ELSEVIER

Brief Article

Horizontal and vertical Simon effect: different underlying mechanisms?

Antonino Vallesi[a], Daniela Mapelli[b], Sami Schiff[c],
Piero Amodio[d], Carlo Umiltà[b,*]

[a]Neuroscience Programme, SISSA-ISAS, Trieste, Italy
[b]Department of General Psychology, University of Padua, Italy
[c]Department of Neurological and Vision Sciences, University of Verona, Italy
[d]Department of Clinical and Experimental Medicine, University of Padua, Italy

Abstract

Reaction times are usually faster when stimulus and response occur at the same location than when they do not, even if stimulus location is irrelevant to the task (Simon effect). This effect was found with both horizontal and vertical stimulus-response arrangements. The same mechanisms have been proposed to be involved in either case. Here, we compared a horizontal and a vertical Simon task by means of a RT time-course analysis of the Simon effect. Also, we analysed the lateralised readiness potential (LRP), an index of covert response-preparation processes. In the horizontal task, the Simon effect decays over time and pre-activation occurs above the motor cortex ipsilateral to the stimulus. In contrast, the Simon effect does not decay over time and no early incorrect LRP deflection is observed in the vertical task. These findings suggest that typical activation accounts can fit only the horizontal Simon effect, while a translation explanation is more suitable for the vertical Simon effect.
© 2005 Elsevier B.V. All rights reserved.

Choice reaction times (RTs) to lateral stimuli are faster when the stimulus appears on the same side of the response than when stimulus and response occur on opposite sides, even though the task relevant stimulus feature is not locational in nature (e.g. colour or

---

* Corresponding author. Tel.: +39 49 827 6610; fax: +39 49 827 6600.
  E-mail address: carlo.umilta@unipd.it (C. Umiltà).

shape). This phenomenon is called the Simon effect (Lu & Proctor, 1995; Simon & Rudell, 1967). In order to explain the mechanisms underlying the Simon effect, two main classes of theories have been proposed. Activation theories (e.g. Hommel, 1994) assume that the spatial code of a stimulus activates the corresponding response, namely the response on the same side. Translation theories (e.g. Hasbroucq & Guiard, 1991) assume that both stimulus and response positions are represented by means of spatial codes, which are matched during response programming and their correspondence, or lack of correspondence, influences RTs.

Because there is evidence in favour of both activation and translation theories, another class of models, the so-called dual-process models, has been proposed to integrate them. For instance, the dual-route model introduced by De Jong, Liang, and Lauber (1994) postulates two separate routes from perception to action. In the conditional route the appropriate response is intentionally selected, whereas in the unconditional route the response ipsilateral to stimulus location is automatically activated. When stimulus and response occur on the same side, the same response is automatically activated through the unconditional route and selected through the conditional route. Therefore RT is fast. When the side of the stimulus and that of the response do not correspond, RT is slow because the corresponding response, activated by the unconditional route, must be blocked, before the correct response, selected through the conditional route, can be executed.

The following assumptions can be made regarding the time-courses of these two processes. The unconditional priming of the spatially corresponding response is assumed to become effective soon after stimulus onset but then to decay rather rapidly. Simon, Acosta, Medwaldt, and Speidel (1976) found that the Simon effect dissolves when subjects are forced to delay their response by 350 ms. Other studies (Hommel, 1993; Rubichi, Nicoletti, Iani, & Umiltà, 1997) showed that the Simon effect decreases as RT increases, that is, when the stimulus locational code has time to decay. The conditional component, in contrast, is assumed not to be time-locked with stimulus onset but to emerge when the translation is applied from the non-spatial relevant stimulus attribute to the spatial response code. To test this model, De Jong et al. (De Jong et al., 1994 and Rubichi et al., 1997) performed an RT distributional analysis that consisted in dividing RTs in quintiles (bins) from the fastest to the slowest, separately for corresponding and non-corresponding trials. The difference between the averaged RTs for related bins of the two distributions then represents the average size of the Simon effect for the specific time-window spanned by these bins. It was found that the Simon effect disappeared, or even reversed, at the slowest bins.

Apart from overt behavioural measurements, automatic response activation can be evidenced by the lateralized readiness potential (LRP; De Jong, Wierda, Mulder, & Mulder, 1988; Gratton, Coles, Sirevaag, Eriksen, & Donchin, 1988). The LRP represents the increase of EEG negativity over the motor cortex contralateral to a planned movement. In stimulus–response (S–R) compatibility tasks, to which the Simon task belongs, an early deflection of the LRP is observed. This deflection, named *Gratton-dip* (Gratton et al., 1988), is thought to reflect the automatic response initially activated by stimulus location. The Gratton-dip would occur when information is partially transmitted from perceptual to motor processes before the end of stimulus evaluation (Gratton, Coles, & Donchin, 1992). If the pre-activated response indexed by this early LRP is correct, the LRP continues to grow until response execution. If the pre-activated response does not correspond to

the required one, incorrect early LRP lessens, and an LRP of contrary polarity will develop in the direction of the required response.

Recently, it has been observed that the early asymmetries calculated over the entire cortex with an LRP-like method (event-related lateralizations) are more pronounced in parieto-occipital regions (Wascher & Wauschkuhn, 1996), as would be expected for processing of bilaterally presented stimuli with asymmetrical relevance (Luck & Hillyard, 1994). Because of that, even if the Simon effect is commonly obtained arranging S–R sets in the horizontal meridian, in ERPs studies the vertical meridian has been often used to avoid the overlapping of those posterior stimulus-related lateralization with the LRP proper (De Jong et al., 1994; Valle-Inclán, 1996). According to some authors (Praamstra & Oostenveld, 2003; Wascher & Wauschkuhn, 1996), however, this parallel activation over motor and perceptual areas is not a mere index of overlapping but strongly supports the assumption of a visuo-motor network that activates responses ipsilateral to a given stimulus.

Using a vertical S–R set for the Simon task, De Jong et al. (1994) found the time-course hypothesized by their model, with the Simon effect decaying over time (see above). It is important to note that they used an uncommon version of the Simon task, in which responses were labelled with colour words. We believe that, with a vertical arrangement of the stimuli, which can be processed by both hemispheres, the unconditional route would not activate the response ipsilateral to the stimulus, and more so, considering that there would not be pre-wired, long-term memory links between stimulus side and response side (Tagliabue, Zorzi, Bassignani, & Umiltà, 2000).

Thus, it can be predicted that in the Simon effect obtained with vertical stimuli and responses, the conditional process and/or the translation from the spatial stimulus code into the spatial response code should play a greater role than that of the unconditional activation of the response ipsilateral to the stimulus. Accordingly, the prediction can be made that the Simon effect does not decay overtime (or decays more slowly), along with the early LRP deflection in the direction of the incorrect response.

1. Method

1.1. Participants

Ten volunteer healthy participants (seven males; mean age: 34 ± 10) took part to the experiment. All were right-handed, had normal or corrected-to-normal visual acuity, and were naive as to the purpose of the experiment.

1.2. Apparatus and stimuli

A Compaq 80386 Proline interfaced to a 14 in. monitor controlled stimuli presentation and behavioural data collection. The head was positioned in an adjustable head-and-chin rest. Distance between the eyes and the screen was 80–85 cm. Target stimuli were 4×4 red-and-black or green-and-black chessboards subtending $1.4°$ of visual angle presented one at a time $3.3°$ to the right or left of a central fixation cross on a uniformly white background. A 4×4 black-and-white chessboard always appeared as filler contralaterally

to the target stimulus, in order to avoid exogenous asymmetries in the ERPs. For the vertical task, the stimuli were presented vertically at 3.3° above or below the central fixation cross. The exposure duration of the stimuli was 176 ms. Response had a deadline of 1200 ms. The inter-trial interval ranged from 800 to 1200 ms. Stimuli were presented using the software package E-Prime 1.0 (Psychology Software Tools, Inc., 2002).

1.3. Tasks and procedure

Participants were required to perform both horizontal and vertical Simon tasks. In the *horizontal task*, the choice was between the left key ('Z') of the computer keyboard if the chessboard was red-and-black and the right key ('M') if it was green-and-black, independently of its spatial position. The color-key assignment was counterbalanced across participants. In the *vertical task*, the keyboard was turned 90° anticlockwise, and the response keys were '1' to the red-and-black and '−' to the green-and-black chessboards, for half of the participants, '0' to the red-and-black and 'Z' to the green-and-black chessboards for the others. The sequence of horizontal and vertical S–R mappings was counterbalanced across participants, as well as the order of presentation of the two tasks.

For both tasks, participants received a practice run of 40 trials, which were not analysed. Then, each color × position combination was presented 75 times in a completely randomized sequence, for a total of 300 experimental trials per task. Participants were instructed to respond as quickly and accurately as possible, and were encouraged to maintain fixation from presentation of the fixation cross to response execution, avoiding both saccadic eye movements and blinks as much as possible.

1.4. Recording

EEG was continuously recorded with Ag/AgCl electrodes from 29 standard locations according to the international 10/20 system (American Electroencephalographic Society, 1994), using a pre-cabled elastic cup, with Fpz as ground and the two earlobes as reference. Horizontal and vertical electrooculograms (hEOG and vEOG) were monopolarly recorded from two electrodes at the outer cantus and under the left eye, respectively. Impedance was kept below 5 kΩ. The amplifier band-pass was 0.03–70 Hz. EEG and EOG were digitalised on-line with a sampling rate of 512 Hz. RTs and accuracy were recorded for each trial.

1.5. Electrophysiological data processing

EEG and EOG were averaged off-line for epochs of 1000 ms, starting 100 ms prior to stimulus onset and ending 900 ms after. Trials with erroneous responses, without response and those with artefacts, namely hEOG and vEOG variations exceeding $\pm 50\,\mu V$, or variations of one of the 29 scalp electrodes exceeding $\pm 100\,\mu V$, were automatically excluded from further analysis. EEG was averaged separately for each of the four experimental combinations of stimulus colour (red vs. green) and position (left vs. right or above vs. below). For the present purposes we only analysed signals from C3 and C4 electrodes, in order to study LRP.

A typical formula was used to calculate LRP (Coles, 1989):

$$[(C3 - C4)\text{right hand} + (C4 - C3)\text{left hand}]/2$$

where *right hand* and *left hand* refer to the hand the participants were instructed to use for the response, and C3–C4 and C4–C3 are the electrical potential difference between two sites, C3 and C4, localized above pre-motor and motor areas.

The polarity of the LRP, calculated as above, is such that correct response activation is recorded as a positive deflection, whereas incorrect response activation is recorded as a negative deflection (Osman, Bashore, Coles, Donchin, & Meyer, 1992). This way, the time-course of response tendencies can be monitored long before the overt movement is executed.

2. Results

2.1. RTs

Mean correct RTs and percentage of correct responses are shown in Table 1. Behavioural data were submitted to repeated measures analyses of variance (ANOVAs). The first ANOVA compared RTs in the two tasks. This analysis had two within-subjects variables: target-response correspondence (corresponding vs. non-corresponding trials) and task (horizontal vs. vertical). The two main effects were significant [$F(1, 9) = 41.3$, $P < 0.001$ for correspondence, and $F(1, 9) = 8.2$, $P < 0.05$ for task]. The main effect of correspondence showed that corresponding trials were faster than non-corresponding ones (423 ± 23 vs. 447 ± 22 ms). The Simon effect amounted to 21 ms for the horizontal task and to 29 ms for the vertical task, respectively. The main effect of task showed that RTs were faster in the vertical task than in the horizontal one (422 ± 24 vs. 448 ± 22 ms). No significant interaction was found.

RT distribution analysis was performed as explained above (De Jong et al., 1994). Mean RTs of correct trials for each bin, condition and task are shown in Table 2. A three-way ANOVA was performed with bin (five quintiles from the fastest to the slowest), task and correspondence as within-subjects variables. This analysis revealed, besides that of bin, significant main effects of task [$F(1, 9) = 7.98$, $P < 0.05$], correspondence [$F(1, 9) = 41.3$, $P < 0.001$] and, more interestingly, the interaction between task, correspondence, and bin [$F(4, 36) = 5.02$, $P < 0.01$]. Planned comparisons between consecutive pairs of bins revealed that in the horizontal task the Simon effect decreased significantly from the third to the forth bin and from the forth to the fifth ($Ps < 0.05$), when it reversed

Table 1
Mean reaction times (in ms) of correct trials in each condition of the horizontal and vertical tasks

	Corresponding trials	Non-corresponding trials
Horizontal task	438 (97%)	459 (96%)
Vertical task	409 (98%)	438 (94%)

Percentages of correct trials for each task and condition are also reported in brackets.

Table 2
Mean reaction times (in ms) of correct trials in each bin and Simon condition of the horizontal and vertical task

Bin	Horizontal task		Vertical task	
	Corresponding	Non-corresponding	Corresponding	Non-corresponding
1	330	358	316	339
2	378	411	361	388
3	415	447	397	424
4	466	488	436	464
5	593	585	530	565

(but not significantly). In contrast, in the vertical task the typical Simon effect had more or less the same magnitude and was significant at all bins ($Ps \leq 0.01$).

In a bin-analysis the choice of how many bins to use is somewhat arbitrary. Therefore, we tried to descriptively corroborate the findings of the bin-analysis by plotting RTs from the fastest to the slowest in the *x*-axis and cumulative percentage distribution in the *y*-axis. For the horizontal Simon effect, the distribution for corresponding responses lies to the left of the non-corresponding distribution only in the faster part, indicating that the correspondence effect is present only when RTs are fast, and then vanishes. In contrast, for the vertical Simon effect, the two curves are more or less parallel, until about RTs over 600 ms, indicating that the correspondence effect does not vary (see Figs. 1 and 2).
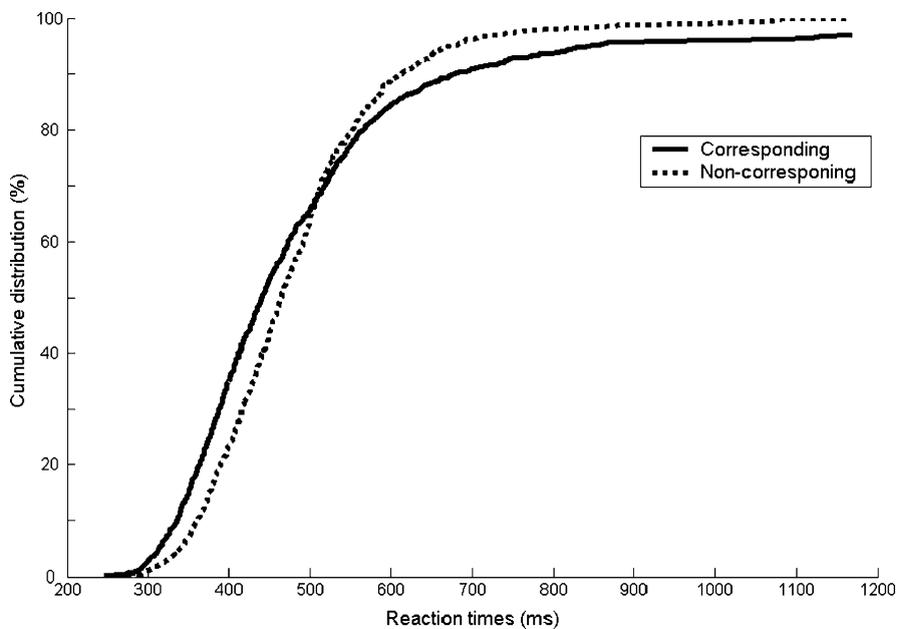

Fig. 1. Cumulative distribution of the mean reaction times of correct trials in the horizontal task as a function of Simon condition (corresponding vs. non-corresponding).
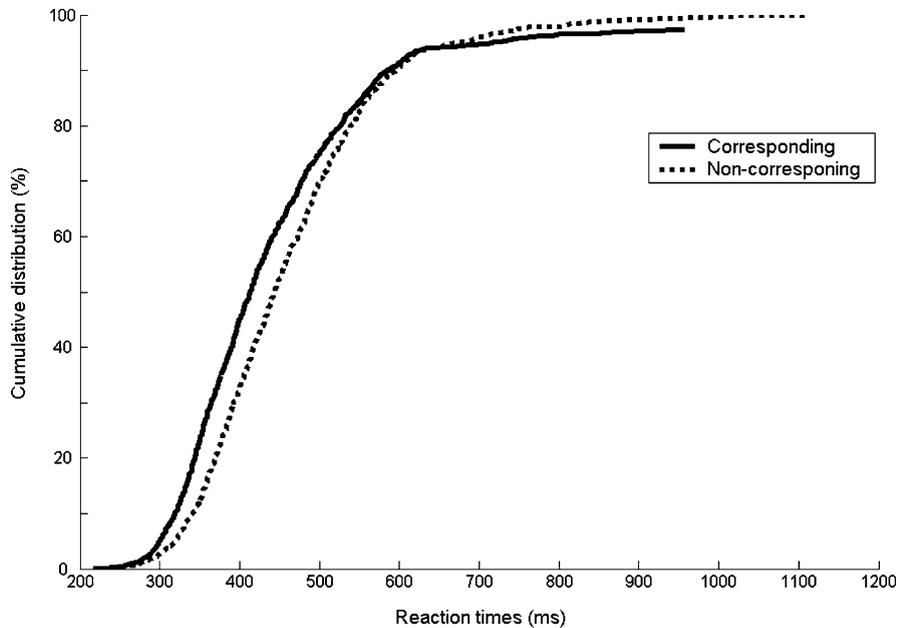
Fig. 2. Cumulative distribution of the mean reaction times of correct trials in the vertical task as a function of Simon condition (corresponding vs. non-corresponding).

Accuracy analysis was performed with an ANOVA with task and correspondence as within-subjects variables (see Table 1). The only significant effect was that of correspondence $F(1, 9) = 21.9$, $P < 0.01$ (corresponding trials: 98% correct, non-corresponding trials: 95% correct).

2.2. LRP

Grand-average LRPs for both tasks are plotted in Figs. 3 and 4. LRPs relative to each combination of task by correspondence were analysed computing, separately for each subject, 20 mean amplitude of 50 ms time-epochs, and comparing each post-stimulus epoch against the baseline (mean amplitude of the first 100 ms pre-stimulus) with paired *t*-tests. For the horizontal task, corresponding LRP differed significantly from baseline in the direction of the correct response activation from 150 to 400 ms, while the non-corresponding LRP differed significantly from baseline for the 150–200 ms time-epoch in the direction of the incorrect response activation, and from 250 to 450 ms in the direction of the correct response activation (for all, $P < 0.05$). For the vertical task, the corresponding LRPs differed significantly from baseline in the direction of the correct response activation from 200 to 400 ms, while the non-corresponding LRPs differed significantly from the baseline in the direction of the correct response activation from 250 to 450 ms (for all, $P < 0.05$). Importantly, in
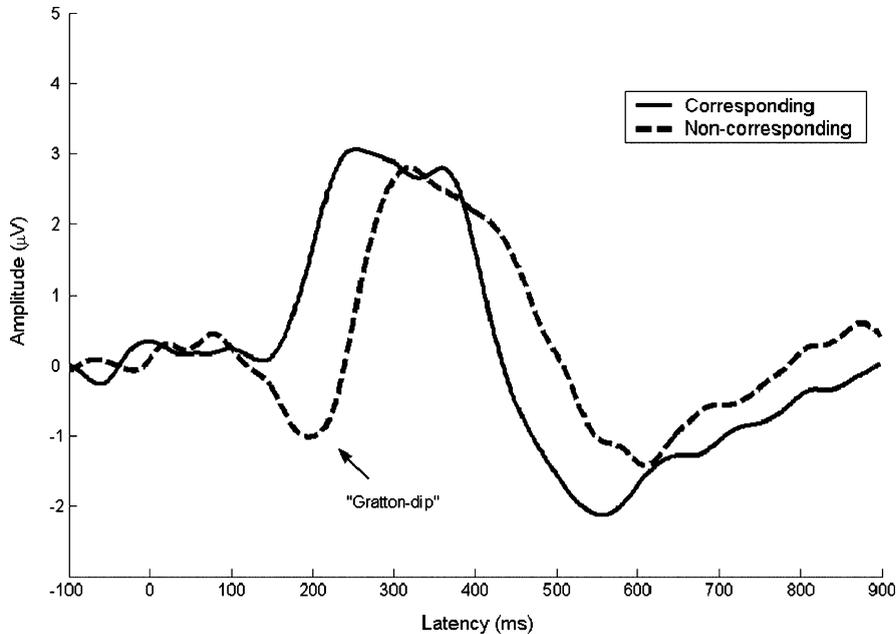
Fig. 3. Grand-average of the stimulus-locked lateralised readiness potential in the horizontal task as a function of Simon condition (corresponding vs. non-corresponding). Only for illustration purposes waves have been smoothed.

the vertical Simon task, there was no early activation in the direction of the wrong response.

Finally, LRP mean amplitude in the time window in which visual inspection suggests the occurrence of the Gratton-dip, namely 175–225 ms post-stimulus, was analysed through a 2×2 ANOVA with correspondence and task as within-subjects variables. This analysis yielded a main effect of correspondence [$F(1, 9) = 22.1$, $P = 0.001$], demonstrating that LRP was more positive on corresponding than on non-corresponding trials. More interestingly, also a correspondence $\times$ task interaction was observed [$F(1, 9) = 5.9$, $P < 0.05$], indicating that the difference between LRP on corresponding and on non-corresponding trials was reliably greater in the horizontal task than in the vertical one (2.6 vs. 1 μV). This finding once again demonstrates that the Gratton-dip is only detectable with a horizontal S–R set.

3. Discussion

The differences between horizontal and vertical tasks suggest the existence of different underlying mechanisms. Although the regular analysis on mean RTs did not show any difference in the magnitude of the Simon effect, the distributional analysis revealed a substantially different time-course of the two effects. In the horizontal task the Simon effect decreased as RT increased in accord with the findings of previous studies
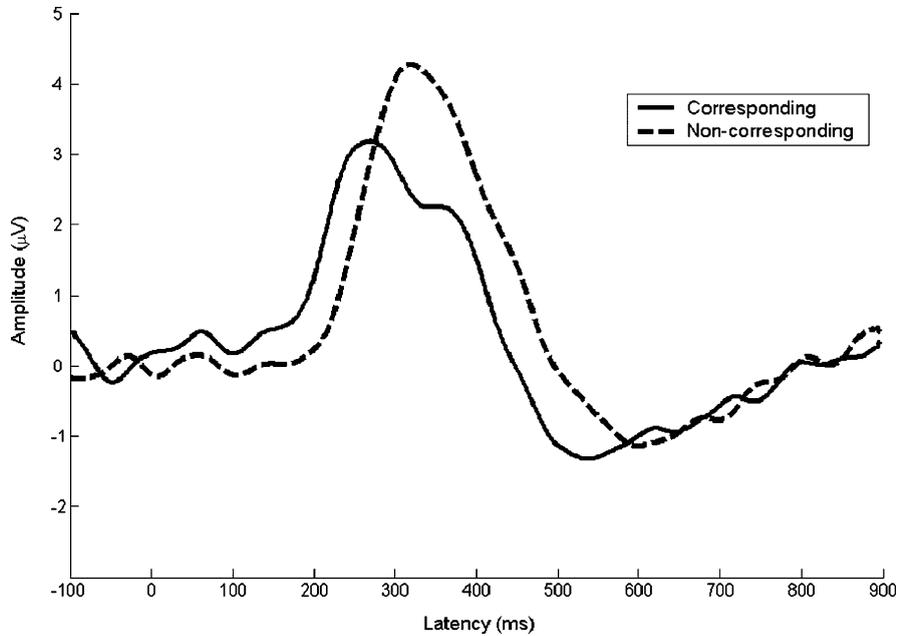
Fig. 4. Grand-average of the stimulus-locked lateralised readiness potential in the vertical task as a function of Simon condition (corresponding vs. non-corresponding). Only for illustration purposes waves have been smoothed.

(e.g. Rubichi et al., 1997), whereas in the vertical task the Simon effect did not change as a function of RT latency. The notion of different underlying mechanisms is corroborated by the LRP analysis showing different waveforms for the two tasks. In the horizontal task, the LRP for non-corresponding trials developed first in the direction of an incorrect response, ipsilaterally to the target side, and then in the direction of the correct response, which was eventually executed. This trend indicates an initial activation of the response corresponding to the position of the stimulus, which arises soon after stimulus-onset and decreases with time, in favour of the preparation of the correct response. In the vertical task, LRPs on non-corresponding trials did not show any deflection in the direction of the response ipsilateral to the stimulus, but just a delay in the onset of the preparation of the correct response.

These findings suggest that the horizontal Simon effect can be explained by activation theories, that is, by postulating an automatic activation of the response on the same side of the target. This activation is stimulus-locked and short-lasting. In the vertical task, instead, the Simon effect would not be stimulus- but response-locked, and because of that it is still present with slower RTs. Perhaps, a translation hypothesis can better account for the vertical Simon effect (see Introduction above).

The locus of the vertical Simon effect might be in the stage in which not only the relevant stimulus attribute (colour), but also its irrelevant spatial code are translated into response characteristics. Therefore, De Jong et al.'s (1994) dual-process model is only in part tenable, because the two processes it proposes seem to be active in different tasks

and not simultaneously. This has already been shown to occur in acoustical Simon tasks and in visual Simon tasks with crossed hands (Wascher, Schatz, Kuder, & Verleger, 2001).

An alternative interpretation of our results derives from the fact that the vertical task was easier than the horizontal one, as shown by faster RTs (but not by higher accuracy). Therefore, the different time-course of the two types of Simon effect might simply be attributable to a difference in overall RTs. That is, the vertical Simon effect would not change as a function of RT because even the slowest bin is still too fast. Further investigation is necessary to test this explanation, for instance with experimental manipulations slowing down RTs in the vertical Simon task. However, this admittedly much simpler explanation seems not to be applicable to the difference in LRP between the horizontal and the vertical Simon effects, as found in our study.

In conclusion, the present study provides behavioural and electrophysiological evidence of different time-courses and possibly different mechanisms underlying the Simon effect in horizontal and vertical tasks. It would seem that the class of so-called Simon tasks is heterogeneous. This should be kept in mind when different spatial S–R settings are used for various purposes, like, for instance, in order to avoid *overlapping* between perceptual and motor lateralizations in ERP studies of the Simon effect.

Acknowledgements

References

American Electroencephalographic Society. (1994). Guidelines for standard electrode position nomenclature. *Journal of Clinical Neurophysiology*, *11*, 111–113.

Coles, M. G. H. (1989). Modern mind-brain reading: Psychophysiology, physiology and cognition. *Psychophysiology*, *26*, 251–269.

De Jong, R., Liang, C. C., & Lauber, E. (1994). Conditional and unconditional automaticity: A dual-process model of effects of spatial stimulus–response correspondence. *Journal of Experimental Psychology: Human Perception and Performance*, *20*, 731–750.

De Jong, R., Wierda, M., Mulder, G., & Mulder, L. J. M. (1988). Use of partial information in responding. *Journal of Experimental Psychology: Human Perception and Performance*, *14*, 682–692.

Gratton, G., Coles, M. G. H., & Donchin, E. (1992). Optimizing the use of information: Strategic control of activation of responses. *Journal of Experimental Psychology: General*, *121*, 480–506.

Gratton, G., Coles, M. G. H., Sirevaag, E. J., Eriksen, C. W., & Donchin, E. (1988). Pre- and post-stimulus activation of response channels: A psychophysiological analysis. *Journal of Experimental Psychology: Human Perception and Performance*, *14*, 331–344.

Hasbroucq, T., & Guiard, Y. (1991). Stimulus–response compatibility and the Simon effect. *Journal of Experimental Psychology: Human Perception and Performance*, *17*, 246–266.

Hommel, B. (1993). The role of attention for the Simon effect. *Psychological Research/Psychologische Forschung*, *55*, 208–222.

Hommel, B. (1994). Spontaneous decay of response-code activation. *Psychological Research/Psychologische Forschung*, *56*, 261–268.

Lu, C. H., & Proctor, R. W. (1995). The influence of irrelevant location information on performance: A review of the Simon and spatial Stroop effects. *Psychonomic Bulletin and Review*, *2*, 174–207.

Luck, S. J., & Hillyard, S. A. (1994). Spatial filtering during visual search: Evidence from human electrophysiology. *Journal of Experimental Psychology: Human Perception and Performance*, *20*, 1000–1014.

Osman, A., Bashore, T. R., Coles, M. G. H., Donchin, E., & Meyer, D. E. (1992). On the transmission of partial information: Inferences from movement-related brain potentials. *Journal of Experimental Psychology: Human Perception and Performance*, *13*, 217–232.

Praamstra, P., & Oostenveld, R. (2003). Attention and movement-related motor cortex activation: A high-density EEG study of spatial stimulus–response compatibility. *Cognitive Brain Research*, *16*, 309–322.

Rubichi, S., Nicoletti, R., Iani, C., & Umiltà, C. (1997). The Simon effect occurs relative to the direction of an attention shift. *Journal of Experimental Psychology: Human Perception and Performance*, *23*, 1353–1364.

Simon, J. R., Acosta, E., Medwaldt, S. P., & Speidel, C. R. (1976). The effect of an irrelevant directional cue on choice reaction time: Duration of the phenomenon and its relation to stages of processing. *Psychophysiology*, *19*, 16–22.

Simon, J. R., & Rudell, A. P. (1967). Auditory S–R compatibility: The effect of an irrelevant cue on information processing. *Journal of Applied Psychology*, *51*, 300–304.

Tagliabue, M., Zorzi, M., Umiltà, C., & Bassignani, F. (2000). The role of long-term-memory and short-term-memory links in the Simon effect. *Journal of Experimental Psychology: Human Perception and Performance*, *26*, 648–670.

Valle-Inclán, F. (1996). The locus of interference in the Simon effect: An ERP study. *Biological Psychology*, *43*, 147–162.

Wascher, E., Schatz, U., Kuder, T., & Verleger, R. (2001). Validity and boundary conditions of automatic response activation in the Simon task. *Journal of Experimental Psychology: Human Perception and Performance*, *27*, 731–751.

Wascher, E., & Wauschkuhn, B. (1996). The interaction of stimulus- and response-related processes measured by event-related lateralizations of the EEG. *Electroencephalography and Clinical Neurophysiology*, *99*, 149–162.

ELSEVIER

Erratum

Erratum to 'Horizontal and vertical Simon effect: different underlying mechanisms?' [Cognition 96 (2005) B33–43]☆

Antonino Vallesi, Daniela Mapelli, Sami Schiff,
Piero Amodio, Carlo Umilta*

Dipartimento di Piscologia Generale, Universita di Padova, via Venezia 8, 35131 Padova, Italy

The publisher regrets that in the publishing of the above article, the formula for calculating the Lateralized Readiness Potential contained a mistake (p. B37, line 2). The formula should read as follows:

$$[(C3 - C4) \text{ right hand} - (C3 - C4) \text{ left hand}]/2$$

To be coherent with the text and the figures, the formula should be:

$$[(C3 - C4) \text{ left hand} - (C3 - C4) \text{ right hand}]/2$$

We apologise for any embarassement caused to the authors due to the above error.