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A memory-based, Simon-like, spatial congruence effect: Evidence for persisting spatial codes

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The Simon effect refers to the finding that in a task where stimulus location is irrelevant, reaction time is faster when stimulus and response locations are congruent than when they are not. Dominant theories of the Simon effect have generally attributed this spatial congruence effect to a spatial code automatically generated upon stimulus presentation. A common assumption of these theories is that this spatial code decays in less than a few hundred milliseconds following stimulus onset. We report two working-memory experiments suggesting a reexamination of this assumption—a Simon-like spatial congruence effect persisted over a delay of as long as 2400 ms. We propose that, in addition to generating short-lived perceptual codes, spatial information may be coded in working memory as part of the context associated with stimulus events. When reactivated by cues from the original event, such information may influence response selection and produce spatial congruence effects (in this case, positive when participants made a "yes" response and negative when they made a "no" response).

The slower reaction time observed when stimulus and response locations do not correspond than when they do, in tasks where stimulus location is formally irrelevant, is called the Simon effect (Simon & Rudell, 1967; see reviews by Lu & Proctor, 1995; Umiltà & Nicoletti, 1990). In a classical demonstration, Craft and Simon (1970) presented a red or a green light to the left or the right visual field. Participants were instructed to respond with a left-hand key to the green light and a right-hand key to the red light. Reaction time was 54 ms faster when the green light was presented to the left field than to the right field. For the red light, reaction time was 41 ms faster when it was presented to the right field than to the left field. A general consensus is that, in the Simon task, a spatial code is automatically generated in response to the stimulus location even though location information is irrelevant to the task of responding to a nonspatial dimension, for example, colour (Umiltà & Nicoletti, 1985, 1990; Wallace, 1971, 1972). Because this spatial code overlaps with the relevant response code derived from the nonspatial dimension (Kornblum, Hasbroucq, & Osman, 1990), it influences the speed of selecting the correct

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response. If the irrelevant spatial code and the relevant response code are congruent, the selection process will be facilitated; if they are incongruent, the selection process will be impeded.

A common assumption of this coding theory is that spatial codes from stimulus location undergo rapid decay within a few hundred milliseconds (usually around 300 to 400 ms, but sometimes somewhat longer, e.g., 700 ms in Roswarski & Proctor, 1996) following stimulus presentation. This assumption, critical to explaining the decrease or disappearance of the Simon effect when reaction time was increased (De Jong, Liang, & Lauber, 1994; Lu & Proctor, 1994), when participants had to withhold their response (Simon, Acosta, Mewaldt, & Speidel, 1976), or when processing of the relevant stimulus dimension was delayed (Hommel, 1993b), forms a cornerstone of several influential theories of the Simon effect (e.g., De Jong et al., 1994; Hommel, 1993a).

However, other findings suggest that implicit spatial information is retained longer. For example, with a visual search paradigm, Chun and Jiang (1998) have shown that spatial configuration information, defined by the spatial locations of a collection of items, can be implicitly encoded and facilitate search efficiency in later trials. Such results would counter the idea that spatial location information invariably undergoes automatic decay in the absence of intentional processing.

Instead of undergoing automatic decay, irrelevant spatial codes may be actively inhibited when competing with the relevant response codes. In light of the research on cognitive inhibition (see DeSchepper & Treisman, 1996; Golding & MacLeod, 1998; Tipper, 1985), inhibited representations can resurface and affect performance on later occasions. Although Hommel (1994) manipulated the relative frequency of spatially corresponding and noncorresponding trials and found that the decay of spatial codes in a Simon task did not seem to be subject to strategic or voluntary control, he also pointed out that his results did not exclude the possibility that spatial codes in the Simon task could be suppressed by some inhibitory mechanism. Therefore, it remains at least logically possible that spatial codes may persist for a longer period of time than is commonly assumed by theories of the Simon effect. To test this possibility, we have to go beyond the typical Simon task. This is because the Simon task is mainly a simple perceptual discrimination task where participants are instructed to respond quickly to the stimulus. As the spatial code is formed upon stimulus onset, the brevity of each single trial makes it hard to examine the effects of spatial codes at a delay longer than the length of the trial, which is usually a few hundred milliseconds.

This was also true in a variant of the standard Simon task where the trial duration could be lengthened. Hommel (1995) presented at the centre of the screen white-coloured arrows pointing either left or right for approximately 1 s followed by either a red or a green colour patch. The patch served as a go/no-go signal, and its location, irrelevant to the task requirements, varied randomly between a left and a right position. Participants were told to respond to the arrows' direction (press a left key for left-pointed arrows and a right key for right-pointed arrows), but they had to withhold their response until they saw the go/no-go signal. They were then to make the response if the patch was green but abort the response if it was red. A Simon effect was found—when the response key and the go stimulus were spatially corresponding, reaction time was faster than when they were not. Although the absolute trial length in this procedure can be quite long due to the inserted delay between the stimulus and the go/no-go signal, responses were still made, just as in a usual Simon task, within a few hundred milliseconds following the onset of the stimulus (i.e., the go/no-go signal) that generated the irrelevant spatial code. Therefore, the presence of the Simon effect with this procedure does not show that spatial codes can last longer than a few hundred milliseconds.

However, this procedure, which increased the trial length by introducing a memory component (i.e., asking participants to maintain their response until they see the go/no-go signal), does suggest a way to test whether irrelevant spatial codes necessarily undergo rapid automatic decay. Incorporating this idea, the following two working-memory experiments present evidence indicating that some form of spatial code persists longer than a few hundred milliseconds.

EXPERIMENT 1

The task used in Experiment 1, as shown in Figure 1, was originally designed to study selection processes in working memory (Zhang & Johnson, 2001). In each trial, participants first see a study display with four letters and are told to hold them in mind. After a short delay, an

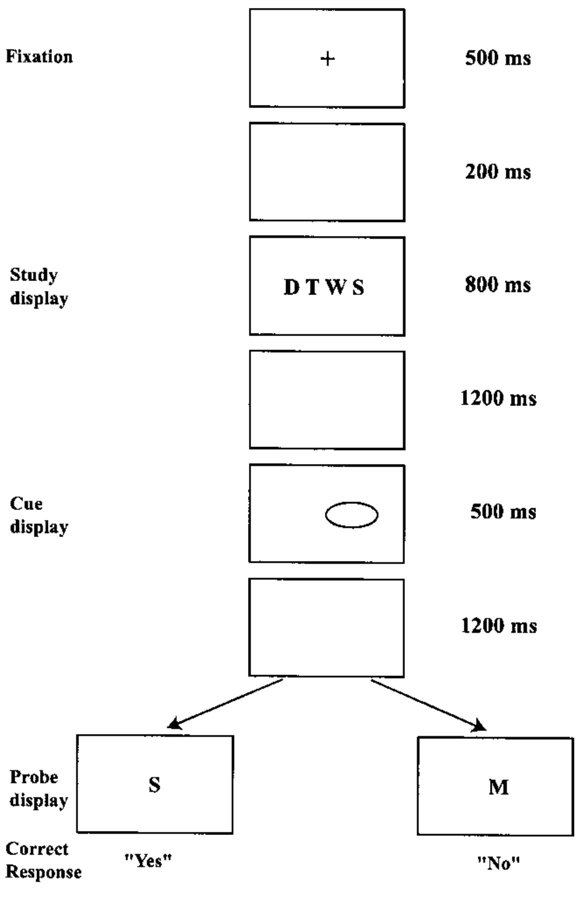

Figure 1. A schematic view of the event sequence of a sample trial from Experiment 1.

ellipse is presented on one side of the screen, instructing them to select the two letters on the same side and to discard the two on the other side. For example, for the trial in Figure 1 participants should focus on "W S" as the target letters and ignore "D T" after they see the cue. Following another blank interval, called the cue-to-probe delay, a single probe letter is presented at the centre of the test display. Participants have to make a speeded "yes/no" judgement indicating whether the probe was one of the two target letters by pressing either a left-hand key or a right-hand key on a computer keyboard.

There are two kinds of spatial code involved in this task, one from the spatial location of the response keys (left or right on the keyboard) and the other from the spatial location of the selection cue (left or right on the screen). Depending on whether these two codes correspond or not, each trial can be classified as either spatially congruent or incongruent. To illustrate, suppose that the left key is for yes responses and the right key for no responses. For the particular sample trial shown in Figure 1, the ellipse cue is on the right. When the probe is an "S", a yes response (i.e., a left keypress), should be elicited. Hence, the trial would be incongruent. When the probe is an "M", a no response (i.e., a right keypress), should be elicited, and the trial would be congruent.

In this task, a spatial code is presumably formed upon the onset of the ellipse cue, but response selection happens only after the probe comes up; thus, the formation of the spatial code and the response selection process are temporally separated by the cue-to-probe delay, which is much longer (1200 ms in Experiment 1) than the typical lifetime of the Simon effect reported in the literature. For example, De Jong et al. (1994) found the Simon effect was reduced almost to zero for responses made around 700 ms. When response execution time was taken into account, the spatial code may have dissipated even earlier than 700 ms after stimulus onset (although this does not hold across all studies; see the above-mentioned Roswarski & Proctor, 1996, study).

Therefore, the current task makes it possible to examine the fate of the spatial code over a period of time longer than that with the standard Simon task. If the activation of the spatial code based on the location of the cue stimulus faded away completely during the cue-to-probe delay, we should not expect it to have any effect on the response selection process, which occurred after the delay. Consequently, no difference between the congruent and the incongruent trials should be observed. On the other hand, the presence of a congruence effect would indicate that the spatial code persists across the delay.

Method

Participants

A total of 12 undergraduate students (8 male) at Princeton University participated in the experiment in fulfilment of course requirements. All had normal or corrected-to-normal vision. All were naïve as to the purpose of the experiment before being debriefed at the end of their individual session.

Stimulus

The experiment was conducted in a well-illuminated testing room. All stimuli were presented against a white background on a 17-inch colour computer monitor, controlled by a Macintosh PowerMac 8100 computer. Participants sat facing the screen with a viewing distance of about 60 cm.

The fixation stimulus was a cross presented at the centre of the screen. The length and thickness of its component lines were 0.5° and 0.06°, respectively. The four letters in the study display were symmetrically positioned relative to the centre of the screen along the horizontal meridian. The centre of the near letters was displaced by 0.63° from the screen centre and that of the far letters by 1.58°. Each letter was in uppercase bold Helvetica font at size 32, extending a visual angle of 0.70° × 0.88° to the participants.

The ellipse in the cue display was constrained in an imaginary rectangle of size 2.84° × 1.14° (width by height) with its centre displaced either to the left or to the right by 1.58° from the screen centre. The thickness of the contour line of the ellipse was 0.10°. There was also a dot with a diameter of 0.25° at the centre of the screen in the cue display. All stimuli were in black and white.

Design

The design was a 2 × 2 factorial with response type (yes/no) and congruence (congruent/incongruent) as within-subject factors. Response type was considered as a factor, as yes and no responses are known to be behaviourally quite different from each other (e.g., Sternberg, 1975).

For each participant, six different letters were first randomly drawn from a set of 21 consonants and constituted the whole stimulus set for this participant. For each trial, four letters were randomly drawn without replacement from the stimulus set and used in the study display. For half of the trials, the ellipse appeared on the left side, and for the other half, the right side.

Each participant had a practice block of 24 trials, followed by eight test blocks with 24 trials each. In each block, half of the trials were yes trials, and the other half were no trials. Incidental to the main interest of the current study, in half of the no trials the probe was drawn from the ignored two letters (i.e., the two letters on the opposite side of the ellipse cue), and in the remaining half it was drawn from the stimulus set but it was different from all four letters in the study display. Within each response type, half of the trials were congruent and the other half were incongruent. All trial types were randomly mixed in each block. Half of the participants pressed the "s" key on the computer keyboard for yes responses and the "l" key for no responses. For the other half, the mapping was reversed.

Procedure

Participants sat before the computer screen and placed their left and right index fingers on the "s" and "l" keys on a computer keyboard. After a few instructional trials, the experimenter left the room and let the participant finish their session. Participants were asked to take a short break between successive blocks.

As shown in Figure 1, each trial started with the presentation of the fixation for 500 ms followed by a blank screen for 200 ms. The study display was then presented for 800 ms before being replaced by another blank screen for 1200 ms. The next display was the cue display, which lasted 500 ms and was followed by a 1200-ms cue-to-probe delay interval. At the end of the delay, the probe was presented and remained on the screen until the participant responded. The next trial started 1200 ms after the response.

Participants were asked to respond as fast as they could while maintaining a high level of accuracy. Incorrect responses were immediately signalled with a short 200-ms beep, providing feedback for the participants to monitor their response accuracy. For incorrect trials, the 1200-ms intertrial interval started at the offset of the beep. Both the keypresses and the reaction times (RTs, relative to the onset of the probe display) were recorded by the computer.

Results and discussion

The mean RTs and error rates for each condition across all participants are shown in Table 1. For both experiments reported in this paper, RTs were calculated only for the correct

TABLE 1
Mean RTs[a] and error rates[b] for all conditions in Experiment 1

	Congruence							
	Congruent				*Incongruent*			
	RT		*Error rate*		*RT*		*Error rate*	
Response type	*M*	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*
Yes	541	29	1.83	0.46	578	32	5.33	0.87
No	639	34	3.67	1.01	595	23	2.17	0.52

[a]In ms. [b]In percentages.

trials. Also, trials in which RT was less than 300 ms or more than 1500 ms were excluded from the analysis as outliers, resulting in 1.5% of the total data points discarded in the current experiment. The valid RT range (300, 1500) ms was chosen to be longer than usually used in perception tasks since reaction times are generally slower in memory tasks. However, the pattern of results was similar when we used a smaller range of (200, 1200) ms. This was true for both Experiment1 and Experiment 2. The significance criterion was set at $p < .05$.

A two-way analysis of variance (ANOVA) of the RT data revealed a main effect of response type, $F(1, 11) = 26.66$, with the yes trials being faster than the no trials (560 vs. 616 ms). This result is typical in tasks with a speeded matching component (e.g., Farell, 1985; Sternberg, 1975). In the following, we omit discussion of the main effect of response type, as it is irrelevant to our current interest.

The main effect of congruence was not significant, $F < 1$. However, there was a significant interaction between congruence and response type, $F(1, 11) = 13.26$. For the yes trials, the congruent condition was significantly faster than the incongruent condition, 541 vs. 578 ms, $t(11) = 4.97$. For the no responses, the opposite was found—the congruent condition was significantly slower than the incongruent condition (639 vs. 595 ms), $t(11) = 13.62$.

An ANOVA of the error rate data showed no main effect of response type, $F(1, 11) = 1.44$, $p > .1$, or congruence, $F(1, 11) = 3.47$, $p = .09$. As with the RT data, there was a significant interaction between response type and congruence, $F(1, 11) = 11.62$. For the yes trials, participants were more accurate in the congruent condition than in the incongruent condition (1.83% vs. 5.33%), $t(11) = 6.67$, but for the no trials, though insignificant, participants were less accurate in the congruent condition than in the incongruent condition (3.67% vs. 2.17%), $t(11) = 2.45$, $p = .13$.

As we mentioned in the design section, there were two types of no trial in this experiment. For half of the no trials, the probe letter was in the study display. For the other half, the probe letter was not in the study display. For easy reference, we call the first type of trial the "no/inside" trials and the second type the "no/outside" trials. The no/inside trials were slower and less accurate than the no/outside trials (648 vs. 586 ms in RT and 3.7% vs. 2.2% in error rate). However, there was no difference across the two types of trial for the congruence effect, either in terms of reaction time ($F < 1$) or in terms of error rate ($F < 1$). For the no/inside trials, compared with the incongruent condition, the congruent condition was slower by 39 ms and less accurate by 0.7%. For the no/outside trials, the corresponding values were 47 ms and 2.3%.

Briefly, in this experiment, we demonstrated that a spatial congruence effect persisted over a time period longer than would be expected based on previous research on the Simon effect. However, to see this effect, one has to take into account response type. For yes responses, the effect was positive—that is, participants were faster in spatially corresponding than in spatially non-corresponding trials. For no responses, the effect was negative—that is, participants were slower in spatially corresponding than in spatially noncorresponding trials. Error rate data showed a pattern consistent with the RT data. Further discussion of these results will be deferred until after we address a potential problem in Experiment 1.

EXPERIMENT 2

To correctly select the target letters, participants in Experiment 1 had to process the ellipse cue based on its spatial location. Although there was no need to maintain the location of the cue during the delay period as this location did not correlate with the correct response, location was relevant for selecting the target set when the cue display was presented. Therefore, it may be argued that the task used in Experiment 1 failed to maintain a central feature of the Simon task paradigm—that is, that spatial location was an irrelevant dimension that participants were never asked to pay attention to.

In Experiment 2, the selection cue was removed. In the "single" display condition, shown in the left panel of Figure 2, a pair of letters was presented in the study display, either to the left or to the right of the screen centre. Following a delay interval, a probe letter was presented at the screen centre. Participants were asked to hold the two study letters in mind during the delay. As in Experiment1, they then responded to the probe by pressing either a left-hand or a right-hand key to indicate whether the probe was one of the two target letters. This simplified task was more comparable to a standard Simon task in that spatial location was completely irrelevant to the task.

To further investigate the nature of the spatial codes responsible for the congruence effect observed in Experiment 1, we also included a "double" display condition, shown in the right panel of Figure 2. It was exactly the same as the single display condition except that the two letters in the study display were always accompanied by two "%" noise symbols, positioned on the other side of the screen. Participants were told to always ignore the symbols and to focus on the two letters. A Simon effect has been reported in many previous studies using symmetrical displays where a noise stimulus was presented to the opposite side of the imperative stimulus (Hommel, 1993b; Proctor & Lu, 1994; Valle-Inclan, 1996; Wascher, Schatz, Kuder, & Verleger, 2001; but see Simon, Small, Ziglar, & Craft, 1970, for a counterexample with auditory stimuli). Such findings have been used to support an attention-shifting account of the Simon effect (Roswarski & Proctor, 1996; Stoffer, 1991; Umiltà & Nicoletti, 1992) that proposes that spatial codes are formed as a result of orienting attention to the imperative stimulus. Whether or not there is a congruence effect with symmetrical displays in our task is relevant for comparing the congruence effect observed here with the typical Simon effect.

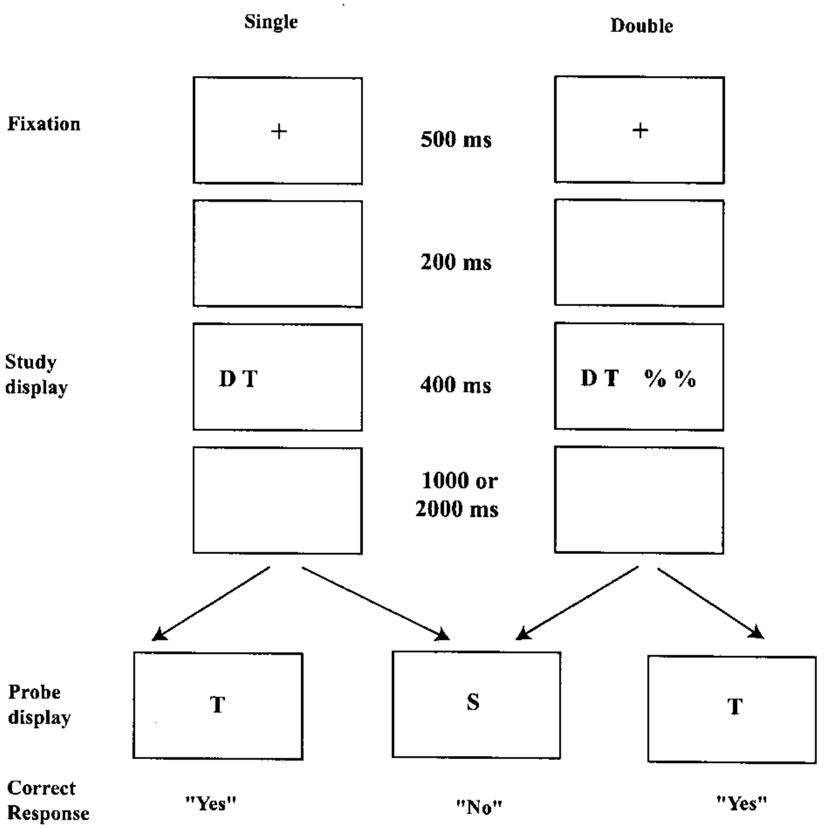

Figure 2. A schematic view of the event sequence of sample trials from Experiment 2.

Method

Participants

A total of 18 undergraduate students (9 male) at Yale University participated in the experiment in fulfilment of course requirements. All had normal or corrected-to-normal vision. All were naïve as to the purpose of the experiment before being debriefed at the end of their individual session.

Stimuli

All stimuli were presented against a white background on a 19-inch colour computer monitor, controlled by a Macintosh G4 computer. Participants sat facing the screen with a viewing distance of about 60 cm.

The fixation stimulus was a dot with a diameter of 0.56° drawn at the centre of the screen. The two letters in the study display were presented 1.76° and 3.18° either to the left or to the right of the screen centre. Each letter was uppercase Courier font at size 64, extending a visual angle of 1.27° × 1.49°. The two "%" symbols were always on the opposite side from the two letters, with equal distance from the screen centre as the letters. They were about the same size as the letters. The probe letter, in the same font and size as the study letters, was always at the centre of the test display. All stimuli used were in black and white.

Design

The design was a 2 × 2 × 2 × 2 within-subject design with response type, congruence, display, and delay as the corresponding factors. The levels for response type and congruence factors were the same as those in Experiment 1. For the display factor, the two levels were the single and the double study display conditions. To see whether the congruence effect would be affected by the length of the delay interval, we also manipulated the cue-to-probe delay to be either 1000 or 2000 ms.

On each trial, two different letters were randomly drawn from a pool of 21 consonants and used in the study display. For a yes trial, the probe was randomly drawn from these two letters; for a no trial, the probe was a letter drawn from the pool but different from either of the two target letters. Besides a few instructional trials, each participant had a practice block of 32 trials, followed by 12 test blocks with 32 trials each. In each block, half of the trials were yes trials, and the other half were no trials. Levels of all four factors were fully crossed to generate all the possible trial types, which were equally represented and randomly mixed in each block. As in Experiment 1, half of the participants pressed the "s" key on the computer keyboard for yes responses and the "l" key for no responses. For the other half, the mapping was reversed.

Procedure

As shown in Figure 2, on each trial, following a 500-ms fixation display and a 200-ms blank interval, the study display was shown for 400 ms. Following a variable delay (either 1000 or 2000 ms), the probe display came up and remained on the screen until response. The next trial started 1200 ms after the response was made. All the other details were the same as those in Experiment 1.

Results and discussion

The mean RTs and error rates for each condition across all participants are shown in Table 2. For RT data, following the same procedure as that described in Experiment 1, 1.4% of the total data points were identified as outliers and discarded.

The four-way ANOVA of the RT data revealed a significant main effect of response type, $F(1, 17) = 5.95$, with the yes trials faster than the no trials (618 vs. 642 ms). There was no main

TABLE 2
Mean RTs[a] and error rates[b] for all conditions in Experiment 2

		Single display								*Double display*							
		Congruent				*Incongruent*				*Congruent*				*Incongruent*			
		RT		*Error rate*		*RT*		*Error rate*		*RT*		*Error rate*		*RT*		*Error rate*	
Delay	*Response type*	*M*	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*
Short delay	yes	624	17	3.61	0.94	645	16	6.72	1.72	650	16	4.00	0.86	648	11	6.50	1.63
Long delay	yes	587	14	2.89	1.01	602	14	5.39	1.03	591	12	2.67	0.97	599	16	4.67	0.98
Short delay	no	669	16	3.39	1.15	667	18	3.61	1.52	668	21	2.72	1.04	672	18	2.22	0.74
Long delay	no	637	18	2.22	0.66	597	15	1.33	0.56	613	18	3.17	1.02	612	17	2.22	0.81

[a]In ms. [b]In percentages.

effect for congruence or display ($F < 1$). RT was 630 ms for both the congruent and the incongruent trials. For the single display condition, RT was 629 ms, and for the double condition it was 631 ms. Unlike in Experiment 1, the interaction between response type and congruence did not reach significance, $F(1, 17) = 3.20$, $p = .09$, even though the results showed a similar pattern. The congruent condition was faster than the incongruent condition by 11 ms for the yes responses (613 vs. 624 ms) but slower than the incongruent condition by 10 ms for the no responses (647 vs. 637 ms). However, there was a significant three-way interaction between response type, congruence, and display, $F(1, 17) = 6.87$. For the single display condition, the congruent condition was significantly faster by 18 ms than the incongruent condition for the yes trials (605 vs. 623 ms), $t(17) = 6.43$, but significantly slower by 21 ms than the incongruent condition for the no trials (653 vs. 632 ms), $t(17) = 8.78$. For the double display condition, there was no significant difference between the congruent and the incongruent conditions for either the yes trials (620 vs. 624 ms) or the no trials (640 vs. 642 ms). This three-way interaction shows that the significant interaction for the RT measure between congruence and response type found in Experiment 1 was only present for the single display condition but not for the double display condition. There was a main effect of delay, $F(1,17) = 115.74$. Reaction time was reduced from the short delay to the long delay (655 vs. 605 ms), reflecting an overall performance improvement that may be attributed to rehearsal processes during the delay. However, delay did not interact with any other factors, $p > .1$. Nevertheless, it is interesting to note that, for the single display condition, the congruence effect was 21 ms for the yes trials and –2 ms for the no trials at the short delay. At the long delay, the effect was 14 ms for the yes trials and –40 ms for the no trials. There was no sign that the magnitude of the congruence effect was decreasing with longer delay. No other significant interactions were found, $p > .1$.

The ANOVA of the error rate data showed a main effect for response type, $F(1, 17) = 25.03$. The yes responses were less accurate than the no responses (4.56% vs. 2.61%). This was consistent with the differences found in Experiment 1. The main effect of delay was not significant, $F(1, 17) = 3.43$, $p = .08$, though, consistent with the RT data, performance was better at the long delay than at the short one (3.07% vs. 4.10%). The main effect of congruence was close to significant, $F(1, 17) = 4.24$, $p = .06$, with the congruent condition being more accurate than the incongruent condition (3.08% vs. 4.08%). In addition, the two-way interaction between response type and congruence was also significant, $F(1, 17) = 10.52$. The congruent condition was significantly more accurate than the incongruent condition for the yes trials (3.29% vs. 5.82%), $t(17) = 14.4$. For the no trials, there was not much difference between the two conditions (2.88% vs. 2.35%, $p > .1$). Such an interaction suggests that for the error rate data, the congruence effect was mainly present for the yes trials but not for the no trials. This pattern of results held for both the single condition and the double display conditions, as the three-way interaction between response type, congruence, and display was not significant, $F < 1$. For the single condition alone, the interaction between response and congruence was close to significant, $F(1, 17) = 3.18$, $p = .09$: for the yes trials, the congruent condition was significantly more accurate than the incongruent condition (3.25% vs. 6.06%), $t(17) = 5.07$, but for the no trials, the difference was not significant (2.81% vs. 2.47%), $p > .5$. For the double condition alone, the response by congruence interaction was also significant, $F(1, 17) = 7.19$; for the yes trials, the congruent condition was significantly more accurate than the incongruent condition (3.33% vs. 5.58%), $t(17) = 8.24$, but for the no trials, the difference was not significant (2.94% vs. 2.22%), $p > .5$.

Results from Experiment 2 indicate that the congruence effect observed in Experiment 1 was not specific to the task used in Experiment 1. In particular, the fact that the task in Experiment 1 had a selection cue based on spatial location did not seem to be critical.

Second, Experiment 2 also replicated the finding in Experiment 1 that the congruence effect interacted with the type of response participants made. For yes responses, participants showed a positive congruence effect—that is, they were faster in spatially corresponding than in spatially noncorresponding trials. For no responses, they showed a negative congruence effect—that is, they were slower in spatially corresponding than in spatially non-corresponding trials.

Third, the pattern of the congruence effect was different across the two display conditions. Although for the error rate data, both display conditions showed a positive congruence effect (the congruent condition was more accurate than the incongruent condition by 2.81% and 2.25%, respectively) in the yes trials, for the RT data, the congruence effect was clear in the single display condition (18 ms for the yes and –11 ms for the no trials) but essentially absent in the double display condition (4 ms for the yes trials and 2 ms for the no trials).

We also examined whether the distance of a study letter from the screen centre mattered. For the yes trials, the probe was the same as one of the two study letters, either the outside or the inside one (further away or nearer to the screen centre). We introduced an eccentricity factor and conducted a three-way ANOVA with display type (single/double), congruence (congruent/incongruent), and eccentricity (far/near) as within-subject factors. The far condition was significantly slower but more accurate than the near condition: 627 vs. 611 ms in RT, $F(1, 17) = 5.69$; 3.3% vs. 5.3% in error rate, $F(1, 17) = 8.10$. The interaction between eccentricity and the congruence effect was significant in terms of both RT, $F(1, 17) = 4.61$, and error rate, $F(1, 17) = 8.97$. The congruence effect was 47 ms (603 vs. 650 ms), $t(17) = 3.83$, $p = .06$, for the far condition but –26 ms (624 vs. 598 ms), $t(17) = 1.17$, $p = .3$, for the near condition. The negative congruence effect in the near condition may reflect speed-accuracy tradeoff since the error rate showed an opposite pattern. That is, the congruent condition was significantly more accurate than the incongruent condition for the near condition (2.8% vs. 7.8%), $t(17) = 13.14$. For the far condition, the error rates were comparable across the congruent and the incongruent conditions (3.4% vs. 3.2%). The three-way interaction between eccentricity, display, and congruence was not significant, $F(1, 17) = 2.25$, $p > .1$.

Briefly, the far condition exhibited a reliable congruence effect but the near condition did not. This conclusion was also supported when we analysed the yes trials in Experiment 1 in a similar way by breaking them down into far and near conditions. We then conducted a two-way ANOVA with eccentricity and congruence as factors. The main effect of eccentricity was not significant for either RT or error rate, $F < 1$. The congruence effect was much larger in the far condition (70 ms), $t(11) = 19.98$, than in the near condition (2 ms), although the interaction between eccentricity and congruence was insignificant, $F(1, 11) = 3.09$, $p = .11$ (which we attributed to unusually large between-subject variance after a closer examination of the data). The same interaction was insignificant for the error rate, $F < 1$.

The different patterns of the congruence effect in the far and the near conditions suggest that in the spatial coding of the study display items, the location of each study letter relative to the screen centre is an important factor. This prompted us to analyse the relative location of the probe letter within the study letter pair for the yes trials (i.e., whether the probe was the same as the left or right letter in the pair) to see whether this relative left/right location was also important in the congruence effect.

We call the location of the letter pair relative to the screen centre the "absolute location", and the location of the probe within the letter pair the "relative" location. This is only intended for easy reference, as the absolute location is in fact not absolute, but relative to a reference point, the screen centre. Depending on whether the absolute location or the relative location was consistent with the location of the response or not, each yes trial can be "absolute congruent/incongruent" and "relative congruent/incongruent". The absolute congruence effect is what we have examined so far. Note that it is orthogonal to the relative congruence effect (i.e., each absolute congruent or absolute incongruent trial can be either a relative congruent or a relative incongruent trial). Note also that this analysis involving relative location and the previous analysis involving eccentricity essentially partitioned the same set of data in two different ways. Although not identical, they are not independent of each other. For example, it can be shown that an absolute congruent/relative congruent trial in the relative location analysis would always be in the congruent far condition in the eccentricity analysis.

We conducted a four-way ANOVA with delay, display, absolute congruence, and relative congruence as factors. The main effect of relative congruence and its interaction with the absolute congruence were significant for both the RT data, $F(1, 17) = 5.59$ and 4.77, and the error rate data, $F(1, 17) = 5.91$ and 9.01. The relative congruent trials were faster than the relative incongruent trials, 600 vs. 640 ms, but less accurate, 5.5% vs. 3.3%. In the absolute congruent condition, compared with the relative incongruent trials, the relative congruent trials were significantly faster (601 vs. 627 ms), $t(17) = 6.69$, with comparable error rates (3.5% vs. 3.3%). In the absolute incongruent condition, the relative congruent trials were significantly faster (599 vs. 653 ms), $t(17) = 32.62$, but less accurate (7.5% vs. 3.2%), $t(17) = 19.85$, than the relative incongruent trials. There may be a speed–accuracy tradeoff in the absolute incongruent condition. Therefore, the results showed that, at least for the absolute congruent condition, there was a reliable relative spatial congruence effect.

The relative congruence effect did not differ across the two display conditions, $F(1, 17) = 1.6$, but interacted significantly with the delay, $F(1, 17) = 17.67$. The effect was 65 ms at the short delay and was reduced to 12 ms at the long delay. The three-way interaction between delay, display, and relative incongruence was close to significant, $F(1, 17) = 3.62$, $p = .07$. This was due to the fact that at the short delay, the congruence effect was quite different across the two display conditions (88 ms for the single display condition and 43 ms for the double condition) but the difference was small at the long delay (12 ms for the single display condition and 17 ms for the double condition). No other interaction effect involving the relative congruence factor was significant, $p > .1$. We also examined the relative incongruence effect in Experiment 1. The effect was not significant, $F(1, 11) = 3.09$, $p = .10$, though the relative congruent trials were faster than the relative incongruent trials (544 vs. 578 ms), in line with the pattern from Experiment 2. Different from Experiment 2, there was no interaction between the relative and the absolute congruence effect in the RT data, $F < 1$. No main effect or interaction effect concerning the relative congruence effect was evident in the error rate data, $F < 1$.

Briefly, the results indicate that, in the current task settings, not only the location of the letter pair relative to the screen centre but also the relative location of each letter within the letter pair were coded. That is, there was an absolute congruence effect in the far condition for both Experiment 1 and Experiment 2 (positive for the yes trials and negative for the no trials), and a relative congruence effect for the absolute congruent trials in Experiment 2. This suggests that more than one type of spatial code was formed in the current tasks, as has been found in the Simon literature (e.g., Lamberts, Tavernier, & d'Ydewalle, 1992). The relative congruence effect is certainly interesting for future study, however, as it is orthogonal to the congruence effect from letter pair locations, which was the main interest here, we do not discuss it further in the following.

GENERAL DISCUSSION

The central finding of the two experiments reported here is that a Simon-like spatial congruence effect occurred and persisted for a period much longer than the few hundred milliseconds that had been suggested by previous research on the Simon effect. In Experiment 1, because the cue stimulus was already presented for 500 ms before the 1200-ms delay, the formation of the spatial code was in fact temporally separated from the response selection stage (i.e., starting from the presentation of the probe) by as much as 1700 ms. In Experiment 2, the effect survived an even longer delay of 2400 ms and it did not interact with the length of the delay. The effect in Experiment 1 may have been caused by the spatial location of either the two letters to be maintained or the ellipse cue, as the two always coincided. Results from Experiment 2 showed that the location of the study letters alone was sufficient to produce the congruence effect. However, the ellipse location may well have made a contribution as the magnitude of the congruence effect was smaller in Experiment 2 (18 ms, averaged across delay and response type for the single display condition only) when the ellipse was removed than that in Experiment 1 (37 ms, average across response type) when the ellipse cue was present.

One may not want to call our tasks Simon tasks and the congruence effect we see here a Simon effect. For example, in Experiment 1, spatial location was still needed to select the right target set and was therefore partially relevant to the task. Although Experiment 2 was more like a Simon task where spatial location was completely incidental to the task, further research is needed to address the relationship between the congruence effect we found and the traditional Simon effect. Even if the same mechanism was involved in our task and in a typical Simon task, differences in task characteristics may have contributed to the differential length of persistence of the spatial codes (see, e.g., Roswarski & Proctor, 1996).

One may speculate that the same type of spatial code that gives rise to the standard Simon effect was responsible for the congruence effect observed here. Maybe when our subjects maintained the letter set across the delay, they also maintained the spatial codes associated with the letters. Instead of undergoing decay, these spatial codes may have had a prolonged lifetime. However, this speculation was not supported in Experiment 2, as the pattern of the congruence effect was different for the single and double display conditions, even though, presumably, the same maintenance process was involved in both conditions. Furthermore, examination of the eccentricity factor in the discussion of Experiment 2 showed that the congruence effect tended to be larger or more reliable when the probe was presented in the study display at a larger eccentricity. This was opposite to a finding by Hommel (1993a) showing a reduced Simon effect at larger eccentricity.

Alternatively, one may assume that spatial location information can be represented in different levels of the cognitive system (see Johnson, 1992, for a discussion of the levels). In addition to producing short-lived perceptual codes, the spatial location of a stimulus may also be coded in memory as part of the spatial context associated with the presentation of the stimulus. Although context representation has long been considered a central ingredient for long-term episodic memory (e.g., Johnson, Hashtroudi, & Lindsay, 1993), it is only starting to be emphasized in working-memory research. For example, Baddeley (2000) added to his working-memory model (Baddeley & Hitch, 1974) an "episodic buffer" where multiple sources of information in working memory are integrated and stored temporarily. In long-term memory, context information can be reactivated by item cues. It is possible that in our tasks the presentation of the probe served as a cue that reactivated the spatial context associated with stimulus presentation earlier in a trial. This may bring the irrelevant spatial codes into the response selection process and generate the congruence effect we observed. In other words, the spatial code may not be present during the delay interval but rather may be reactivated upon the presentation of the probe item.

This reactivation explanation also helps to account for the different patterns of the congruence effect across the two display conditions in Experiment 2. Participants may, while retrieving the relevant target information, also reactivate the location of the noise stimuli. Therefore, the spatial codes from the noise stimuli may counteract those from the study set, resulting in a reduced or absent congruence effect (actually only present in the error rate data) for the double display condition relative to the single display condition. If this reactivation explanation is correct, it would also suggest that the spatial codes involved in Experiment 2 cannot simply be the consequence of attentional orienting to the imperative stimulus, as was proposed in some perceptual Simon effect studies (Roswarski & Proctor, 1996; Stoffer, 1991; Umiltà & Nicoletti, 1992). This is because, given that shifting attention to the two target letters should be similarly involved in both the single and the double display conditions, we would expect to find the same pattern of congruence effect across the two conditions, but we did not.

There is also a possibility that the spatial codes were not generated until the probe display. That is, participants may have maintained a visual representation of the entire study display in working memory and, when the probe was presented, mentally scanned that representation. Spatial codes were generated during the scanning process. Although this possibility is consistent with the reactivation explanation, it is unlikely that participants adopted this strategy. For example, in Experiment 1, if participants knew from the cue display that they were only going to be tested on the two letters on the left, it seems unlikely that they would spend the effort in maintaining the two letters on the right.

Independent of our studies, Hommel (2002) has recently reported a similar memory-based spatial congruence effect with a different task. He asked participants to respond to the shape (circle or square) of an object by pressing either a left-hand or a right-hand key. The object, which could be on either the left or right side of the screen, was selected from an array of four objects based on a colour cue. Hommel showed that even when the cue was presented as long as 1000 ms after the relevant object was perceptually masked, the spatial information associated with that object still influenced response selection and generated a spatial congruence effect (Experiment 2). Hommel proposed that spatial information was automatically integrated with nonspatial information in representing the previewed object, and the act of retrieving the nonspatial information (i.e., colour) would (re)activate the associated spatial information and generate the memory-based spatial congruence effect. Clearly, this proposal is compatible with the reactivation idea offered above to account for our current results.

It is also worth noting that Hommel (2002) referred to "object files" (Kahneman, Treisman, & Gibbs, 1992) in discussing the integrated representation of an object (which may further form more complex "event files" containing both stimulus information and associated response information, see Hommel, 1998). As the concept of "object file" emphasizes a single representation of multiple attributes of an object and the persistence of such a representation over time, it shares some central features with the episodic buffer of Baddeley (2000) and the idea of bound feature information in working memory (e.g., Mitchell, Johnson, Raye, Mather, & D'Esposito, 2000) and long-term memory (e.g., Chalfonte & Johnson, 1996). This reflects a convergence of perception research, working-memory research, and long-term memory research.

A surprising and robust finding from the two experiments was the reversal of the direction of the congruence effect depending on the type of responses that participants made. When a yes response had to be made, participants were faster if the stimulus location corresponded to the response key location than if it did not; when a no response had to be made, participants were slower if the two locations corresponded than if they did not. No similar finding was previously reported in the literature as the Simon effect has been primarily studied with perceptual discrimination tasks that do not involve yes/no responses.

Although there have been several recent studies reporting reversals of the Simon effect (Marble & Proctor, 2000; Proctor & Lu, 1999; Tagliabue, Zorzi, Umiltà, & Bassignani, 2000), our finding reminds one of a classical study of Hedge and Marsh (1975). Their task was like a standard Simon task where participants were shown a red or green light in either the left or the right visual field except that two response buttons, one on the left and one on the right, were permanently coloured in either red or green. There were two experimental conditions. In the *same-colour mapping* condition, participants were instructed to press the button of the same colour as that of the stimulus. The typical Simon effect was found in this condition—reaction time was faster when the stimulus and the response button were spatially corresponding than when they were not. In the *alternate-colour mapping* condition, participants were instructed to press the button different in colour from that of the stimulus. In this condition, surprisingly, a reversed Simon effect was found—reaction time was slower when the stimulus and the response button were spatially corresponding than when they were not.

To account for this reversal, Hedge and Marsh (1975) proposed a logical recoding principle. Based on the assumption that participants make their responses by applying a rule to transform (or to *recode* in their terms) the relevant stimulus attribute (i.e., colour) to the appropriate response code (i.e., left or right response key), the principle states that in trials where this transformation rule can be successfully applied to the irrelevant dimension (i.e., location), responses will be faster, relative to when the rule cannot be applied. As the rule in the same-colour mapping condition was supposed to be an "identity" rule, this rule applied to trials with congruent spatial locations. In the alternate-colour mapping condition, the rule was supposed to be an "alternate" rule that applied to trials with incongruent spatial locations. This way, the principle explains why spatially congruent trials were faster than spatially incongruent trials in the former condition but the pattern was reversed in the latter condition. There is still a controversy in the field regarding the validity of the logical recoding principle (e.g., De Jong et al., 1994; Zhang, 2000).

We suggest that in the same-colour mapping condition of the Hedge and Marsh (1975) study, participants were essentially making a yes response when they tried to press the response key the colour of which was the same as (or matched) that of the stimulus. Similarly, when they tried to press the response key the colour of which was different from (or mismatched) that of the stimulus in the alternate-colour mapping condition, they were essentially making a no response. Therefore, the two conditions in their study can be mapped onto the two types of response in our study. This may account for the finding that a reversal of the congruence effect was found in both studies.

On the other hand, our study is also related to research in the "same–different" matching literature (see Farell, 1985, for a review). It has been found that when participants were asked to compare two multidimensional stimuli based on a subset of all the dimensions, attributes on the irrelevant dimensions had opposite effects on the same and different responses (e.g., Proctor, Van Zandt, & Watson, 1990). While increased similarity on irrelevant dimensions facilitated yes responses but interfered with making no responses, decreased similarity facilitated no responses but interfered with making yes responses. This is consistent with our finding that for the yes trials, the irrelevant spatial location information was associated with faster responses when it was congruent with the relevant response code than when it was incongruent, and for the no trials the pattern was exactly the opposite.

Therefore, the reversal of the congruence effect in the current study suggests a link between the same–different matching literature and the Simon effect literature. One particular implication of this link is that the logical recoding principle is not an ad hoc proposition specific to the task of Hedge and Marsh (1975), but rather reflects central characteristics of the response selection process. Consequently, in evaluating different theories of the Simon effect, those that explicitly incorporate this principle, such as De Jong et al. (1994), should be given more weight.

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