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Change detection evokes a Simon-like effect

Giovanni Galfano [a,*], Veronica Mazza [b,c], Luigi Tamè [c], Carlo Umiltà [d], Massimo Turatto [b,c]

[a] Dipartimento di Psicologia dello Sviluppo e della Socializzazione, Università di Padova, Via Venezia, 8, 35131-I Padova, Italy
[b] Dipartimento di Scienze della Cognizione e della Formazione, Università di Trento, Rovereto, Italy
[c] Centro Interdipartimentale Mente-Cervello, Università di Trento, Rovereto, Italy
[d] Dipartimento di Psicologia Generale, Università di Padova, Padova, Italy

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Abstract

A change detection paradigm was used to estimate the role of explicit change detection in the generation of the irrelevant spatial stimulus coding underlying the Simon effect. In one condition, no blank was interposed between two successive displays, which produced efficient change detection. In another condition, the presence of a blank frame produced a robust change blindness effect, which is crucially assumed to occur as the consequence of impaired attentional orienting to the change location. The results showed a strong Simon-like effect under conditions of efficient change detection. By contrast, no Simon-like effect was observed under conditions of change blindness, namely when attention shifting towards the change location was hampered. Experiment 2 supported this pattern by showing that a Simon-like effect could be observed when the blank was present, but only when participants detected the change by means of a cue that was informative as to change location. Overall, our findings show that a Simon-like effect can only be observed under conditions of explicit change detection, likely because a shift of attention towards the change location has occurred.

PsycINFO classification: 2346; 2323

Keywords: Simon effect; Visual attention; S–R compatibility; Change detection

1. Introduction

The Simon effect refers to the observation that performance in two-choice reaction time (RT) tasks is more efficient when the location of a target stimulus spatially corresponds to the location of the appropriate response key than when it does not, despite the fact that the spatial dimension of the target is task-irrelevant (e.g., Simon & Small, 1969). This phenomenon has been the focus of intensive study in the last 30 years, which resulted in the clarification of several characteristics of the underlying mechanisms. For instance, there is a wide agreement that the locus of the Simon effect resides at the response-selection stage (for a review, see Lien & Proctor, 2002). Dual-process models (e.g., De Jong, Liang, & Lauber, 1994; Eimer, Hommel, & Prinz, 1995; Kornblum, Hasbroucq, & Osman, 1990) hold that both task-relevant (e.g., colour, in a colour discrimination task) and task-irrelevant (i.e., space) stimulus dimensions activate response codes. When the spatial codes activated by the task-relevant and task-irrelevant features are different, a competition between response codes is generated that needs to be resolved before the correct response can be executed.

One of the open questions in the literature concerns the determinants of the generation of the irrelevant spatial code for the target stimulus. With this regard, two hypotheses have been proposed that emphasise different aspects of the environmental information to explain the mechanisms underlying the creation of the stimulus spatial code.

* Corresponding author. Tel.: +39 049 8276535; fax: +39 049 8276511.
E-mail address: giovanni.galfano@unipd.it (G. Galfano).

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According to the 'attention shift' hypothesis, the irrelevant spatial code would result from a lateral shift of attention to the location occupied by the target stimulus, triggered by the onset of the stimulus itself (Stoffer & Umiltà, 1997; Umiltà & Nicoletti, 1992). The alternative hypothesis, known as the 'referential coding' hypothesis (Hommel, 1993), states that the irrelevant spatial code is generated as a result of the comparison that is assumed to take place between the location of the target stimulus and the location of an intentionally defined reference stimulus (e.g., the fixation point).

Predictions stemming from these two accounts have often been set in opposition in the literature, with some studies reporting evidence in support of the attention shift hypothesis (e.g., Ansorge, 2003; Nicoletti & Umiltà, 1994; Notebaert, Soetens, & Melis, 2001; Rubichi, Nicoletti, Iani, & Umiltà, 1997; Zorzi, Mapelli, Rusconi, & Umiltà, 2003) and others favouring the referential coding hypothesis (e.g., Bosbach, Prinz, & Kerzel, 2005; Hommel & Lippa, 1995; Kerzel, Hommel, & Bekkering, 2001). Accordingly, it seems that both attention shifting and referential coding play a major role in spatial code formation, and perhaps the two accounts should not be treated as mutually exclusive.

In the present study, instead of focussing on this long-lived debate, we aimed to investigate the processes subtended to the generation of the stimulus spatial code by adopting a different perspective. Both the attention shifting and the referential coding accounts of the Simon effect have linked the processing of the spatial code to attention, to some extent at least. Whereas the former account basically postulates that the spatial code results from attention shifting, the referential coding approach claims that attention is shifted after spatial code has been generated. Under the assumption that attended events are likely to be consciously represented (e.g., Posner & Boies, 1971; Umiltà, 2000; cf. Lamme, 2004), we were interested in exploring further the issue of whether conscious representation of the stimulus associated to the task-irrelevant spatial code is a prerequisite for observing the Simon effect (see Treccani, Umiltà, & Tagliabue, 2006). More specifically, we tried to assess whether awareness of the target stimulus is critical for forming the stimulus spatial code by relying on a change detection paradigm in which participants were required to detect a change randomly occurring in one of two laterally disposed visual arrays. The crucial role of attention for change detection has been unequivocally established, in that successful change detection implies that attention has been shifted towards the change location, as shown by several studies (e.g., Cavanaugh & Wurtz, 2004; Cole & Liversedge, 2006; Cole, Kentridge, & Heywood, 2004; Mazza, Turatto, & Umiltà, 2005; Rensink, O'Regan, & Clark, 1997; Scholl, 2000; Wright, 2005; Yaxley & Zwaan, 2005; see Rensink, 2002, for a review). In addition, in the change detection paradigm, attention can be prevented from being attracted to the change location by interposing a blank frame in between the original and the modified stimulus displays. This manipulation results in the *change blindness* phenomenon, whereby even large changes in the visual image remain unnoticed. Change blindness is explained by the fact that the blank frame masks the signal produced by the visual change, thus impairing the correct allocation of attention to the change location (Turatto, Bettella, Umiltà, & Bridgeman, 2003).

In the present set of experiments, we looked for stimulus–response compatibility effects related to the 'change-present' response key and the location of the change (when present) along the horizontal meridian. As anticipated above, the change could occur in one of two lateralised arrays of objects. Because spatial location of the change was irrelevant to the task at hand, we refer to this phenomenon as a Simon effect. However, because to our knowledge no evidence to date is available in the literature concerning possible Simon effects in tasks requiring to report the presence vs. absence of the target stimulus, we refer more properly to a 'Simon-like' effect in order to differentiate the phenomenon under investigation in the present study from the classic Simon effect, traditionally observed under conditions in which a single stimulus is shown and participants are required to discriminate its defining attributes according to a predefined target feature. Clearly, we were mainly interested in change-present trials as, in trials in which no change occurred, no change-response compatibility could be established.

In Experiment 1, we used a traditional change blindness paradigm. Because correct change detection can be used to infer that attention had been correctly allocated to the object that had changed (Rensink et al., 1997), it can be expected that a Simon-like effect should occur under conditions of successful change detection (i.e., better performance when the change is related to an object located on the same side as the 'change-present' response key, compared to when the change concerns an object located on the opposite side as the 'change-present' response key) . By contrast, no Simon-like effect should emerge if attention shifting towards the task-relevant stimulus is hampered (i.e., under conditions of change blindness) and no referential code can be established.[1] That is, no differences in performance should be observed as a function of change location, because participants' attention was likely prevented from shifting towards the change location.

However, because lack of awareness of change does not necessarily imply lack of attention to the change location or region, in a second experiment we combined the change detection task employed in Experiment 1 with a spatial cueing paradigm. Note that Treccani et al. (2006) found a (reversed) Simon effect when attention shifts occurred but the stimulus remained nonetheless undetected (see below for a discussion of this issue). Basically, by using a highly predictive cue, we aimed to induce a directional bias in

[1] We thank Wim Notebaert and an anonymous reviewer for drawing our attention on the view that referential coding can only take place if the change is correctly detected.

attention shifting, the purpose being that of providing a highly reliable measure of the locus of attention (e.g., Posner, Nissen, & Ogden, 1978). This is particularly true during trials in which the change, although present, occurred in the array opposite to the one that had been cued. In these trials, not only we expected participants to miss changes, but we also wanted to make sure that their attention had been shifted towards the array opposite to the one in which the change took place.

2. Experiment 1

The likelihood to shift attention efficiently towards the change location was manipulated in two conditions. In one condition, a change occurred randomly in one of the two lateralised arrays of elements, without concomitant visual disturbances. In another condition, before the change occurred, a blank frame was briefly presented that hindered attention shifting to the change location, with the purpose of inducing change blindness. Participants were asked to respond as fast as possible depending on whether they detected a change in one of the two arrays. On change trials, participants also performed a recognition test concerning the type of change, to ensure that they both detected and recognised the change consistently.

In the first condition, in which the change was accompanied by the corresponding visual transient, we predicted a Simon-like effect relative to the location of the change (left vs. right array), as a result of attention shifting towards that location, and thus allowing for the establishment of a referential code. To test this prediction, we focused on change-present trials in which the change was both detected and recognised, and looked for possible differences in performance between trials in which the change location was spatially corresponding to the location of the 'change-present' response key, and trials in which the change location was spatially non-corresponding to the location of the 'change-present' response key. Because no other extraneous transients occurred at the time of change, attention was likely to be shifted to the change location and a referential code could be established. As a result, we expected an advantage in performance for corresponding over non-corresponding trials, that is a Simon-like effect.

In the second condition, in which the blank frame was introduced, we focussed on trials in which the change, although present, was neither detected (i.e., trials in which participants pressed the 'change absent' key), nor recognised. In other words, we looked for a Simon-like effect, if any, under conditions of inattention. To this purpose, we compared performance between trials in which change location was spatially corresponding or spatially non-corresponding to the location of the 'change absent' response key. If conscious representation of the spatial event is necessary for a Simon-like effect to occur, then one should expect no Simon-like effect under these conditions. Indeed, when the change remains unnoticed, it is likely that attention has not been shifted towards its location, and no referential code could be established.

2.1. Method

2.1.1. Participants

Twenty-four undergraduates (17 female; 2 left-handed; age range: 19–28 years) from the University of Padua participated in the experiment as volunteers. All reported normal vision and were unaware of the purpose of the experiment.

2.1.2. Apparatus and stimuli

An IBM-compatible Pentium computer was used for controlling the timing of events, generating stimuli and recording responses. Participants sat in a dimly lit room with their head positioned on a headrest, at a viewing distance of 57 cm from a 17-in. colour monitor (640×480, 60 Hz).

Stimuli appeared on a black background, and consisted of two lateralised arrays, each composed of six objects arranged in a 3×2 matrix (7.4 cm $\times$ 4.7 cm; see Fig. 1). The shape of each object was chosen randomly among circles (2 cm in diameter), triangles (2 cm in side) and squares (2 cm in side). The distance between the objects in each array was 0.7 cm. Each matrix was centred 8.7 cm apart from the centre of the screen, aligned with the horizontal meridian. The colour of each object was chosen randomly among red, green, and blue.

2.1.3. Design and procedure

Three within-participant factors were manipulated. Type of change (colour vs. shape) and change-response correspondence (corresponding vs. non-corresponding) varied unpredictably on a trial by trial basis, whereas blank presence (present vs. absent) was varied across two blocks of 240 trials each. In each block, the change always occurred on 50% of trials, and consisted of one of the objects in the arrays changing its colour (60 trials) or shape (60 trials). The change occurred equally often in the left and right array. In the blank-present block, the change always occurred during the blank frame. In the blank-absent block, the change occurred without any concomitant visual disturbance. The order of blocks was counterbalanced across participants.

Each trial began with the onset of a white central fixation circle (0.4 cm of diameter) lasting for 500 ms. Then, two successive displays, each consisting of two arrays of objects, appeared for 500 ms, separated by an Interstimulus Interval (ISI) of either 0 (blank-absent condition) or 300 ms (blank-present condition). On half of the trials the two displays were identical, on the remainders they differed in one of the objects. Synchronous with the onset of the second display, a centrally presented 20-ms 2000-Hz tone (see Fig. 1) prompted participants to report as fast as possible whether a change had occurred. RTs were recorded synchronous to tone onset. Participants

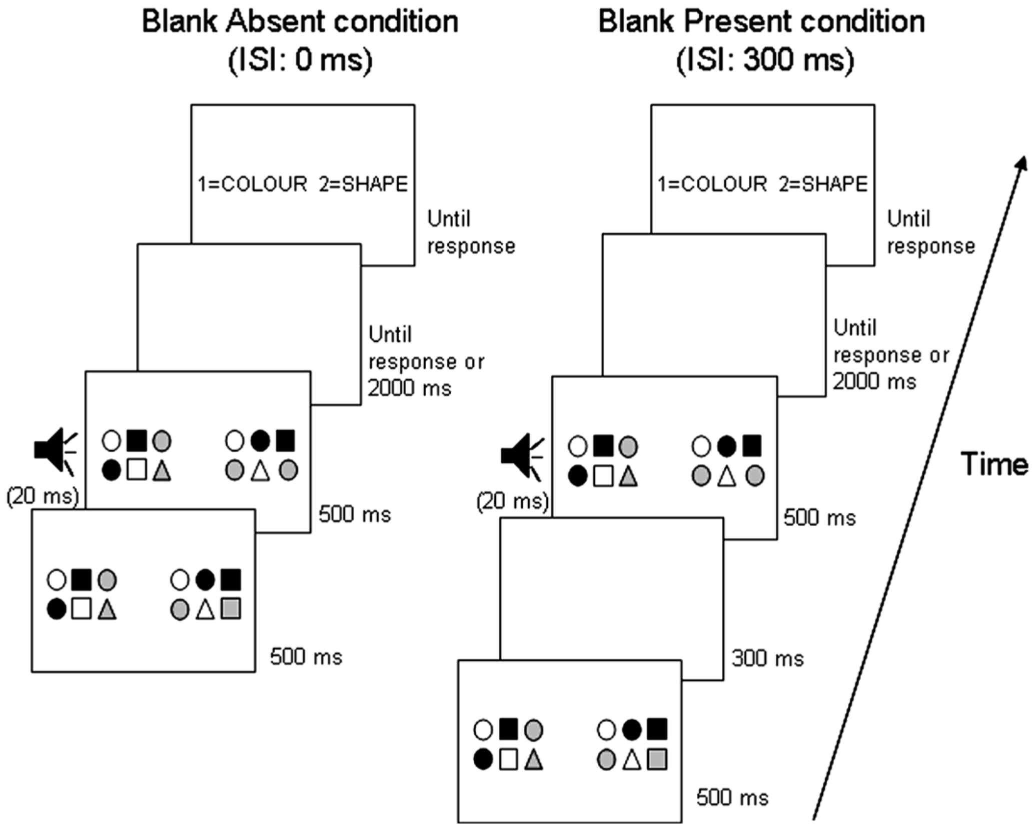

Fig. 1. Sequence of events on a single trial in Experiment 1. A 'blank-absent' trial (on the left) and a 'blank-present' trial (on the right) are illustrated. In this example, the change occurs in the array located on the right side in both trials. See text for details.

responded by pressing one of the two keys of the keyboard with their left or right hand. The assignment of keys to responses was counterbalanced across participants. After the offset of the second display, the screen went black for 2000 ms or until a response was made, whichever came first. On change trials, regardless of whether participants detected the change, a display appeared asking participants to indicate the type of change (colour vs. shape) with no temporal restrictions. After they pressed one of the two keys allowed for responding, a fixed 2000-ms intertrial interval followed. Prior to each experimental block, participants performed 16 practice trials.

2.2. Results

2.2.1. Accuracy data

The analyses reported below refer to change trials, as no-change trials served no purpose to test our predictions.

Overall, participants correctly reported a change on 80% of change trials in the blank-absent condition but only on 40% in the blank-present condition, thus showing a clear change blindness for the latter condition. A three-way Analysis of Variance (ANOVA) on proportion of correct responses gave statistical support to this interpretation, revealing a significant effect of blank presence, $F(1,23) = 136.143$, $\text{MSE} = 0.057$, $p < .0001$, indicating that participants' ability to detect the change was strongly weakened in the blank-present condition ($M = 0.40$, $\text{SE} = 0.02$) as compared to the blank-absent condition ($M = 0.80$, $\text{SE} = 0.02$). In addition, a significant main effect emerged for change-response correspondence, $F(1,23) = 6.797$, $\text{MSE} = 0.012$, $p = .016$, due to an overall performance advantage of corresponding trials ($M = 0.62$, $\text{SE} = 0.03$) over non-corresponding trials ($M = 0.58$, $\text{SE} = 0.03$). Both the blank presence × change-response correspondence interaction, $F(1,23) = 16.362$, $\text{MSE} = 0.01$, $p = .001$ and the blank presence × type of change interaction, $F(1,23) = 16.228$, $\text{MSE} = 0.09$, $p = .001$, were significant. No other sources of variance were significant (all $ps > .1$). Pairwise comparisons (two-tailed t-tests) aimed to qualify the blank presence × change-response correspondence interaction revealed that participants, in the blank-absent condition, were more accurate in corresponding ($M = 0.86$; $\text{SE} = 0.02$) than in non-corresponding trials ($M = 0.76$; $\text{SE} = 0.03$) $t(23) = 4.54$, $p < .0001$. By contrast, no such a difference emerged when the blank was present ($p > .3$). Hence, the effect of correspondence on change detection performance seems to reflect the influence of stimulus–response correspondence on the error rate in the choice task, but is unrelated to the efficiency in change detection. As for the blank presence × type of change interaction, when the blank was absent, participants were more accurate in detecting a change in shape ($M = 0.84$;

SE = 0.02) than in colour ($M = 0.77$; SE = 0.03), $t(23) = 4.31$, $p < .0001$. This perhaps reflects the fact that a dynamic discontinuity is more powerful in capturing attention than a static discontinuity (e.g., Lu & Zhou, 2005). When the blank was present, no difference between shape and colour was evident ($p > .1$).

2.2.2. RT data

Before the analyses were carried out, outliers (RTs exceeding 2 SD) were removed from the data set. This resulted in the trimming of a maximum of 2.4% of trials for each participant.

In order to assess the presence of a Simon-like effect when attention was likely to be shifted to the change location and a referential code could be established (i.e., in the blank-absent condition), only trials in which *correct detection* was accompanied by *correct recognition* were selected. By contrast, for assessing the presence of a Simon-like effect when attention shifting towards the change location was hampered and a referential code could hardly be formed (i.e., in the blank-present condition), only trials with *incorrect detection* and *incorrect recognition* were included.

An ANOVA with blank presence, change-response correspondence, and type of change as factors, revealed a significant effect of blank presence, $F(1,23) = 4.40$, MSE = 150234.14, $p = .04$, with overall higher RTs for the blank-present condition ($M = 581$ ms, SE = 16) compared to the blank-absent condition ($M = 525$ ms, SE = 11). The blank presence × change-response correspondence interaction was also significant $F(1,23) = 7.56$, MSE = 23929.49, $p < .01$. No other sources of variance were significant (all ps > .2). Planned comparisons revealed the presence of a Simon-like effect under conditions of efficient attentional allocation (no-blank condition), as RTs for corresponding trials ($M = 508$, SE = 17) were lower than RTs for non-corresponding trials ($M = 541$, SE = 14), $t(23) = -3.62$, $p < .001$. By contrast, no significant difference ($p > .4$) between corresponding ($M = 586$, SE = 22) and non-corresponding ($M = 575$, SE = 25) trials emerged when attention shifting towards the change location was hampered by the presence of the blank, which also resulted in preventing the formation of a referential code. The low number of observations for corresponding ($M = 9$, max = 19 and min = 1 per participant) and non-corresponding ($M = 8$, max = 16 and min = 3 per participant) trials in the blank-present condition did not allow for performing a quantile analysis for assessing whether a Simon-like effect was present at least in lower RT bins, as it has been reported in standard Simon paradigms (e.g., De Jong et al., 1994). In this regard, however it is worth remarking that significant overall Simon effects (i.e., significant overall differences between corresponding and non-corresponding trials) have been reported with RTs in the same order of magnitude as those we observed in the blank-present condition (e.g., Van Der Lubbe, Jáskowski, & Verleger, 2005).

We also attempted to determine the presence of a Simon-like effect in the blank-present condition for the hit trials. A Simon-like effect might have been expected on these trials, given that the change was both detected and recognised despite the blank presence, indicating that attention was shifted towards the change location and that a referential code could have been established. To this end, we performed an ANOVA on RTs in the blank-present condition including only trials with *correct detection* and *correct recognition*, with change-response correspondence and type of change as factors. Four participants had to be removed because they had no data in at least one of the cells in the design. No sources of variance were significant (all ps > .2), and no hint of differences between corresponding ($M = 717$, SE = 31) and non-corresponding ($M = 692$, SE = 31) trials emerged. We suspect that the lack of a Simon-like effect on these trials might be due to the very few data points available for both corresponding ($M = 11$, max = 20 and min = 1 per participant) and non-corresponding ($M = 12$, max = 22 and min = 1 per participant) trials.

2.3. Discussion

In the present experiment, two arrays of stimuli were shown, the target being a change occurring in one of the two arrays. In the blank-absent condition, a Simon-like effect was predicted for changes that were both detected and recognised, as attention could be efficiently allocated to the change location. By contrast, no Simon-like effect was expected in the blank-present condition for changes that were missed and not recognised, as the blank should have both prevented attention from being efficiently oriented towards the change location and hindered the establishment of a referential code. RT data confirmed that, under conditions of change blindness, no Simon-like effect was observed. Importantly, however, when the change occurred without concomitant visual disturbances, a clear Simon-like effect was observed as participants could efficiently shift attention towards the change location and create a referential code bound to change location.

Accuracy data substantiated our interpretation, showing a better performance for corresponding than non-corresponding trials, but only when attention could be correctly allocated to the change location. This, in turn, rules out any possible speed-accuracy tradeoff.

Although the presence of the blank had a strong impact on perceptual performance, it is important to remark that the effects of correspondence on change detection can hardly be interpreted as strictly related to perceptual performance. Indeed, it seems quite implausible that the location of a response can make change detection easier.

Overall, we interpret these results as evidence that the Simon-like effect we observed, being present only when explicit change detection was achieved, originates from attention shifting towards the change location, which is also the only condition in which a referential code can be established.

However, it could be argued that interpretation of change-missed trials with reference to where attention has been allocated is more problematic. Indeed, it may be objected that even if attention is necessary for change detection (e.g., Rensink et al., 1997), it may not be sufficient. That is, under conditions of change blindness, we cannot really be sure that the changes went unnoticed because attention had not been shifted towards the change location in the second display. In addition, it may be argued that attention could have shifted towards the correct array (the one in which the change was about to occur) in the first display, but selected only few items for consolidation in visual short-term memory (e.g., Averbach & Coriel, 1961). If the changing object was not one of those consolidated into visual short-term memory, then the change could have been missed despite an effective shift of attention to the side of the screen where the change had occurred.

In order to ensure that, when the blank was present, attention was really not shifted towards the change location, in the next experiment we provided participants with a predictive cue about the most likely location for the change to take place. Along these lines, we aimed to induce a directional bias in attention shifting, with the purpose of achieving a more reliable measure of the locus (in terms of left vs. right array) of attention (e.g., Posner et al., 1978). In particular, we were interested in examining trials in which the change, although present, occurred in the array opposite to the one that had been cued (invalid trials). On these trials, we expected participants to fail to notice changes, as their attention was likely shifted towards the array opposite to the change.

3. Experiment 2

Experiment 2 was modelled after the blank-present condition of the previous experiment. In the first display, one object in both the left and right array was surrounded by a cue (a bright white square). Participants were told that on change trials (50% of the total), the cue indicated the most likely locations (one in the left and one in the right array) for the change to occur. After the blank, in the second display, only one of the two cues was visible and briefly flickered in order to increase its saliency. Participants were informed that, during change trials, the object surrounded by the cue was the one that had changed (either in colour or shape) with 70% probability. We made the cue both endogenous (because it was informative as to change location) and exogenous (because it was briefly flickered) in order to boost the effectiveness of our cueing manipulation. Unlike the previous experiment, there was no need to use a tone to prompt participants for responding. Also, in order to decrease the duration of the whole experimental session, we decided to remove the recognition test after the change detection task.

In the majority of trials (valid trials, i.e. trials in which the cue correctly indicated the side of change, when this occurred), we expected participants to be able to detect changes. We also predicted a Simon-like effect, as a consequence of efficient attention shifting towards the change location (and cued location) despite the presence of the blank frame.

Two possible outcomes might have been expected in the present experiment with reference to invalid trials (i.e., trials in which the cue and the change were located in opposite arrays). Given that shifting attention to the location opposite to the change location should likely result in missing the change, this would also prevent the establishment of a referential code related to the change itself. Hence, if the Simon-like effect in the present experiment was primarily caused by explicit awareness of the task-relevant event (i.e., the change), we should not expect any regular Simon-like effect. Conversely, if the irrelevant spatial coding in the present experiment is primarily caused by an attention shift towards cue location, then a significant reverse Simon-like effect should emerge.

3.1. Method

3.1.1. Participants

Twelve undergraduates (nine female; all right-handed; age range: 21–31 years) from the University of Padua participated in the experiment as volunteers. None had participated in the previous experiment. They reported normal vision and were unaware of the purpose of the experiment.

3.1.2. Apparatus and stimuli

The same apparatus as in the previous experiment was used. Stimuli were the same as in the blank condition of the previous experiment. The cue was a bright white square (2.8 cm of side) centred on one of the six items in the two arrays.

3.1.3. Design and procedure

Three within-participants factors were manipulated, Type of change (colour vs. shape), Change-response correspondence (corresponding vs. non-corresponding), and Cue validity (valid vs. invalid). All factors were varied unpredictably on a trial by trial basis. There were five blocks of 80 trials each. In each block, the change always occurred on 50% of trials. The cue was valid in 70% of change trials (28), and invalid in the remaining 30% of change trials (12). During invalid trials, the change occurred in the array opposite to the cued one. More specifically, during these trials, the change occurred in any of the objects of the uncued array in the second display, except for the object that had been cued in the first display. The change occurred equally often in the left and right array (14 trials with a valid cue and six trials with an invalid cue), and consisted of one of the objects in the arrays changing its colour or shape (seven trials with a valid cue and three trials with an invalid cue).

The experiment proceeded as the blank condition of Experiment 1, with the following exceptions. The first display, presented for 500 ms, consisted of the two arrays of objects with a cue surrounding one of the objects in each array. After the 300-ms blank, the second display appeared with no cues. Eighty milliseconds after the onset of the second display, only one of the cues shown in the first display was presented both on change and no-change trials (see Fig. 2). The adoption of this procedure was justified based on the following rationale. Firstly, we wanted to provide landmarks of the objects that were more likely to change in the second display. This was done because a single cue in the second display would have been of little help for a successful change detection if no monitoring had been done before the blank, given that we used a number of elements likely exceeding short-term memory capacity (e.g., Luck & Vogel, 1997; Delvenne, 2005). The reason for not presenting a single cue already in the first display relies on the well-known observation that in the Simon effect the activation resulting from the generation of the stimulus spatial code is short-lived and spontaneously dissipates over time (e.g., Hommel, 1994). Thus, by presenting the single cue in the second display we wanted to ensure the stimulus code to be still active.

Participants were encouraged to pay attention to the cue, in that it was highly predictive of change location when a change occurred. They knew, however, that if the cued object in the second display was not changed, there might have been a change to another object in the opposite array. Participants were instructed to report as fast as possible whether a change had occurred. RTs were recorded synchronous to the onset of the second display. Prior to the experimental session, participants performed 32 practice trials.

3.2. Results

3.2.1. Accuracy data

Overall, participants reported that a change had occurred on 19% of no-change trials. In addition, participants correctly reported a change on 87% of change trials in the valid cueing condition but only on 19% in the invalid cueing condition, which indicates that when the cue was valid, participants could efficiently shift their attention towards the change location. Thus, the cue was strongly effective in preventing change blindness (also see Cavanaugh & Wurtz, 2004).

Data analysis included change trials only, and was conducted separately for valid and invalid trials.

As for valid trials, a two-way ANOVA on proportion of correct responses, with Type of change and Change-response correspondence as factors, revealed a significant main effect of change-response correspondence, $F(1,11) = 7.431$, $MSE = 0.003$, $p < .05$, indicating that accuracy was higher in corresponding trials ($M = 0.90$, $SE = 0.02$) compared to non-corresponding trials ($M = 0.85$, $SE = 0.02$).

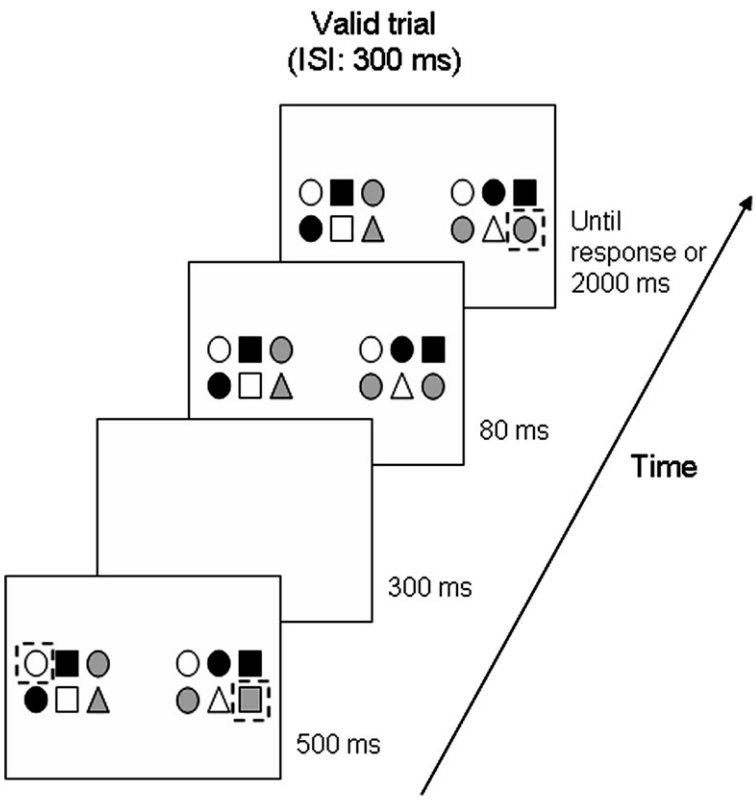

Fig. 2. Sequence of events on a single trial in Experiment 2. Unlike Experiment 1, there were only blank-present trials. On change trials, the cue (a white dashed square, here depicted in black) was 70% predictive of the change location. In this example, the change occurs in the array located on the right side. A valid trial is illustrated. See text for details.

The two-way interaction was far from significance ($p > .4$). The results seem to indicate that when participants shift their attention towards the change location as suggested by the cue, a clear Simon-like effect can be observed.

As for invalid trials, the two-way ANOVA did not reveal any significant source of variance ($p > .3$).

Hence, the results suggest that when the cue was invalid, and participants' attention was shifted to the array opposite to the one in which the change took place, not only change detection was impossible, but no Simon-like effect was evident in accuracy measures.

3.2.2. RT data

The analyses reported below refer to change trials, as no-change trials served no purpose to test our predictions. Before the analyses were carried out, outliers (RTs exceeding 2 SD) were removed from the data set. This resulted in the trimming of a maximum of 1.8% of trials for each participant. Data analysis was conducted separately for valid and invalid trials.

For the valid condition, only trials with correct detection were selected. By contrast, to assess the presence of a reliable Simon-like effect in the invalid condition, following the same rationale as in Experiment 1 and because correct detection in this condition was very low (i.e., 19%), we analysed only trials with incorrect detection, where we have a greater number of trials.

As for valid trials, an ANOVA with change-response correspondence, and type of change as factors, revealed a significant main effect of change-response correspondence, $F(1,11) = 10.884$, $\text{MSE} = 4283.717$, $p < .01$, with overall higher RTs for the non-corresponding condition ($M = 821$ ms, $\text{SE} = 35$) compared to the corresponding condition ($M = 759$ ms, $\text{SE} = 32$). No other sources of variance were significant ($p > .3$). Thus, consistent with the accuracy analysis, a significant Simon-like effect emerged for valid trials.[2]

As for invalid trials, the ANOVA revealed a significant main effect of type of change, $F(1,11) = 5.304$, $\text{MSE} = 1678.250$, $p < .05$. No other sources of variance were significant ($p > .5$). Participants were faster in detecting a change in shape ($M = 789$ ms, $\text{SE} = 28$), as compared to a change in colour ($M = 816$ ms, $\text{SE} = 30$). In light of the pattern emerged in accuracy data, we suspect that a speed-accuracy tradeoff might have affected the data. However, as shown by the analysis, it is very unlikely that this had any impact on the Simon-like effect we reported, as accuracy and latency measures converged, as far as the change-response correspondence factor was concerned. Of more relevance for the purpose of the present study, the results for invalid trials showed no hint of Simon-like effect, as performance in corresponding trials ($M = 804$ ms, $\text{SE} = 32$) was not different from performance in non-corresponding trials ($M = 801$ ms, $\text{SE} = 27$).

3.3. Discussion

The present experiment was designed to discount two alternative accounts for the results of Experiment 1 related to the fact that under conditions of change blindness we cannot be sure about where attention was allocated. There are several possible causes of change blindness in the paradigm we adopted in Experiment 1. We have reasoned that participants might have missed changes because they shifted attention to the wrong array. Another possibility is that participants might have shifted attention to the correct array but selected the wrong few objects due to short-term memory limitations (e.g., Averbach & Coriel, 1961). The combination of these two possibilities may well account for the lack of Simon-like effect on trials in which change was neither detected nor recognised.

In order to strengthen the interpretation that the Simon-like effect originates from attention shifts towards the change location and from the related establishment of a referential code, in the present experiment we used a cueing manipulation devoted to biasing attention towards one of the two arrays. We relied on this technique because spatial cueing paradigms, although producing somewhat mixed results when coupled with traditional Simon paradigms (see, e.g., Ivanoff & Peters, 2000), are among the most reliable instruments to manipulate the allocation of the attentional focus in the visual field (e.g., Posner et al., 1978).

By using a cue that was highly predictive of change location, we biased participants' attention towards one of the two arrays. This was confirmed by the fact that on valid trials (i.e., when the change occurred at the cued location), participants were very accurate in detecting changes, despite the presence of the blank frame. By contrast, on invalid trials (i.e., when the change occurred in the uncued array), participants exhibited a strong change blindness, likely because their attention had been oriented to the 'wrong' array. Importantly, we did observe a robust Simon-like effect on valid trials, whereas no Simon-like effect emerged on invalid trials. Hence, the results support the notion that a Simon-like effect in a change detection task such as that employed in the present study, is contingent on a shift of attention corresponding to the change location and the related possibility for a referential code to be created. Finally, it is important to note that the pattern observed in invalid trials seems to indicate that only

[2] One may argue that according to the attention shifting hypothesis no Simon-like effect had to be expected, because the stimuli producing the Simon effect always appeared at the expected location. However, it may also be argued that, during the blank frame, attention had no object to be engaged in and, when the second display was presented, attention had to be shifted again towards the change location signalled by the cue. According to this line of reasoning, the Simon-like effect observed in valid trials would reflect the fact that change occurred at the expected position, but attention had to be shifted in that very same location, because objects were no longer visible during the blank frame. Evidence consistent with this interpretation can be found in the observation that attention-based phenomena such as inhibition of return only operate when stimuli are visible (e.g., Müller & Von Mühlenen, 2000; Takeda & Yagi, 2000).

explicit change detection is able to elicit a Simon-like effect and that irrelevant spatial coding in the present experiment only takes place with reference to the location of the stimulus which is relevant for the task (i.e., the change, not the cue).

4. General discussion

In the present study, we used change detection as a tool for exploring the possible dynamics underlying the generation of the irrelevant spatial code which is responsible for the Simon effect. In particular, we adopted a change detection paradigm based on the widely shared assumption that explicit change detection requires the allocation of spatial attention towards the change (e.g., Rensink et al., 1997). We want to reiterate that the purpose of the present study was not that of distinguishing between the attention shift hypothesis and the referential coding hypothesis, as both mechanisms have proved to be important for spatial code formation (e.g., Hommel & Lippa, 1995; Rubichi et al., 1997). More simply, we aimed to investigate whether awareness of the target stimulus as assessed by change detection is critical to the observation of Simon-like effects.

In Experiment 1, we devised two change detection conditions, one with and one without blank between the original and the modified display. Whereas participants performed accurately in the former condition, the blank determined a dramatic drop in performance, leading to change blindness. This effect is explained by the fact that the blank frame obscured the transient signal produced by the visual change, which results in disrupting an effective allocation of attention to the change location (Turatto et al., 2003). We exploited this technique and checked for a possible Simon-like effect under conditions of explicit change detection and change blindness. If attention shifting and referential coding take place efficiently only when participants are aware of the target stimulus (i.e., the change in the present experiments), a regular Simon-like effect relative to change location should have emerged only when efficient change detection was achieved because attention was shifted towards the change location. Under conditions of change blindness, we predicted no Simon-like effect, because attention was likely to be either in an unfocused mode, or to be shifted leftwards and rightwards at random because of the blank. Both predictions were confirmed by the results. In Experiment 2, in order to have a more reliable measure of the attentional focus in the blank-present condition, we employed a spatial cueing manipulation, with the purpose of biasing attention by means of a cue that, on change trials, was highly predictive of change location. In so doing, we expected participants to recover from change blindness during valid trials in spite of blank presence. We also expected to find evidence for change blindness during invalid trials. However, unlike Experiment 1, the cueing manipulation allowed us to obtain a more precise idea of where attention was during change blindness. If awareness of the target stimulus was crucial, we predicted a regular Simon-like effect on valid trials, but no Simon-like effect on invalid trials. The results were fully in accordance with these predictions.

Because we wanted to increase the likelihood that participants oriented their attention to the location occupied by the cue, we made the cue both endogenous (i.e., informative as to change location) and exogenous (i.e., peripheral). One may argue that using a peripheral cue might have induced a Simon-like effect relative to cue location, just as it happens in the variant with the accessory stimulus (e.g., Proctor, Pick, Vu, & Anderson, 2005). We dismiss this possibility based on the fact that if the cue were responsible for the Simon-like effect observed on valid trials, then one should have found a reversed (with relation to the cue) Simon-like effect on invalid trials, which was clearly not the case in the analysis conducted on trials with incorrect detection. Importantly, the very different experimental paradigm adopted here makes it difficult to compare this experiment with previous studies on the accessory Simon effect, and thus any clear explanation for the difference in the results is unwarranted. However, we could speculate that the lack of an accessory Simon-like effect in invalid trials might be due to successive shifts of attention in invalid trials. Indeed, participants might adopt the strategy of shifting attention towards the hemifield opposite to the cue location in order to search for a change in that part of the display.

Alternatively, one may wonder whether a Simon-like effect could be found in our study on invalid trials where participants correctly detected a change. Note, however, that very little can be said as concerns possible Simon-like effects on invalid trials because of the limited number of data points for both corresponding ($M = 3$) and non-corresponding ($M = 3$) trials. In light of the results, we conclude that the Simon-like effect in the present paradigm occurs relative to the change location, and is only detectable when participants are explicitly aware that a change has occurred, likely because they shifted their attention towards the change and established a referential code.

Recently, Moore, Lleras, Grosjean, and Marrara (2004) have tested whether stimuli subjected to *inattentional blindness* (i.e., stimuli that are not consciously perceived) can engage response-selection processes. To this purpose, in an accessory-stimulus variant of the Simon task (Simon & Craft, 1970), they used the Simon effect as a behavioural measure to infer the presence of implicit processing, if any. No evidence that accessory stimuli could induce a significant Simon effect under conditions of inattention was observed. In the present study, the rationale was opposite to that of Moore et al., as a Simon-like effect was our main focus, instead of an instrument to investigate implicit processing under conditions of inattention. In addition, unlike Moore et al., in the change detection paradigm we devised, participants were *actively* looking for a change in the display. Thus, unlike inattentional blindness, change blindness results from a failure to process *task-relevant* information, which makes this latter phenomenon even more striking. Moore et al. (2004) did not report any Simon effect when participants were not aware of the accessory stimulus. They concluded that unattended stimuli cannot engage response-selection processes. It is very likely the accessory stimulus was not consciously perceived because in fact attention was not permitted to focus on it, given the highly demanding task participants were engaged in at fixation. In their study, Treccani et al. (2006), by using an accessory-stimulus paradigm combined with a subthreshold spatial cueing procedure, found that a regular Simon effect manifested itself when the accessory stimulus was consciously perceived, whereas the Simon effect reversed when the accessory stimulus was not consciously perceived. Treccani et al. argued that the regular Simon effect was caused by the shifting of attention to the location of the accessory stimulus, whereas the reversed Simon effect was caused by the reorienting of attention from the location of the accessory stimulus to fixation. Also, they argued that the lack of a Simon effect in Moore et al.'s (2004) study was attributable to the fact that attention could not move from fixation to the accessory stimulus. Therefore, one cannot rule out the possibility that a Simon effect (regular or reversed in nature) may be found even in the absence of awareness of the accessory stimulus, as long as attention shifts towards it are not hindered. This very same argument may also apply to the present study. This may well reconcile our results with the pattern reported by Treccani et al., although it should also be kept in mind that the use of different experimental paradigms (i.e., change blindness, inattentional blindness, and subthreshold spatial cueing) and the different types of stimulus–response correspondence (i.e., accessory-stimulus Simon effect vs. standard Simon effect) may play a substantial role in accounting for the different results obtained here and those obtained by Moore et al. (2004) and Treccani et al. (2006). Indeed, it is worth stressing that in the present study, we investigated a Simon-like effect instead of using the variant with the accessory stimulus, which is known to lead to weaker effects in terms of overall magnitude (Notebaert & Soetens, 2003; Proctor & Pick, 1998). Our results fit well with those reported by Moore et al. (2004) and corroborate their conclusion that stimuli that are not attended (i.e., stimuli that undergo inattentional blindness in Moore et al.'s study and change blindness in the present study) cannot engage response-selection processes as assessed by the Simon effect.

To our best knowledge, no evidence to date is available in the literature concerning possible Simon effects in tasks requiring to report the presence vs. absence of the target stimulus. In general, the Simon effect is investigated under conditions in which a single stimulus is shown and participants are required to discriminate its defining attributes according to a predefined target feature (e.g., colour). At variance with the traditional paradigm, in which the target attentional set is very precise (e.g., press the right key if the target is red, press the left key if the target is green), in our task participants were to press the 'change-present' key whatever the feature involved (i.e., colour or shape). Thus, our finding may represent an important generalisation, which adds to other recent demonstrations testifying the robustness and pervasiveness of stimulus–response correspondence effects (e.g., De Houwer, 2004; Tagliabue, Zorzi, & Umiltà, 2002). In conclusion, the present set of results indicates that only conscious and task-relevant events are capable of producing Simon effects. Future work will possibly extend this pattern to other experimental contexts with different stimuli (e.g., naturalistic scenes) and methods for inducing change blindness (see Rensink, 2002).

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