute to the total effect. Third, it must be taken into consideration that non-goal-related correspondence effects simply add to the goal-related effect, instead of interacting.

Although several approaches to the Simon effect have been suggested, namely *attentional, perceptual,* and *coding* approaches, none of them can account for our results without additional assumptions and/or considerable modifications. As was outlined in the Introduction, this is a consequence of the little attention the term *response* has received in this theorizing. Especially attentional approaches, at least their stimulus-centered (Simon, 1969; Stoffer, 1991) and hemispherical (Verfaellie, Bowers, & Heilman, 1990) versions, are not able to explain the response-related effects obtained in our study. However, in order to account for the results, coding and perceptual approaches may be supplied with an intentional flavor in the following way:

An intentional-coding approach

The original coding approach to the Simon effect proposed by Wallace (1971, 1972) attributes the effect to an interplay among three codes. First, there is a relevant stimulus code (e.g., low pitch) that has to be mapped onto a response (e.g., a left-key press). Second, there is a response code that represents and, if sufficiently activated, triggers the response. Third, there is a further stimulus code, coding stimulus location. The activation of the correct response code is thought to be facilitated if response code and spatial stimulus code are similar – that is, share a feature: e.g., that of being left to a given reference.

Note that Wallace's account is not complete, in that it can explain correspondence benefits, but not interference effects in relation to a neutral condition. To do this, it has to be assumed that similarity between codes not only facilitates translation between codes, but results in an automatic preactivation of response codes that are similar to the stimulus (Kornblum, Hasbroucq, & Osman, 1990; Prinz, 1990). From this it would follow that a noncorresponding stimulus activates the wrong response, this leading to delayed reaction due to response competition.

The coding approach implies that responses are coded as stimuli in the cognitive system. That is, actions are cognitively represented as events both perceived and to be

[3] As one of the reviewers pointed out, additive effects of correspondence relations may be read as evidence for that they affect different stages of information processing (Sternberg, 1969). However, such a conclusion is neither plausible nor necessary. On the one hand, contrary to Sternberg's claims, there is no a-priori reason to exclude the possibility that the effects of factors affecting the same stage (and, perhaps, the same process) combine additively. On the other hand, it would make some sense to interpret the three statistical correspondence factors and their combinations as different levels of a single theoretical factor, representing S-R similarity.

perceived. If so, the way an action is perceived may be considered an important determinant of the way it is cognitively coded. This could be the basis of our instruction effect. The description of an action as a key-pressing action should attract the actor's attention to the key that is pressed, its location, and the location of the effector that does the pressing. That is, events are perceived whose locations are, without exception, identical to key location.

Given that this perception determines action coding, the cognitive response code should refer mainly to key location. On the other hand, if the same action were described as a light-producing action, attention would be drawn to the light, and the response code should therefore refer to light location. Thus the instruction effect in Experiment 1 could be explained as a consequence of attention drawn to the event the instruction had described as the main goal of the action.

This intentional-coding approach would also imply non-goal-related correspondence effects. It seems plausible to assume that attention does not work as a perfect filter during half an hour or so. That is, even a subject receiving a light instruction would not be willing or able to restrict his or her attention exclusively to the light, without even noticing the response key being pressed, its location, or his/her finger moving. If so, the cognitive representation of the action would mainly refer to the intended action effect, but would also include other features (perceived effects) of the action, just as object representations may include both relevant and irrelevant features of an object.

That is, an action would be cognitively coded by all of its perceived features, even if some of them refer to differing and possibly opposing points in space. Given that response codes are activated by similar stimulus codes, presentation of a left stimulus would not only activate responses causing left-located goal events, but (to a lesser degree) also responses that evoke any left-located event. Under the plausible assumptions that these activations simply add, and that the resulting response conflict increases with the activation level of the incorrect, compared to that of the correct response, an additive contribution of non-goal-related correspondence effects can be accounted for. Further, congruence effects may be interpreted along these lines as effects of the heterogeneity of cognitively coded response features.

An intentional-perceptual approach

The original perceptual approach to the Simon effect has not yet been elaborated in detail. According to Hasbroucq and Guiard (1991), as well as Stoffels, Van der Molen, and Keuss (1989), the Simon effect results from stimulus congruence. It is assumed that the cognitive code of a stimulus includes not only the perceived features of this stimulus, but also those of the mapped response. If, for example, a red stimulus signals a right-hand response, this being right of the response becomes part of the stimulus representation. Given that the stimulus appears on the left side, there would be a conflict between its meaning ("right") and the code of its actual position.

This approach may be extended in a similar way as the coding approach to account for our findings. The instruction effect could be understood, if one only assumes that instruction draws attention to the goal event, the location of which is included in the stimulus representation. Non-goal-related effects may also be explained by attention failing to exclude all events apart from the intended action effect to be perceived and coded. Even congruence effects could be explained by the logic applied in the intentional extension of the coding approach.

Conclusion

It is obvious that both the coding and the perceptual approach can be intentionalized to account for our results. That is, the results of the present study do not selectively support one approach over the other. However, it is remarkable that both can be extended in the same way, so that we may query whether the perceptual and the coding approach grossly differ at all. Both unanimously assume that a conflict arises from an interaction of three perceptually derived codes, one of them representing the relevant stimulus feature, one representing its location, and one referring to the response as a perceived event. Further, both approaches state that the response-related code is automatically activated by the location-related stimulus code. The remaining difference is that the coding approach assumes that the activation of the response-related code equals a preactivation of the response, while the perceptual approach supposes that the response-related code preactivates one of the stimulus codes that represent the relevant stimulus features. Since, logically, both assumptions can be true at the same time, it does not seem useful, or even necessary, to try to decide between them on the basis of our or other data.

At any rate, our results encourage the claim for a more intentional emphasis in theorizing about the effects of irrelevant spatial information on the speed and accuracy of action initiation. Taking into account the actor's intention seems to be indispensable for predicting the direction of the Simon effect and, perhaps, of other compatibility effects as well.

Acknowledgments. This study was conducted in partly fulfilling the requirements for attaining a doctoral degree at the University of Bielefeld, Germany. Some of the data presented here were reported at the 32nd Annual Meeting of the Psychonomic Society, San Francisco, CA, November 1991.

I wish to thank Ilona Feierabend and Ulrich Simon for assistance in collecting the data, Jonathan Harrow and Heidi John for checking the English, and Carlo Umiltà, Herbert Heuer, and an anonymous reviewer for their helpful critique, suggestions, and comments on an earlier draft.

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