Response Selection and Attention Orienting

A Computational Model of Simon Effect Asymmetries

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Abstract. Recently, there has been a redirection of research efforts toward the exploration of the role of hemispheric lateralization in determining Simon effect asymmetries. The present study aimed at implementing a connectionist model that simulates the cognitive mechanisms implied by such asymmetries, focusing on the underlying neural structure. A left-lateralized response-selection mechanism was implemented alone (Experiment 1) or along with a right-lateralized automatic attention-orienting mechanism (Experiment 2). It was found that both models yielded Simon effect asymmetries. However, whereas the first model showed a reversed pattern of asymmetry compared with human, real data, the second model's performance strongly resembled human Simon effect asymmetries, with a significantly greater right than left Simon effect. Thus, a left-side bias in the response-selection mechanism produced a left-side biased Simon effect, whereas a right-side bias in the attention system produced a right-side biased Simon effect. In conclusion, results showed that the bias of the attention system had a larger impact than the bias of the response-selection mechanism in producing Simon effect asymmetries.

Keywords: spatial attention, spatial compatibility, dual-route model, brain specialization, lateralization

Past research has widely investigated stimulus-response (S-R) compatibility effects. In 1967, Simon and Rudell demonstrated the existence of a strong, natural tendency to associate a lateralized stimulation with an ipsilateral hand response. In the typical Simon task, although stimulus position encoding is not required to perform response selection, reaction times (RTs) are faster in the S-R compatible condition, that is, when stimulus side and response side correspond, rather than in the S-R incompatible condition, that is, when stimulus side and response side do not correspond (for reviews, see Lu & Proctor, 1995; Proctor & Vu, 2006). Umiltà and Nicoletti (1992) suggested that two mechanisms are crucially involved in producing the Simon effect. The automatic attention orienting toward stimulus position causes the automatic generation of a spatial code for the task-irrelevant stimulus location attribute. This spatial code affects the response-selection mechanism by activating the spatially corresponding response (Eimer, 1995; Lu & Proctor, 1995; Proctor, Lu, Wang, & Dutta, 1995; Spironelli, Tagliabue, & Angrilli, 2006; Stoffer, 1991). It is widely accepted that attention orienting and response selection are the crucial mechanisms in producing the Simon effect. The present paper is focused on Simon effect asymmetries and its aim is to understand the role of attention orienting and response selection in determining such asymmetries.

Simon Effect Asymmetries

In spite of the great effort devoted to the investigation of the Simon effect, attested by the number of studies that used a variety of experimental manipulations to elucidate the underlying mechanisms, the interest for asymmetries, which are often present in the Simon effect, is quite recent. Tagliabue et al. (2007) reviewed the literature, showing that the Simon effect asymmetries, that is, performance differences when comparing left- and right-hand responses in the Simon task (response SE) as well as when comparing stimuli presented in the left or right half of the visual field (stimulus SE), are robust and stable (e.g., Figure 1).

Because left/right asymmetries should be taken into consideration by all hypotheses aimed at explaining the Simon effect, increasing attention has been paid to mechanisms underlying Simon effect asymmetries (e.g., Angrilli, Zorzi, Tagliabue, Stegagno, & Umiltà, 2001; Rubichi & Nicoletti, 2006; Spironelli et al., 2006; Tagliabue et al., 2007). The basic notion is that a motor program is automatically produced every time an attention shift is required (i.e., the premotor theory of attention orienting: Rizzolatti, Riggio, Dascola, & Umiltà, 1987). Therefore, asymmetrical functioning of neural mechanisms for response selection or attention orienting might play a decisive role in producing behavioral asymmetries in the Simon effect. In addition, Tagliabue et al. (2007) investigated if handedness significantly affected Simon effect asymmetries by comparing the Simon effect of left-handed subjects with that of right-handed participants. Results revealed significant Simon effects in both groups, but showed a reversed pattern of asymmetries for left- and right-handed subjects, suggesting that the lateralization of the response-selection and attention-orienting processes that are reversed in left-handers, at least to some extent, may be instrumental in determining Simon effect asymmetries.

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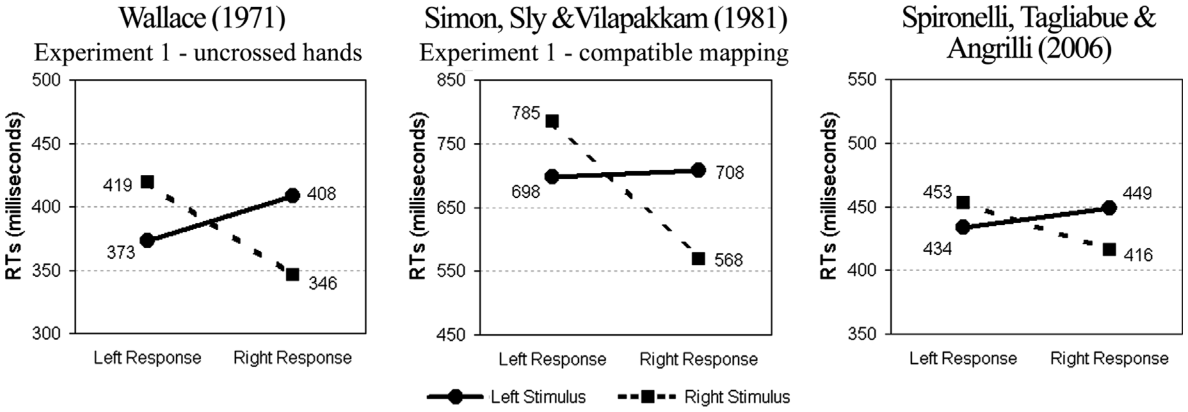

Figure 1. Two-way stimulus position by response position interaction in three previous studies: Simon effect asymmetries, that is, a greater Simon effect on the right than the left side, are apparent.

Starting from this consideration, in the following we will review evidence attesting to the lateralization of neural mechanisms involved in response selection and attention orienting, with special reference to research on the Simon effect.

Neuroimaging evidence demonstrated that both premotor and parietal cortices of the left hemisphere play a dominant role for preparing selected movements (e.g., Hester, D'Esposito, Cole, & Garavan, 2007; Koch et al., 2006; Rushworth, Johnansen-Berg, Gobel, & Devlin, 2003; Schluter, Krams, Rushworth, & Passingham, 2001; Schluter, Rushworth, Passingham, & Mills, 1998). Spironelli et al. (2006) analyzed event-related potential activity evoked by stimulus position during a typical Simon task. In this study, authors found that a significant delay in the very early (automatic) phases of stimulus processing affected selectively left-lateralized stimuli, i.e., the right-side stimulus elicited greater negativity at the central electrode located in the left hemisphere (i.e., C3 electrode), whereas the left-side stimulus evoked bilateral activation (i.e., in C3/C4 electrodes). Therefore, the central site of the left hemisphere was significantly activated by both contralateral (i.e., right-side squares) and ipsilateral (i.e., left-side squares) stimuli, whereas the central electrode of the right hemisphere was activated only by contralateral stimuli (i.e., left-side squares), supporting the hypothesis that, in right-handed subjects, the left hemisphere is specialized for response selection.

Besides neural asymmetries in response selection, neural asymmetries of the automatic attention-orienting mechanism may also produce Simon effect asymmetries. The role of the right hemisphere for shifting spatial attention to both sides of space, in right-handed subjects, was shown both in studies on brain-damaged patients (e.g., Bisiach, Cornacchia, Sterzi, & Vallar, 1984; Han et al., 2004; Mesulam, 1981; Posner, Walker, Friedrich, & Rafal, 1984, 1987) and in studies employing visuo-spatial attention tasks in healthy subjects (e.g., Corbetta, Miezin, Shulman, & Petersen, 1993; Mesulam, 1990; Norbre et al., 1997; Rounis, Yarrow, & Rothwell, 2007). Therefore, automatic attentional orienting, which is triggered by stimulus appearance in the Simon task, should be crucially affected by the neural asymmetrical organization of the visuo-spatial attentional system. In addition, because in this task stimulus presentation necessarily requires choosing between two possible responses, it is clear that the motor attention system too should be involved. Several previous studies referred to the attentional processing associated with somatomotor responses (i.e., motor attention), as the function closely related with both spatial attention orienting (in superior parietal lobules) and motor planning (in premotor cortices; Rushworth, Nixon, Renowden, Wade, & Passingham, 1997). From a neurophysiological point of view, compared with the system responsible for orienting attention, the motor attention system has been localized in more anterior parietal regions (i.e., the supramarginal gyrus (SMG)). Interestingly, studies using rTMS (Rushworth, Ellison, & Walsh, 2001) and PET techniques (Rushworth, Krams, & Passingham, 2001) found this system to be asymmetric too, showing a clear-cut dominance of the left SMG.

Therefore, the two main forms of attention mechanisms involved in the Simon task (i.e., orienting attention and motor attention) showed complementary hemispheric dominance, the former being right-lateralized and the latter left-lateralized. However, attentional cerebral asymmetries have never been investigated with the Simon task. Part of our effort was thus devoted to filling this gap. Finally, we also considered neural network models of the Simon effect, showing that they implemented both response-selection and attention-orienting mechanisms, but did not take into account their lateralization.

Computational Models

Several dual-route models were proposed to establish how response-selection and automatic orienting mechanisms interact (e.g., De Jong, Liang, & Lauber, 1994; Kornblum, Stevens, Whipple, & Requin, 1999; Tagliabue, Zorzi, Umiltà, & Bassignani, 2000). Dual-route models propose that a conditional, controlled route, starting from stimulus coding and ending with the execution of the correct response, through a series of intermediate steps, acts in parallel with an unconditional, automatic route, which is directly associated with the corresponding response (Barber & O'Leary, 1997; Zorzi & Umiltà, 1995). These connectionist models, aimed at implementing cognitive mechanisms underlying S-R compatibility effects in general (De Jong et al., 1994; Kornblum et al., 1999), and the Simon effect in particular (Tagliabue et al., 2000), did not explicitly implement the neural substrates. Indeed, presumably, the response-selection and the automatic orienting mechanisms affect the execution of the correct response in different ways. Thus, task-relevant (nonspatial) stimulus features could be processed by the conditional route and directly related to response-selection mechanisms, whereas task-irrelevant (spatial) stimulus features could automatically activate the unconditional route and be related to orienting mechanisms. However, this issue has never been explicitly addressed.

The present study aimed at verifying, in simulated right-handed subjects, the role of both response-selection and attention-orienting mechanisms in producing Simon effect asymmetries. We took into account hemispheric lateralization of the mechanisms involved, combining known neural asymmetries and behavioral data. To this end, starting from Tagliabue et al.'s (2000) neural network, a new computational model of the Simon task was implemented first to simulate a response-selection mechanism (Experiment 1). Subsequently, this model was extended by adding an automatic orienting mechanism (Experiment 2). The idea was that, if the response-selection mechanism alone is able to explain Simon effect asymmetries, this model should show an asymmetrical activation pattern close to that obtained in behavioral data (e.g., Figure 1). In contrast, if response selection is necessary but not sufficient to produce Simon effect asymmetries, both response-selection and automatic orienting mechanisms should be involved in generating Simon effect asymmetries. Thus, the second but not the first model should reveal the asymmetrical pattern observed in behavioral results.

In summary, our principal aim was to investigate the role of response selection and attention orienting in producing Simon effect asymmetries by devoting special emphasis to the role played by asymmetries in the neural mechanisms of spatial attention. This attempt was carried out by means of neural network simulation. In the present study, we modified our existing connectionist model (Tagliabue et al., 2000) so as to make it more biologically plausible by introducing a lateralized response-selection mechanism in the first model, and both a lateralized response-selection mechanism and an attention-orienting mechanism in the second model.

Experiment 1

Methods

Architecture of the First Connectionist Model of Simon Effect Asymmetries

The neural model was implemented as a connectionist network consisting of five layers of interconnected processing nodes (Figure 2). The input layer comprised four different units: two color nodes mapping the relevant stimulus attributes (i.e., red or green color) which have to be discriminated for response selection by way of the controlled pathway, and two position nodes coding the (irrelevant) spatial dimension of the imperative stimulus (i.e., left or right position).

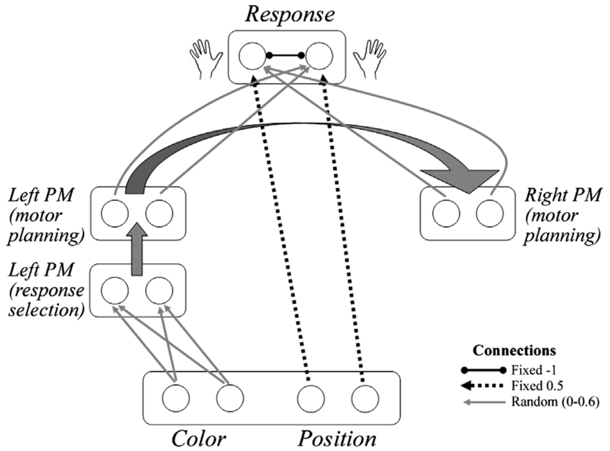

Figure 2. Connectionist model aimed at simulating the response-selection mechanism. Continuous gray lines represent short-term memory (STM) links modified by backward propagation: thin lines for single-node connections; thick lines for whole-to-whole connections. Black dotted lines represent direct LTM links from input to output nodes excluded from learning algorithm.

The output layer comprised two units, representing possible responses (i.e., two response nodes for left or right key pressing). Unlike Tagliabue et al.'s (2000) model, in the present study we propose a connectionist model with three hidden layers, each comprising two nodes. The first hidden layer, which represents the response-selection stage in the left hemisphere, received stimulus information only from the color nodes of the input layer (Figure 2, thin gray arrows) and was in turn fully connected with the second hidden layer, representing left premotor areas (Figure 2, thick gray arrow). From the latter, two different pathways of connections originated: one to the contralateral output node, which represents right-hand responses (Figure 2, thin gray arrows) and one with the third hidden layer, representing homologues right premotor areas (Figure 2, thick gray arrow). This latter layer was in turn connected to the output node representing left-hand responses (Figure 2).

In addition, input nodes that code stimulus position were directly connected to output nodes: These connections are depicted in Figure 2 by dotted arrows to represent automatic preactivating links between stimulus positions and corresponding responses, that is, the so-called long term memory (LTM) pathway (Barber & O'Leary, 1997). This is the reason why these two connections had fixed weights, which are not modified by learning. All remaining connections were initialized, trained and backwards corrected using a back-propagation algorithm (Rumelhart & McClelland, 1986).

Network Connections

Color and position nodes are linked to response nodes through two different connecting pathways. Because the

Simon task requires arbitrary associations based on the task instructions, the weights of each connection layer from the two color nodes to the response nodes are initialized with random values in the 0 to 0.6 range, using the random function of the Matlab software (Figure 2, continuous arrows). In addition, to simulate automatic task-unrelated LTM links between stimulus position attributes and corresponding responses, each position node is directly connected with the corresponding response node using excitatory connections fixed at a 0.5 value (Figure 2, dotted arrows). Finally, by way of lateral inhibitory connections, the response system incorporates a competitive mechanism[1]: Thus, the two output nodes set up a dipole in which every node has an inhibitory connection (fixed to -1 value) with the other one. The activation values of input and output nodes range between 0 and 1, whereas those of all remaining nodes vary in the -1 to 1 range.

Simulations and Data Analysis

In order to simulate performance in the Simon task by 20 human subjects, we trained the neural network, starting from 20 different initializations, until the target learning criterion was reached for all the four stimuli representing the four Simon task conditions. Actually, in this task, four conditions were contrasted, two representing S-R correspondence (i.e., left stimulus – left response [a] and right stimulus – right response [d]), and the other two representing S-R noncorrespondence (i.e., left stimulus – right response [c] and right stimulus – left response [b]). For each condition, we calculated the difference between the expected distance among the activation values of the two output units (correct-response unit completely activated and incorrect-response unit completely inhibited: 1 – 0 = 1) and the obtained distance among the response nodes after training (dist). Thus, the dependent variable is given by

$$\mathrm{PI} = (1 - \mathrm{dist}) * 1000,$$

where the multiplier represents a linear transformation that does not modify the shape of data distribution but allows us to refer to integer instead of real numbers. The idea was that the greater the distance between the output node activations, the better the performance should be in terms of both speed and accuracy. We reasoned that the higher the correct-response unit activations (closer to 1), the faster the response should be, and also, the lower the incorrect-response unit activation (closer to 0), the lower the probability to execute the incorrect response (i.e., to make an error). In brief, we have assumed the variable Performance Index (PI) as a global index of goodness of network's performance.[2]

Both learning constant (η) and momentum (α) were set to 0.3. Learning finished when the difference between the expected response and the obtained response was <0.1, for each condition (a, b, c, and d) and for either response node. The maximum number of cycles allowed was 5,000.

Results

All 20 initializations reached learning criterion and no network ran more than 2,000 cycles. We carried out an analysis of variance (ANOVA) on the dependent variable PI with two within-subjects factors, that is, stimulus position (Factor A, two levels: left vs. right) and response position (Factor B, two levels: left vs. right). In addition, according to Tagliabue et al. (2007), we carried out orthogonal planned comparisons to more closely examine asymmetries. Thus, we considered the asymmetrical Simon effect in relation to both the stimulus side (stimulus SE), that is, when the stimulus was kept constant and the two responses were compared (left stimulus SE = [c-a], right stimulus SE = [b-d]), and the response side (response SE), that is, when the response was kept constant and the two stimuli were compared (left response SE = [b-a], right response SE = [c-d]).

Results show a significant stimulus position main effect, $F(1, 19) = 24.48$, MS Effect = 48,613.20, MS Error = 1,985.92, $p < .001$, revealing better performance for the left than the right stimulus (102.56 vs. 151.87 PI, respectively), which would indicate a left response SE significantly greater than the right response SE, as also found in Tagliabue et al. (2007). The two-way interaction stimulus position by response position, that is, the Simon effect, is also significant, $F(1, 19) = 1289.02$, MS Effect = 121,081.90, MS Error = 93.93, $p < .001$; Figure 3, showing a global Simon effect of 77.5 PI. Data plotted in Figure 3 confirm the presence of the asymmetry in favor of the left response SE.

Orthogonal planned comparisons show that, despite the fact that left and right response SEs are significantly different, both of them are significant. In addition, both left and right stimulus SEs are significant but their comparison is not (see Table 1 for contrast weights and statistical values).

In other words, left and right response SEs, although significantly different, are both present, whereas left and right stimulus SEs are significantly present and do not differ from each other.

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[1] Our model considered primary motor cortex (MI) as the final stage of task processing, corresponding to the execution of correct response by the MI contralateral to the effector, and to the simultaneous inhibition of the MI ipsilateral to the effector. Thus, hand-related asymmetries within the MI system (e.g., Stürmer, Siggelkow, Dengler, & Leuthold, 2000) are not crucially involved in producing Simon effect asymmetries.

[2] As we were interested in the simulation of mechanisms underlying Simon effect asymmetries, and not in the study of how a computational model learned to perform the Simon task, we focussed on the difference in performance between corresponding and noncorresponding trials, regardless of the number of cycles necessary for producing them.

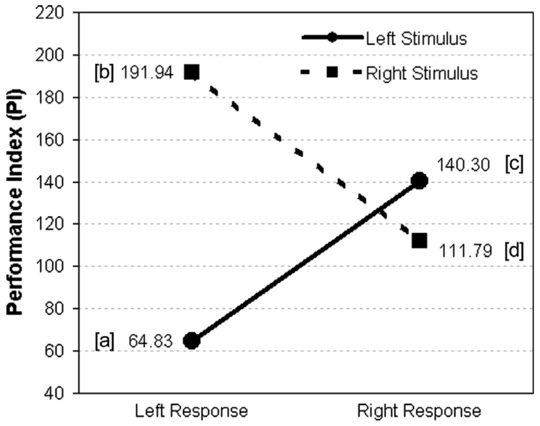

Figure 3. Two-way interaction stimulus position by response position obtained from the first model. Simon effect asymmetries were reversed in comparison with real, human data.

Discussion

The first connectionist model seems to be able to simulate the Simon effect, as attested by the significance of the two-way stimulus position by response position interaction. However, the pattern of asymmetries is reversed in comparison with RTs obtained with human subjects (e.g., Figure 1). Indeed, behavioral data from previous studies revealed greater right than left Simon effect, either stimulus SE or response SE (e.g., Hedge & Marsh, 1975; Rubichi & Nicoletti, 2006; Simon & Rudell, 1967; Simon, Sly, & Vilapakkam, 1981; Spironelli et al., 2006; Tagliabue et al., 2007; Valle-Inclán, 1996; Wallace, 1971). The present simulation shows significant stimulus SEs and response SEs on both left and right sides, but also an advantage of the left response SE compared to the right response SE. Because the model was aimed at simulating the response-selection mechanism, results demonstrate that this system is critically involved in generating the Simon effect asymmetries, and they also show that it is not sufficient to fully explain them. For this reason, we decided to add, to the model of Experiment 1, the other mechanism involved in the Simon task (i.e., the automatic attention-orienting mechanism).

Experiment 2

Methods

Architecture of the Second Connectionist Model of Simon Effect Asymmetries

Starting from the first model, the second model was implemented as a connectionist network consisting of seven layers of interconnected processing nodes. As can be seen in Figure 4, the present model added to the model of Experiment 1 two hidden layers between the position nodes of the input layer and the two right premotor area layers to simulate automatic orienting mechanisms. Because the visuo-spatial attention system has been demonstrated to be asymmetrical, that is, in right-handed subjects, the right superior parietal lobule is activated by left- and right-lateralized stimuli, whereas the left superior parietal lobule is activated only by right-lateralized stimuli (e.g., Mesulam, 1981, 1990), two additional separate layers were implemented. Thus, each position node of the input layer was connected to one of the two units of the right superior parietal lobule layer (each coding one position) (Figure 4). One node of this latter layer (the one encoding left position) was directly connected to both nodes of the right premotor areas, already present in the previous model, whereas the other node (the one encoding right position) was connected to the one-node layer added in left superior parietal lobule. The latter was in turn connected to a new node representing part of the left SMG (Figure 4). This new pathway was set up in order to simulate a callosal transfer of attention-orienting information from the right-lateralized attention system to left-lateralized attention system. Thus, information flows into the subset of left supramarginal areas supposed to underlying the so-called motor attention system.

In addition, only the position node that encoded right stimulus position in the visual field was linked to the node that represented the left superior parietal lobule. All these new connections are depicted in Figure 4 by black dotted arrows in order to represent automatic preactivating links, because it has been supposed that attentional orienting involved in the Simon task is triggered automatically at stimulus presentation and is not modified during task execution.

Table 1. Orthogonal planned comparisons obtained from the first model. According to Tagliabue et al. (2007), the orthogonal contrast weights (CWs) for planned comparisons are reported in the central columns. Results of planned comparisons are in the last four columns. Left and right stimulus SEs refer to the Simon effect for left and right stimuli, respectively; left and right response SEs refer to the Simon effect for left and right responses

	Orthogonal planned comparisons (CWs)				Results			
	a	b	c	d	MS effect	MS error	*F*(1, 19)	*p* level
Left stSE	−1	0	1	0	56,952.18	299.55	190.12	<.001
Right stSE	0	1	0	−1	64,239.37	55.22	1163.29	<.001
A or reSE	1	−1	1	−1	48,613.17	1985.92	24.48	<.001
Left reSE	−1	1	0	0	161,569.00	1,247.60	129.50	<.001
Right reSE	0	0	1	−1	8,126.12	832.26	9.76	<.01
B or stSE	1	1	−1	−1	109.64	260.84	0.42	.524

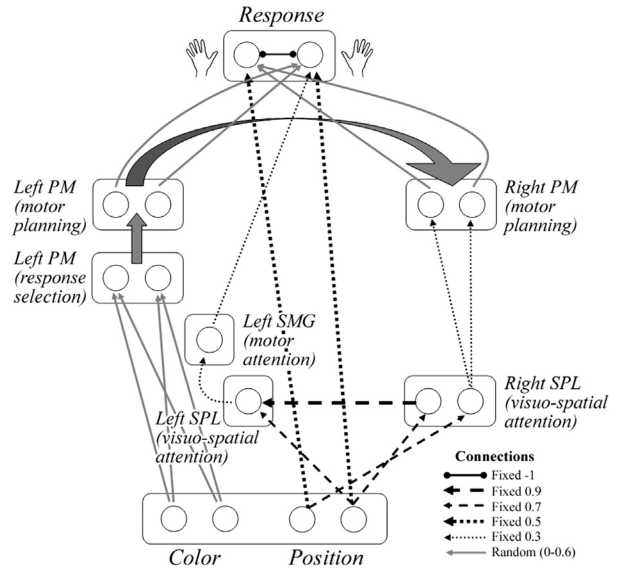

Figure 4. Connectionist model aimed at simulating both response-selection and attention-orienting and motor attention mechanisms. Continuous gray lines represent STM links modified by backward propagation: thin lines for single-node connections; thick lines for whole-to-whole connections. Black dotted lines represent direct LTM links with fixed weights excluded from learning algorithm.

For this reason, all these connections had fixed weights, which were not modified by learning.

All connections implemented in the first neural model remained unchanged, and were initialized, trained, and backwards corrected using the same back-propagation algorithm as before.

Network Connections

As just said, all the added connections had fixed weights. The first layer of connections was set at 0.7 value (Figure 4, thin broken arrows), whereas connections between the two parietal lobules and left and right premotor areas were set at 0.3 (Figure 4, thin-dotted arrows). This was because we hypothesized a smaller influence of attention on the response system. In addition, the connection representing the callosal transferring process was set at 0.9 (Figure 4, thick broken arrow) to implement the minimum lack of information demonstrated in the literature (Marzi, Bisiacchi, & Nicoletti, 1991). All the other connections were as in the model of Experiment 1. Also simulations and data analysis were carried out as in Experiment 1.

Results

We trained 20 different initializations of the model. Because two initializations failed in reaching the learning criterion due to a local minimum, we trained two additional initializations. Thus, as in Experiment 1, data analyses were carried out on 20 initializations. The same ANOVA as before was carried out on PI. The results showed significant stimulus position, $F(1, 19) = 9.68$, MS Effect = 12,887.47, MS Error = 1,331.27, $p < .01$, and response position, $F(1, 19) = 100.74$, MS Effect = 12,477.37, MS Error = 123.85, $p < .001$, main effects. The significance of these two factors revealed better performance for the right than the left side (stimulus: 143.47 vs. 168.85; response: 143.67 vs. 168.65). This means, following the rationale of Tagliabue et al. (2007), on the one hand that the right response SE was significantly greater than the left one, on the other hand that the right stimulus SE was greater than the left stimulus SE, as shown in Figure 5. The two-way interaction stimulus position by response position was also significant, $F(1, 19) = 58.89$, MS Effect = 50,225.68, MS Error = 852.83, $p < .001$, showing a global Simon effect of 45.5 PI.

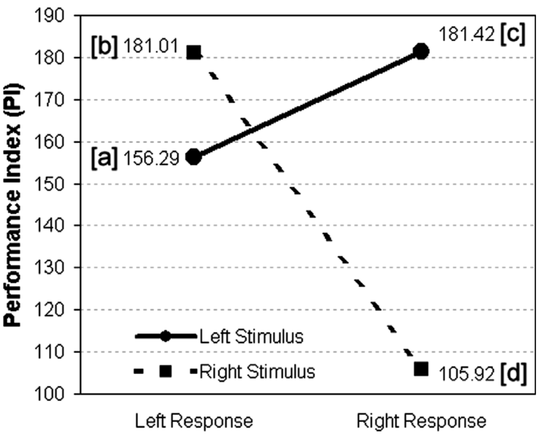

Figure 5. Two-way interaction stimulus position by response position in the second model. Simon effect asymmetries closely resemble those present in human performance.

In addition, orthogonal planned comparisons revealed that, with reference both to the stimulus SE and to the response SE, left and right Simon effects were significant, although asymmetric (see Table 2).

Discussion

The second connectionist model succeeded in simulating not only the Simon effect but also the typical asymmetries that appear in human performance (e.g., Figure 1). Indeed, taken together, results show that both response SE and stimulus SE are significantly present but also significantly asymmetric. Unlike the previous model, this model shows the Simon effect typical of most behavioral results (e.g., Rubichi & Nicoletti, 2006; Simon & Rudell, 1967; Spironelli et al., 2006; Tagliabue et al., 2007; Valle-Inclán, 1996; Wallace, 1971). With respect to the first model, the main novelty of the present one was the attempt to simulate the asymmetrical

Table 2. Orthogonal planned comparisons obtained for the second model. According to Tagliabue et al. (2007), the orthogonal contrast weights (CWs) for planned comparisons are reported in the central columns. Results of planned comparisons are in the last four columns. Left and right stimulus SEs refer to the Simon effect for left and right stimuli; left and right response SEs refer to the Simon effect for left and right responses

	Orthogonal planned comparisons				Results			
	a	b	c	d	MS effect	MS error	*F*(1, 19)	*p* level
Left stSE	−1	0	1	0	6,317.86	591.71	10.68	<.01
Right stSE	0	1	0	−1	56,385.20	384.97	146.46	<.001
A or reSE	1	−1	1	−1	12,887.47	1331.27	9.68	<.01
Left reSE	−1	1	0	0	6,114.84	161.19	37.93	<.001
Right reSE	0	0	1	−1	56,998.32	2022.91	28.18	<.001
B or stSE	1	1	−1	−1	12,477.37	123.85	100.74	<.001

visuo-spatial system and its influence in producing Simon effect asymmetries. Thus, it can be concluded that the response-selection system alone is not sufficient to fully explain such asymmetries, but response-selection and attention-orienting mechanisms combined allow us to generate plausible Simon effect asymmetries.

General Discussion

The present study attempted to establish the role of response selection and attention orienting in producing Simon effect asymmetries. Indeed, neuroimaging research on brain-damaged patients and healthy subjects showed, in right-handed subjects, opposite hemispheric dominance for response-selection processes (i.e., in the premotor/parietal areas of the left hemisphere; e.g., Hester et al., 2007; Koch et al., 2006; Rushworth et al., 2003; Schluter et al., 1998, 2001) and visuo-spatial attention (i.e., in the superior parietal lobule of the right hemisphere; e.g., Bisiach et al., 1984; Corbetta et al., 1993; Han et al., 2004; Mesulam, 1981, 1990; Norbre et al., 1997; Posner et al., 1984, 1987; Rounis et al., 2007). Starting from Tagliabue et al.'s (2000) neural network, a new computational model of the Simon task was implemented in order to simulate the response-selection mechanism (Experiment 1), and both the response-selection and orienting and motor attention mechanisms (Experiment 2).

Interestingly, results show different patterns of asymmetries depending on the neural architecture implemented. Indeed, the simulations showed that the left-side bias of the response-selection mechanism produced a left-side bias in the overt Simon effect (Experiment 1), whereas the right-side bias of the attention system produced a right-side bias in the overt Simon effect (Experiment 2). Thus, the present findings provide clear-cut evidence that the bias of the attention system has a larger impact than the bias of the response-selection mechanism in generating Simon effect asymmetries.

When only the response-selection process is implemented (Experiment 1), an asymmetrical Simon effect appears, which, however, compared with human data, show a reverse pattern: that is, the model reveals a significant advantage of the left compared with the right response SE. The first implication of this result refers to the importance of subjects' handedness assessment: indeed, the connectionist model just described was implemented simulating the response-selection system of a hypothetical right-handed subject. This is a crucial point also in reviewing previous studies employing the Simon task without taking into consideration the handedness. The second important implication concerns the opportunity to underline the critical involvement of the attentional system: Using a connectionist model, the contribution of the automatic attention-orienting mechanism becomes clear. To our knowledge, this is the first attempt to investigate the Simon effect simulating the anatomical asymmetries of the processes engaged, an attempt with a strong neuropsychological relevance.

Future behavioral studies could investigate how these mechanisms affect Simon task performance by manipulating separately the response-selection mechanism (e.g., when subjects respond by two fingers of the same hand) and the automatic attention-orienting process (e.g., when both stimuli are presented in the same visual hemi-field). Using the connectionist model that was successfully implemented here, the simulation of these possible experimental manipulations would be critical because it would allow us to identify the specific contribution of each mechanism.

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