

## FACILITATION AND INTERFERENCE COMPONENTS IN THE SIMON EFFECT

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### INTRODUCTION

The Simon effect arises when subjects are required to make a rapid left or right motor response on the basis of a stimulus dimension other than position (e.g., form), and the stimulus appears in one of two lateralized positions, that is, on the left or on the right (16, for reviews see 10, 17). For example, in a typical Simon task, subjects respond with the left-side key to one stimulus (e.g., a square) and with the right-side key to a different stimulus (e.g., a circle). Although the task requires shape discrimination, and stimulus position is task irrelevant, responses are faster when the position of the stimulus and the position of the response correspond (i.e., corresponding stimulus-response pairings; i.e., the stimulus and the response are both on the right or the left side) than when they do not correspond (non-corresponding stimulus-response pairings; i.e., the stimulus is on one side and the response is on the other side).

Most authors agree that the Simon effect occurs because in the Simon task a spatial code is generated for the irrelevant stimulus location attribute in relation to one of several possible reference axes (see, e.g., reviews in 10, 17).

Another widely shared assumption is that the Simon effect is a response selection phenomenon (e.g., 10). The idea is that the stimulus position code automatically activates its spatially corresponding response code. On trials in which the automatically activated response code corresponds to the code signalled by the relevant stimulus feature, there is no competition at the response selection stage, but rather a facilitation originates from the redundant response codes. Hence, reaction times (RTs) are faster on corresponding trials. On trials in which the automatically activated response code does not correspond to the one signalled by the relevant stimulus feature (i.e., on non-corresponding trials), a competition must be resolved before the correct response is executed. This competition is considered to cause interference. Hence, RTs are slower on non-corresponding trials.

The activation of the corresponding response code by the spatial stimulus code, for which there is behavioural and psychophysiological converging evidence, is often incorporated in a dual-route model (2-4, 8, 9, 11). According to this model,

two processing routes are proposed for response selection after the stimulus identification stage. Through the automatic route, a stimulus automatically activates its spatially corresponding response. Through the non-automatic route, the relevant stimulus dimension is coded and the correct response is selected on the basis of task instructions.

All versions of the dual-route model predict that RT for corresponding stimulus-response (SR) pairings should be faster and RT for non-corresponding S-R pairings should be slower than RT for a neutral, non-lateralized condition. This is because on neutral trials speed of response is not affected by either the automatic fast activation of the correct response, as occurs on corresponding trials, or the conflict between the wrong, but automatically activated response node, and the correct response node, as occurs in non-corresponding trials.

It is clear that the presence of both facilitation and interference is critical for the dual-route model. Indirect evidence of facilitation and interference effects was provided by some studies (7-9, 14, 18). However, the reliability of those effects was not tested. In addition, recently Hietanen and Rämä (1995) found only a facilitation effect, whereas the interference effect was absent.

Because Hietanen and Rämä's (1995) results create difficulties to the dual-route model, we planned a series of experiments to provide definitive evidence on the presence of both facilitation and interference in the Simon effect.

## EXPERIMENT 1

No study to date has addressed this issue by using what would seem to be the most straightforward procedure. It consists in presenting, on neutral trials, the imperative stimulus in a position equidistant from the two response positions. This was the neutral condition that was used in the following experiment. In the present experiment, and in the following ones, facilitation was measured as the RT difference between neutral and corresponding trials, whereas interference was measured as the RT difference between non-corresponding and neutral trials.

## METHODS

*Subjects.* - Twenty-two students of the University of Urbino were selected for the experiment. All were right-handed, had normal or corrected-to-normal visual acuity, and were naive as to the purpose of the experiment.

*Apparatus and display.* - The experiment took place in a dimly lit and noiseless room. The participants were seated facing a cathode-ray tube screen driven by a Tulip dt 386sx computer. The subject's head was positioned in an adjustable head-and-chin rest. The distance between the eyes and the screen was about 45 cm. The visual display comprised the following items (Fig. 1): Three empty boxes,  $3.8^\circ \times 2^\circ$  in size; a  $1^\circ \times 1^\circ$  cross, which was shown  $1.9^\circ$  up (or down) from the geometrical centre of the screen and positioned  $8.3^\circ$  up (or down) from the geometrical centre of the central box; one  $3.8^\circ \times 1^\circ$  filled rectangle and one  $2^\circ \times 2^\circ$  filled square (i.e., the stimuli), which were shown, one at a time, centred in one of the three boxes. For half of the



Fig. 1. - Schematic drawing of the two displays used in Experiment 1.

subjects the fixation point was above and the three empty boxes below the centre of the screen, whereas for the other half the display was reversed.

Subjects responded to the imperative stimulus by pressing one of two lateralized keys (“z” and “/”) with the index fingers that rested on the response keys. Response timing and data collection were controlled by the Micro Experimental Laboratory software system (MEL, 12).

*Procedure.* - On each trial, the sequence of events was as follows. The fixation cross and the three boxes were visible on the screen throughout the trial. On each trial a warning tone (25 ms in duration) was delivered. Subsequently, after an interval of 300 ms, one stimulus (either the square or the rectangle) appeared for 100 ms inside one of the three boxes.

The subjects were instructed to maintain fixation and press one of the two keys as fast as possible upon stimulus presentation, depending on stimulus shape. Half of the subjects used the right-side key for the square and the left-side key for the rectangle, whereas the other half had the reverse assignment. At the end of each trial, the subjects were informed about RT and accuracy through a feedback shown below the fixation cross, followed by a 1-s intertrial interval.

Every participant was tested individually in one experimental session, which comprised 240 trials, splitted into two equal blocks. The first experimental block was preceded by a block of



practice trials. Stimulus presentation occurred according to a quasi-random sequence, with the constraints that both the square and the rectangle appeared an equal number of time in the three boxes, thus requiring half of the time a right hand response and the other half a left hand response.

## RESULTS AND DISCUSSION

Only RTs in the range from 100 to 900 ms were considered for the analysis. Errors amounted to 5.1%. Correct RTs and errors were entered into two ANOVAs with two within-subjects factors, that is stimulus position (left, centre, or right), and response position (left or right).

The RT analysis yielded three significant effects. The first was response position,  $F(1, 20) = 5.14$ ,  $p < 0.05$ , indicating that the stimuli were responded to faster with the right key (284 ms) than with the left key (295 ms). The second was stimulus position,  $F(2, 40) = 6.45$ ,  $p < 0.005$ , indicating that the stimuli that appeared on the centre (284 ms) were responded to faster than the stimuli on either the left (296 ms) or the right (291 ms).

More important was the significant interaction between stimulus position and response position,  $F(2, 40) = 42.22$ ,  $p < 0.0001$ , which showed an overall Simon effect of 35 ms. Pairwise comparisons showed that RT for corresponding trials was significantly faster than RT for neutral trials (276 vs. 284 ms; a facilitation effect of 8 ms), which in turn was significantly faster ( $p < 0.01$ ) than RT for non-corresponding trials (311 ms; an interference effect of 27 ms).

Also, the error analysis showed the significant interaction,  $F(2, 40) = 10.80$ ,  $p < 0.001$ , demonstrating the same pattern as that demonstrated by RTs.

Experiment 1 clearly showed that the Simon effect has two components: a facilitatory component for corresponding responses and an interference component for non-corresponding responses. This is exactly what the dual-route models predict.

More surprising was the fact that the interference component was more than three times as great as the facilitation component. No models seem to predict such a great asymmetry between facilitation and interference. There is, however, the possibility that RT on neutral trials was favoured by visual acuity. The central box, where the stimulus was presented on neutral trials, was closer the fixation than the lateral boxes, where the stimulus was presented on corresponding and non-corresponding trials. Likely, the advantage caused by visual acuity decreased the facilitation component (i.e., the difference between neutral and corresponding trials) and enhanced the interference component (i.e., the difference between non-corresponding and neutral trials).

## EXPERIMENT 2

In this experiment the three boxes that marked the stimulus positions were positioned at equidistant locations from the fixation point. The aim of the present

experiment was to test whether in the previous experiment the facilitation component of the Simon effect was smaller than the interference components because of visual acuity.

## METHODS

*Subjects.* - Fourteen students of the University of Urbino, selected as before, were recruited for the experiment. None had taken part in the previous experiment.

*Apparatus, display, and procedure.* - They were the same as before, except for the following aspects (Fig. 2). The fixation cross was at the geometrical centre of the screen. The two lateral boxes were positioned at  $5.1^\circ$  to the left and to the right of the fixation point. For half of the subjects the central box was positioned  $5.1^\circ$  above the fixation point, whereas for the other half it was positioned  $5.1^\circ$  below the fixation point.

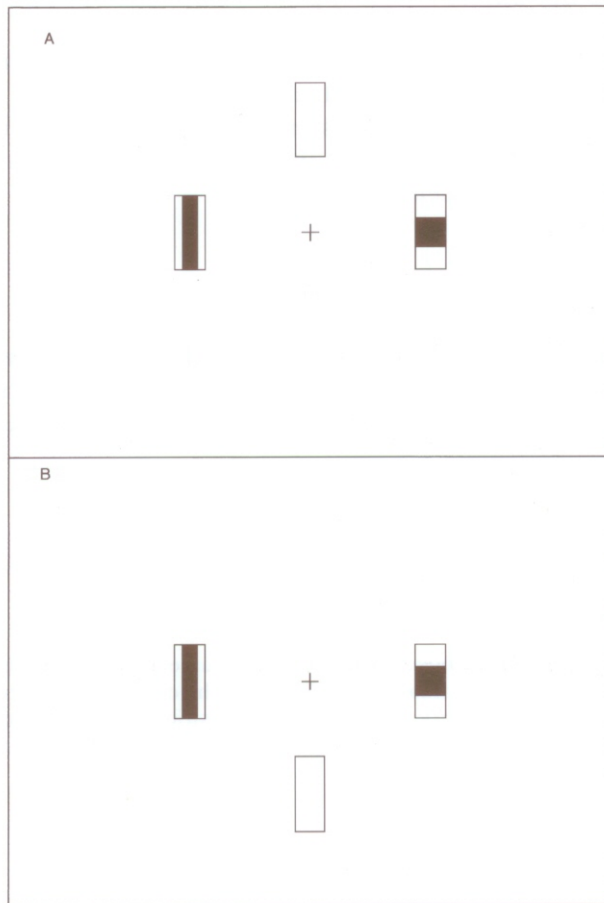


Fig. 2. - Schematic drawing of the two displays used in Experiment 2.

## RESULTS AND DISCUSSION

Only RTs in the range from 100 to 900 ms were considered for the analysis. Errors amounted to 7.2%. Correct RTs and errors were entered into the same ANOVAs as for Experiment 1.

For the RT analysis, the main effect of response position,  $F(1, 13) = 4.71$ ,  $p < 0.05$ , and the interaction,  $F(2, 26) = 21.70$ ,  $p < 0.001$ , were significant. Responses with the right-side key (320 ms) were faster than responses with the left-side key (331 ms). Pairwise comparisons computed on the interaction means showed that there was an overall Simon effect of 37 ms, corresponding trials (307 ms) being faster than non-corresponding trials (346 ms). Neutral trials (323 ms) were significantly slower than corresponding trials and significantly faster than non-corresponding trials. Thus, the Simon effect was comprised of a 16-ms facilitation effect and by a 23-ms interference effect. A post-hoc analysis showed that the two effects did not differ,  $t = 0.84$ ,  $p = 0.416$ .

The interaction was significant also for the error analysis,  $F(2, 26) = 10.72$ ,  $p < 0.001$ . It indicated that the error rate for non-corresponding trials was greater than for either corresponding or neutral trials.

It is clear that, when the imperative stimulus appeared at equidistant locations from the fixation point, facilitation and interference components of more or less the same magnitude were present.

## EXERIMENT 3

In this experiment the three boxes for the stimulus positions were on the same horizontal axis, to the left or the right of fixation. Basically, the stimulus positions were as in Experiment 1, but the problem of visual acuity was eliminated.

## METHODS

*Subjects.* - Eight students of the University of Urbino, selected as before, participated in the experiment. None had taken part in the previous experiments.

*Apparatus, stimulus, and procedure.* - They were the same as in Experiment 1 except for the following differences (Fig. 3). The fixation point was on the centre of the screen. For half of the subjects the three boxes which marked the stimulus positions were to the right of fixation, whereas for the other half they were to the right. Therefore, visual acuity was counterbalanced across conditions and subjects.

## RESULTS AND DISCUSSION

Errors were 6.4%. Correct RTs, in the same range as before, and errors were submitted to the same ANOVAs that were used in the previous experiments.

For the RT analysis, only the interaction was significant,  $F(2, 14) = 20.50$ ,  $p < 0.001$ . Pairwise comparisons showed that corresponding trials (269 ms) were faster than neutral trials (291 ms), which in turn were faster than non-corresponding trials (312 ms). Thus, there was a 43-ms overall Simon effect, which was comprised of a 22-ms facilitation component, and a 21-ms interference component.

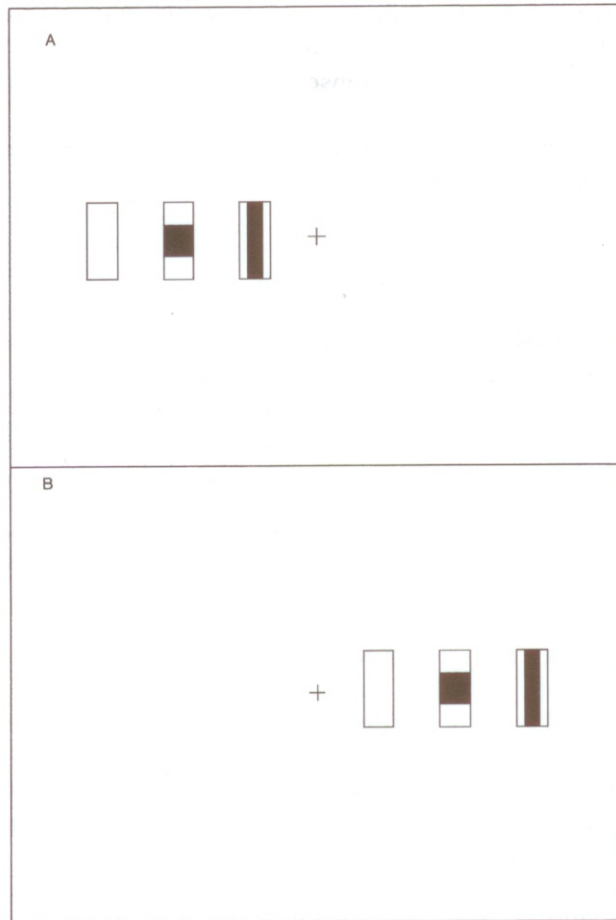


Fig. 3. - Schematic drawing of the two displays used in Experiment 3.

Also, the interaction in the error analysis was significant,  $F(2, 14) = 6.33$ ,  $p = 0.011$ , showing that error were more frequent for non-corresponding than for corresponding or neutral trials.

As in Experiment 2, the facilitation and interference effects resulted of the same magnitude.



## EXPERIMENT 4

Previous studies that directly looked for facilitation and interference effects used a neutral condition in which both sides were simultaneously stimulated (1, 14-16). In the Simon and Acosta study, for example, subjects were required to press a left- or right-hand key in response to a visual stimulus (X or O), which was accompanied randomly by a monaural or a binaural tone as the irrelevant locational cue. On corresponding trials, the stimulus appeared simultaneously with a monaural tone ipsilateral to the response, whereas on non-corresponding trials the monaural tone was contralateral to the response. The trials with the binaural tone were considered as a baseline neutral condition.

In the present experiment we reproduced this experimental procedure, but all the stimuli were presented in the visual modality.

## METHODS

*Subjects.* - Eight new students of the University of Urbino took part in the experiment. They were selected as before.

*Apparatus, display, and procedure.* - They were the same as in Experiment 1, except for the following differences (Fig. 4). The fixation cross was at the centre of the computer screen. The boxes for the stimulus positions were two and were positioned to the left and the right of fixation. On neutral trials, there were two stimuli (i.e., two squares or two rectangles), one for each box. There were two kinds of corresponding (and non-corresponding) trials. The first was, as usual, one stimulus ipsilateral or contralateral to the response. In the other, a distractor (i.e., a 1° circle) was shown simultaneously with the imperative stimulus, but in the other box.

## RESULTS AND DISCUSSION

Errors were 4.7% and were no further analysed. Only RTs in the same range as was used in the previous experiments were considered for the analyses. From an informal assessment, corresponding and non-corresponding trials with the distractor resulted to be slower than the other types of trial. Therefore, data from those trials were independently analysed.

Correct RTs were entered into an ANOVA with two within-subjects factors: stimulus position (right or left), and response position (right or left). The only significant source of variance was the interaction,  $F(1, 7) = 15.39$ ,  $p = 0.006$ . Basically, the interaction indicated that there was a 3-ms Simon effect, corresponding trials being responded to faster than non-corresponding trials (426 vs. 456 ms).

Thus, the Simon effect occurred even when a distractor appeared together with the imperative stimulus.

An ANOVA identical to that used in the previous experiments was performed on the rest of the data: corresponding, non-corresponding trials without the distractor, and neutral trials.

The main effect of response position,  $F(1, 7) = 7.48$ ,  $p = 0.029$ , and the inter-



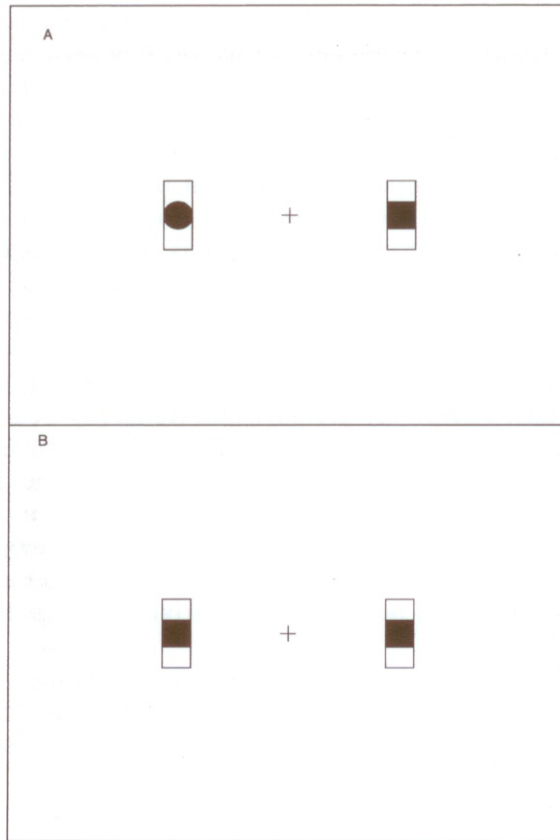


Fig. 4. - Schematic drawing of the two displays used in Experiment 4.

action,  $F(2, 14) = 10.50$ ,  $p = 0.002$ , were significant. The former indicated that responses with the right-side key were faster than responses with the left-side key (378 vs. 399 ms). The latter indicated that corresponding trials (371 ms) were faster than neutral trials (388 ms), which in turn were faster than non-corresponding trials (408 ms).

Again, there was a 37-ms overall Simon effect, which was comprised of a 17-ms facilitation component and a 20-ms interference component.

#### CONCLUSIONS

The notion that the Simon effect originates at the response selection stage is widely accepted (see, e.g., review in 10), the only dissenting opinion being that of Hasbroucq and Guiard (1991), who attributed the Simon effect to the stimulus encoding stage. The stimulus position code is assumed automatically to activate

the spatially corresponding response. When the automatically activated response corresponds to the response that is indicated by the imperative stimulus (i.e., on corresponding trials), there is no competition, but rather a facilitation, at the response selection stage. When the automatically activated response does not correspond to the response indicated by the imperative stimulus (i.e., on non-corresponding trials), a competition ensues at the response selection stage.

In particular, the dual-route models (e.g., 2) are based on this notion of a competition at the response selection stage, which is also supported by compelling empirical evidence (e.g., 3) and by computational models (19).

If the Simon effect occurs at the response selection stage, and the mechanism is the one outlined above, then there should be, in comparison to neutral trials, a facilitation effect on corresponding trials and an interference effect on non-corresponding trials. Therefore, Hietanen and Rämä (6) created a very serious problem to the model by finding facilitation in the absence of interference.

By employing a regular Simon task in Experiment 1 we found facilitation and interference effects that were both significant. The interference component, however, was much greater than the facilitation component. By employing different types of display, Experiments 2, 3, and 4 clearly demonstrated that the asymmetry found in Experiment 1 occurred because neutral trials were speeded up by visual acuity.

The present results disprove Hietanen and Rämä (6) findings and, for the first time, provide clear evidence that facilitation and interference components arise simultaneously from the processes that take place at the response selection stage and produce the Simon effect.

#### SUMMARY

In four experiments we investigated whether the Simon effect consists of both facilitation and interference. In Experiment 1 subjects had to press one of two lateralized keys in response to one of two stimuli (a rectangle or a square). The stimuli were presented at fixation or to the right or left of it. The stimulus-response mappings could be corresponding (i.e., right key - rectangle or square on the right side), non-corresponding (i.e., right key - rectangle or square on the left side), or neutral (i.e., stimulus in the center). Results showed both facilitation and interference effects, but interference was three times greater than facilitation. To test whether the neutral position was favored by visual acuity, Experiments 2, 3 and 4 used slight different displays where visual acuity was the same at every stimulus position. Results indicated that the Simon effect is comprised of facilitation and interference components of the same magnitude. These findings were discussed with reference to dual-route models of the Simon effect.

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