Psychophysiological Studies of Unattended Information Processing

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The article describes the general methods and some of the results obtained in the Psychophysiology Laboratory of the University of La Coruña. The paper covers our research on the Simon effect and accessory effect, although it is not a review of the literature. The research strategy we followed is built around the use of lateralized motor potentials recorded from scalp. These measures allow observing the way responses are selected and when they are selected, providing an invaluable tool to study response interference and to split reaction time into two halves. The research on the Simon effect concludes that interference during response selection is critical in the Simon effect but it is dubious whether this process should be considered as automatic and stimulus-driven, as is widely accepted. The experiments with the accessory effect indicate that facilitation is produced before response selection is over, which ends a long controversy about the locus of the accessory effect.
Keywords: Simon effect, accessory effect, ERP, LRP

El artículo describe el método y algunos de los resultados obtenidos en el laboratorio de Psicofisiología de la Universidad de La Coruña. El trabajo abarca nuestra investigación sobre el efecto Simon y sobre el efecto accesorio, aunque no es una revisión del corpus teórico. La estrategia de investigación seguida en estos experimentos se basa en la utilización de potenciales motores lateralizados que se registran sobre cuero cabelludo. Estas medidas permiten observar cómo y cuándo se seleccionan las respuestas, proporcionando una valiosísima herramienta para estudiar la interferencia de respuesta y para partir el tiempo de reacción en dos mitades. Nuestra investigación sobre el efecto Simon concluye que la interferencia durante la selección de respuesta es crucial en el efecto Simon, pero no está tan claro si este proceso debe considerarse automático y guiado por el estímulo, como defienden la mayoría de las teorías actuales. Los experimentos con el efecto accesorio indican que la facilitación se produce antes de que termine la selección de respuesta, lo que acaba con una larga controversia acerca del locus del efecto accesorio.
Palabras clave: efecto Simon, efecto accesorio, ERP, LRP

In this article, we discuss the aims, methods, and results of the Psychophysiology Laboratory at the University of La Coruña. The common thread of our work has been to study the way in which the processing of relevant information is affected by irrelevant information. We have investigated tasks in which a conflict between relevant and irrelevant information is produced, and others in which no such conflict occurs. The classic example of conflict phenomena is the Stroop Effect (Stroop, 1935), but there are others, such as the noise compatibility effect (Eriksen & Eriksen, 1974) and the Simon effect (Simon & Rudell, 1967). This latter phenomenon has been the focus of our work. For each of the three effects mentioned above, the typical outcome is faster reaction time (RT), and higher percentage of correct answers when the relevant and irrelevant information signals the same response, as opposed to different responses.

These conflict phenomena tend to be explained using a theoretical model developed by Kornblum, Hasbroucq, and Osman (1990) that, in essence, states one processing route guided by the experimental instructions and another automatic route activated by the irrelevant information. These paths converge in the process of selecting responses, in such a way that interference is produced when two different responses are activated, and facilitation when only one is activated. Our investigation was initially centered on testing predictions from this model with measures derived from electroencephalogram (EEG) recordings. The general method is summarized in Section 1. The results confirmed that the Simon effect is produced by interference during response selection (that Gratton, Coles, and Donchin also demonstrated in 1992 for the noise compatibility effect). However, we have not been able to verify that the irrelevant information automatically activates a response. The data suggests, instead, that the influence of the irrelevant information depends on top-down processes. These studies may be found in Section 2.

We have also examined the role of irrelevant information when it is not associated with a response (unlike in the three examples cited above). Here, we focused on the accessory effect, which, basically consists of an RT that is faster when the imperative stimuli (generally visual) are accompanied by other stimuli (accessory stimuli, generally auditory), than when they are presented alone (see the review by Nickerson, 1973). Our results showed that effect was produced before response selection ended, and not further along in the processing sequence, as Sanders (1980) maintained (see Section 3).

1. Measurements Derived from EEGs: ERPs

The electromagnetic fields produced by postsynaptic activity of synchronously activated neurons organized in an "open field" (i.e., aligned along a symmetry axis) generate an electromagnetic field that can be recorded at scalp as electrical activity (EEG) or as magnetic fields (magnetoencephalogram, MEG). The brain's response to stimulation involves neural activity related to the analysis of the stimulus ("signal") and that of the other neurons whose activity is not time-locked to the stimulation ("noise"). The magnitude of noise is several times larger than that of the signal, and thus, the first problem is separating signal from noise. The most common procedure is based on the fact that noise is a random variable whereas the signal is assumed to be constant. If those two assumptions hold, a coherent averaging (time point by time point) will abolish the noise (random values will tend toward the mean) and the signal will be visible. Recording from an array of electrodes, and interpolating values, yields a distribution of electrical potential over the scalp at each time point. This electrical distribution is produced by neural processing related to the event of interest (event-related potential, ERP). Obviously, one could also attain ERP time-locked to response (e.g., Hackley & Valle-Inclán, 1998).

The basic problem with the EEG and derived measures is that, generally speaking, it is not possible to locate the neurons responsible for the distribution of potential observed. The number of spatial configurations that could account for a particular distribution is endless, something that is referred to as the "insolubility of the inverse problem."[1] It could be argued that localization of the active structures is not one of the challenges of psychological investigation and that there are many questions that could be addressed without recourse to anatomy. The pioneer studies of Hillyard, Hink, Schwent, and Picton (1973) concerning auditory attention demonstrated that even without knowing the origin of recorded potentials, we can know *when* attended stimuli are differentiated from the unattended, and this information, in turn, is pertinent to the early/late selection debate.

Nonetheless, if one intends to go beyond a functional model (that is, a psychological model), one cannot dismiss the structural information. There are various ways to assign anatomical information to the ERPs, one of the most popular being the analysis of dipoles in combination with magnetic resonance imaging (MRI). However, we have to state that these are ad hoc methods that, at best, demonstrate only that the proposed dipole structure is *compatible* with the distribution of potential found. Nor can the combination of ERP and

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[1] The inverse problem is insoluble even when the recordings are of magnetic fields (MEG, magnetoencephalography), that are not distorted by the skull or scalp. If certain restrictions based on hypotheses, such as anatomical information, are imposed, then one could arrive at a solution to the inverse problem, but this solution, though feasible, will not be unique.

functional magnetic resonance (FMRI) be considered a solution. In general, it is inexact to search for centers of activity with FMRI, and then place dipoles in the corresponding coordinates, and then generate a distribution of potential and compare it with the one obtained through ERP recording. It is inexact, despite the relation between blood flow and postsynaptic activity, because one cannot usually ascertain whether the activity reflected in FMRI corresponds to a closed field, in which case, it would not be reflected in the EEG. Furthermore, even if one knows that the "lit up" area in FMRI has neurons organized in an open field, the difference in temporal scale between ERP and FMRI is so great (even in single-trial FMRI) that, at most, a coincidence between an FMRI focus and an equivalent dipole could be taken as suggestive.

Another solution to the spatial indetermination of ERPs is to work with those whose neural origins are known, thanks to invasive recording and experimentation with animals. These days, neural generators are known for potentials produced along the sensory pathways, before the activation reaches cortex. The utility of these very short latency potentials in the study of "superior" functions is certainly very limited. At cortical levels, we possess only a reasonable certainty regarding the origins of motor potentials that antecede movement and of early (< 100 ms) visual, auditory, and somatosensory cortical potentials. Most of our research was directly concerned with motor-related potentials preceding the execution of simple responses (such as pressing a key). It is generally agreed that these scalp-recorded potentials originate in the primary motor cortex. We have also utilized early visual potentials, which display retinotopic organization. Given the organization of V1 around the calcarine fissure, the polarity of the primary components is inverse for stimuli presented in the upper hemifield and in the lower hemifield (see Valle-Inclán, Hackley, de Labra, & Álvarez, 1999a, 1999b).

In the following section we present the method employed for obtaining potentials related to movement.

Lateralized Readiness Potential (LRP)

The LRP is an EEG-derived measurement that was developed simultaneously and independently at the University of Groningen (de Jong, Wierda, Mulder, & Mulder, 1988; Smid, Mulder, & Mulder, 1987) and at the University of Illinois (Coles, 1989; Coles & Gratton, 1986). The LRP is relatively easy to compute and nowadays, cheap to implement, but the information obtained is inversely proportionate to the procedure's simplicity, as will be detailed below.

Method for obtaining the LRP. Some hundredths of milliseconds before a hand or finger movement is executed, a negative potential develops over the motor cortex (at positions C3 and C4 of the 10-20 international system, or at positions 1 cm anterior). This negative and symmetrical potential is known as the "readiness potential." Before execution of the movement, the readiness potential becomes more negative in the contralateral hemisphere of the hand that is to execute the response. By subtracting the potentials recorded over left and right hemispheres, the time point at which the readiness potential begins to lateralize will be observed. If the RT for left- and right-hand responses is similar, we can construct an activation index for the correct response by subtracting left- and right-hand responses. The result of this double subtraction (hemispheres, response hand) is known as the LRP (other names such as "corrected motor asymmetry," de Jong et al., 1988, are no longer used).
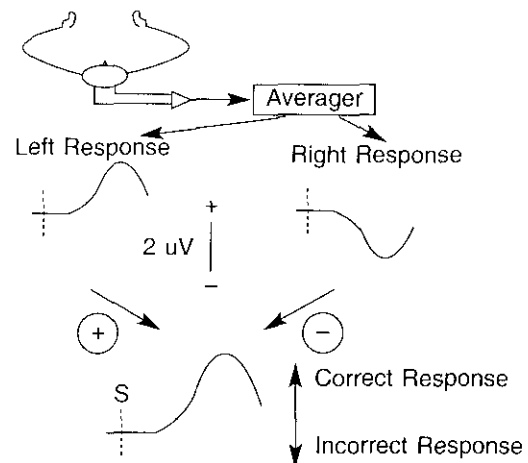

Figure 1. LRP calculation.

There are several methods to compute the LRP (see Coles, 1989; Osman, Bashore, Coles, Donchin, & Meher, 1992) but perhaps the easiest, in computational terms, is that of Osman et al. (1992):

$$LRP = (C3-C4)_{Left} - (C3-C4)_{Right}$$

To further clarify the method, imagine the simplest experimental task: Stimuli presented centrally that require left- or right-hand responses. In this case, the LRP can be obtained using only one EEG channel, a digital-to-analog converter, and a simple averaging program (see Figure 1). Connecting electrodes placed at the C3 and C4 positions of the international system 10-20 (a C3-C4 "bipolar derivation") will yield the difference between left and right motor cortices (the first subtraction is done on-line). With this procedure, blinking and vertical ocular movements (a common problem in EEG research) are nullified because the values are the same for both electrodes. Since the stimuli are presented centrally, there are no horizontal ocular movements (at least, not relevant to the task and, thereby, affecting the results) that could distort the EEG recording. EEG epochs will then be obtained and averaged according to the response hand and the stimulus type. Trials with left-hand reactions will show a positive deflection whereas a negative wave will be observed on trials

with right-hand reactions. Finally, ERPs for left- and right-hand responses will be subtracted. More complex designs might also require eye-movement correction programs (Gratton, Coles, & Donchin, 1983) or rejection of trials contaminated with ocular activity, or a larger array of electrodes.

Functional significance of the LRP. Figure 2 displays a minimalist model of information-processing stages for a choice-RT task. The figure includes three processing stages and the two psychophysiological markers (P300 and LRP) that were used to divide the interval between stimulus presentation and response execution. P300 latency had been considered for many years an adequate indicator of the end of the stimulus evaluation phase (e.g., McCarthy & Donchin, 1981), despite the fact that many studies indicated that factors implicated in response selection affected the latency of P300 (e.g., Valle-Inclán, 1996b). Verleger (1997) reviewed the literature on P300 latency and concluded that it is incorrect to consider P300 latency as a pure index of stimulus evaluation time.
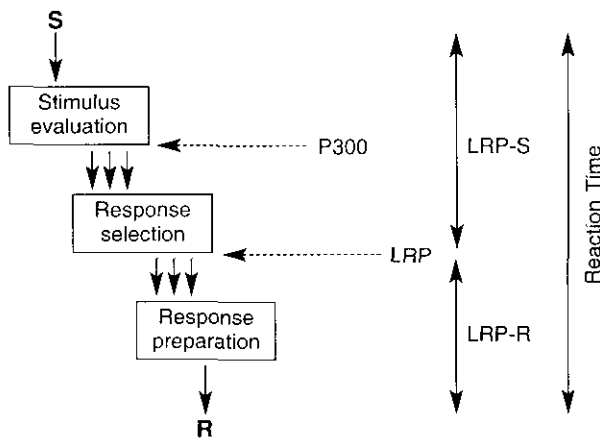

Figure 2. Minimalist model of information processing stages for choice-RT tasks.

However, the other psychophysiological index included in Figure 2, the LRP, is a measurement with clear functional significance and known neural origins. The LRP provides a method for dividing the RT in half and testing to see whether the observed behavioral effects are produced before or after response selection; additionally, it affords information about which responses were activated. Initiation of the LRP indicates the moment when one of the hands has been chosen to respond, that is, the end of the response selection stage. Therefore, the onset latency of the stimulus-locked LRP (LRP-S in Figure 2) indicates the time that elapses from stimulus presentation to the conclusion of response selection. Meanwhile, if we calculate the response-locked LRP (LRP-R in Figure 2), its onset latency indicates the time that elapses from response selection to its execution. In other words, the LRP onset allows us to halve the RT

without having to assume a particular information-processing arquitecture or the way information is transmitted from one stage to the next. These two issues weigh heavily on a good many of the conclusions reached using behavioral measures. Our work with the accessory effect (see Section 3) is an example of the way one can utilize LRP to divide RT and to determine the stage of information processing at which the observed effects in behavior are produced.

On the other hand, the form of the LRP enables us to know which responses were activated before response execution. Calculating the LRP according to the formula offered above, correct responses exhibit a positive LRP and incorrect responses a negative LRP. In this case, if only one response is activated, the LRP will be positive, whereas if two responses are activated and the correct one is executed in the end (that is, if there is interference in the response-selection stage), the LRP will be biphasic: first a negative deflection, followed by a positive deflection. Our studies with the Simon effect (see Section 2) illustrate how LRP can be used to determine which responses are selected.

2. The Simon Effect

The Simon effect, first described by Simon and Rudell (1967) and so designated by Hedge and Marsh (1975), emerges in choice-RT tasks in which stimuli have a task-relevant (e.g., color) and a task-irrelevant dimension (spatial location), and response keys are located in a manner congruent with the irrelevant stimulus spatial dimension. For example, the stimuli (two color patches) are randomly presented at the left and right of the fixation point, and subjects answer by pressing keys that are also positioned at left and right. Under these conditions, the RT is faster in those trials in which the stimulus and response are ipsilateral (compatible trials) than in those in which the stimulus and
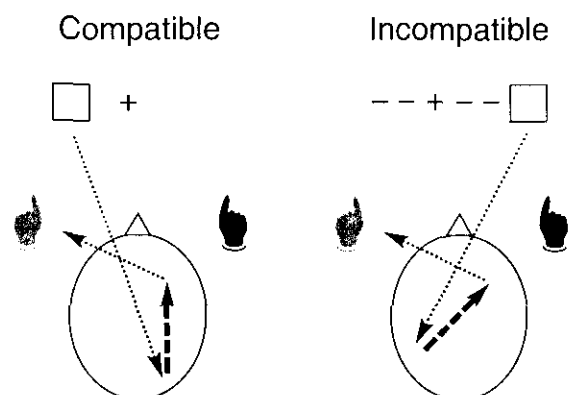

Figure 3. Anatomical hypothesis to explain the Simon effect.

response are contralateral (incompatible trials). The effect is very consistent, it can be found in various sensory modalities, and it does not dissipate with practice (see the revisions of Lu & Proctor, 1995; Simon, 1990).

One of the explanations for the Simon effect that first comes to mind is shown in Figure 3. When the stimulus location and the required response are ipsilateral, stimulus and motor processing occur in the same hemisphere, whereas if stimulus and response are contralateral, an interhemispheric transmission is required. This explanation is false for many reasons, but the simplest and most convincing arc the following: (a) If the hands are crossed over the midline in such a way that the right hand presses the left key and vice versa, the Simon effect is maintained (Simon, Hinrichs, & Craft, 1970); and (b) if the two response keys are operated by two fingers of the same hand, the Simon effect also occurs.

In general, current explanations for the Simon effect hold the following: (a) The two attributes of the stimulus are processed in parallel, (b) spatial localization processing automatically activates the spatially compatible response, and (c) this automatic activation of the compatible response is transitory and declines over time (Hommel, 1993a, 1994; Kornblum, et al., 1990; Kornblum, Stevens, Requin, & Whipple, 1999). In our laboratory, we have striven to determine where the interference of irrelevant information is generated and to what extent behavioral effects can be considered the product of an automatic, stimulus-driven process.

The Locus of the Simon Effect as Studied with LRP

First, we attempted to elucidate at which processing stage (see Figure 2) the Simon effect is produced. At that time, this was the subject of lively debate following the publication by Hasbroucq and Guiard (1991) of two experiments that seemed to demonstrate interference during stimulus evaluation. (Credit for the demonstration of the artifact that produced these results belongs to Hommel, 1995.)

A functional description of the Simon effect could begin with a model that is very similar to that of Figure 2. The model is quite generic, but it is an approximation that has proven to be useful for understanding and studying information processing in choice-RT tasks. Adopting this model as a basis, there are three possible loci for interference in the Simon effect, and each of them corresponds to a pattern of results of stimulus-locked LRP, as is represented in Figure 4.

It could be assumed that the conflict between the two dimensions is caused during perceptive processing (as claimed by Hasbroucq and Guiard, 1991) so that the system takes longer to classify a stimulus in incompatible than in compatible trials. If this were the case, compatible trials would show earlier LRP onset than incompatible trials, without there being signs of incorrect response activation (see Figure 4, upper row). If, on the other hand, the Simon effect occurs during the response selection, the LRP should start at the same moment for both compatible and incompatible trials, but, for the latter, there would have to be LRP signs of incorrect response activation (Figure 4, center row). Lastly, if the Simon effect is produced during response preparation or execution, the stimulus-locked LRP should be the same for compatible and incompatible trials (Figure 4, lower row) and the differences would arise in the response-locked LRP (not represented).
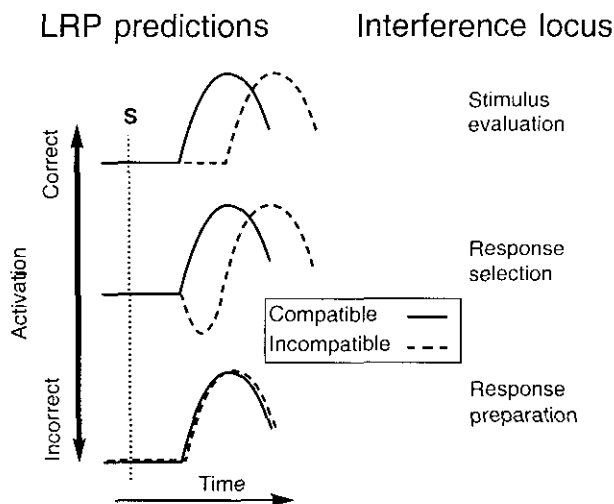

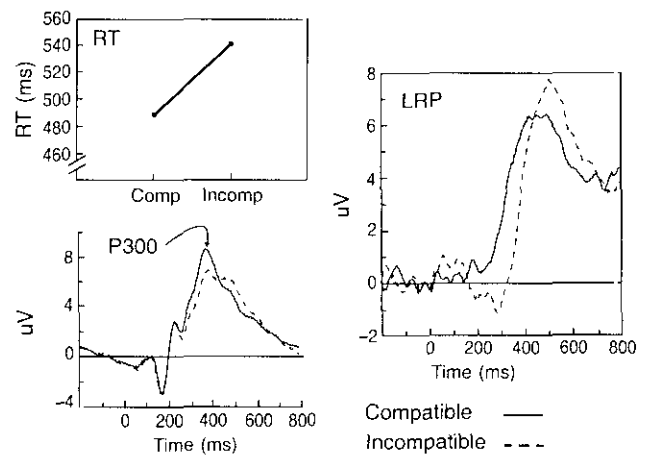*Figure 4.* Stimulus-locked LRP predictions for different interference loci in the Simon effect.

Figure 5. Typical RT and ERP results for a Simon task. The ERPs illustrating the P300 effect were recorded at Pz. The LRP was obtained from recordings at C3 and C4. Data from Valle-Inclán (1996a, Experiment 3).

With these hypotheses in mind, we conducted several experiments (Valle-Inclán, 1996a, 1996b) that consistently showed that LRP onset occurs at the same time for both compatible and incompatible trials and that, for the latter, the incorrect response is also activated. Figure 5 shows the results of one of these experiments (Valle-Inclán, 1996a, Experiment 3). In the upper left are the RT averages showing faster RT for compatible trials. In the lower left are the ERPs recorded in Pz for compatible and incompatible trials. Note that P300 is delayed for incompatible trials, as compared to compatible trials. The LRP results are plotted on the right of Figure 5. LRP onsets are very similar for compatible and incompatible trials and that the incorrect response is activated (the negative dip in the graph) in the incompatible trials. This pattern of results is very clear and consistent, such that we can confidently state that response interference is a critical factor in the production of the Simon effect.

The Automatic Character of the Simon Effect

The usual hypothesis argued to explain the Simon effect is that the abrupt stimulus onset automatically activates the compatible response (e.g., Craft & Simon, 1970; de Jong, Liang, & Lauber, 1994; Kornblum et al., 1990). There are various lines of conflicting evidence concerning this hypothesis. First of all, as it was originally presented, the hypothesis has trouble explaining the appearance of Simon effects when target and noise are simultaneously presented (e.g.,Valle-Inclán, 1996a, Experiment 2). Since, in these experiments (see also Grice, Canham, & Burroughs, 1984), the stimuli occupy both sides, it is obvious that the appearance of the stimulus cannot be responsible for the Simon effect. Recently, Shiu and Kornblum (1999) have proposed that the automatic activation of the compatible response can take place after identification of the stimulus, which could explain occurrence of the Simon effect in visual-search tasks.

Second, if the mere presentation of the stimulus, or its identification, activates the compatible response, one could expect that, with respect to neutral trials (N), where no lateralized presentation exists, compatible trials (C) will exhibit facilitation (C < N), whereas incompatible trials (I) will exhibit interference (N < I). However, the comparison of compatible, neutral, and incompatible trials yields different results depending on the experimental design. For example, Simon and Small (1969) presented compatible and incompatible trials mixed in the same block, and neutral trials in another block. Their results display a N < C < I pattern. Simon and Craft (1970) presented the three types of trials in the same block and achieved the aforementioned pattern, C < N < I (see also Hommel, 1993b; Umiltà, Rubichi, & Nicoletti, 1999). Simon and Acosta (1982) showed that the presence of facilitation depends on the method of blocking used.

Third, the notion of an automatic activation of the compatible response cannot explain the inversion of the

Simon effect, which Hedge and Marsh (1975) were the first to describe. These authors utilized colored keys and presented colored patches. The task was to press the key of the same color as the stimulus (direct mapping condition) or of the opposite color (alternate mapping condition). In four different experiments, the stimuli were presented in a vertical or horizontal meridian and the responses arranged in a vertical or horizontal dimension. The Simon effect showed up when stimuli and responses shared the same spatial dimension (vertical or horizontal), but only under direct mapping conditions. Surprisingly, the Simon effect was inverted under the alternate mapping condition. Since the work of Hedge and Marsh, two other ways to invert the Simon effect have been reported (Hommel, 1993b; Proctor & Lu, 1999).
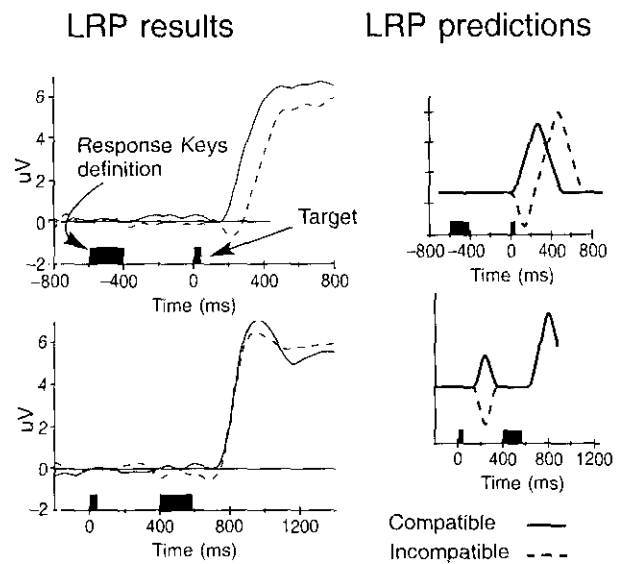

Figure 6. Predictions (right column) and actual results (left column) of an LRP experiment designed to test whether stimulus onset automatically activated the compatible response (Valle-Inclán & Redondo, 1998). The upper row contains results and predictions for immediate-reaction trials. The lower row contains those for delayed-reaction trials.

The evidence just summarized is incongruent with explanations for the Simon effect constructed around an automatic activation of the compatible response. Valle-Inclán and Redondo (1998) tested to see whether the presentation of a stimulus actually activated the compatible response using the LRP. Red or green circles were randomly presented above and below a central fixation point and response keys were located "above" and "below." The assignment of response keys to colors was randomly changed on every trial and presented to the subjects before (immediate-reaction trials) or after (delayed-reaction trials) the presentation of the imperative stimulus (the colored

circle). In this way, there were four types of trials defined by spatial compatibility and by the moment at which the response keys were defined. The critical manipulation is in the delayed-reaction trials. If one assumes that the stimulus presentation activates the spatially compatible response, the LRP should show signs of response activation in the interval between the stimulus presentation and the definition of the response keys. The predicted pattern of results according to this hypothesis is shown in Figure 6, right panel. The results, illustrated in the left panel of Figure 6, confirm that the presentation of a stimulus does not activate the spatially compatible response.

Recently, we have begun to study the role of expectations in the Simon effect, measuring the influence of sequential dependencies. The influence of a trial (N-1) on the following one (N) is pervasive in choice-RT tasks, and repetition effects (the $RT_n < RT_{n-1}$) and alternation effects ($RT_n > RT_{n-1}$) have been described. The repetition effects appear at relatively short intervals between the response and stimulus (RSI, response-to-stimulus interval) and are linked to perceptive processing. The alternation effects, on the contrary, appear at long RSIs and are linked to response factors. This pattern varies when stimuli and responses are spatially incompatible, and repetition effects with RSI greater than 1000 ms can be observed.

Valle-Inclán et al. (1998) studied the effects of compatibility between trial N-1 and trial N in a Simon task. On each trial, they presented in the center of a screen a letter (S or T). Simultaneous with the appearance of the letter, they presented a noise of 65 dB through one of the loudspeakers located above or below the monitor. The noise was not informative, and its localization, up or down, was random. Responses to the letter were given pressing "upper" or "lower" keys.
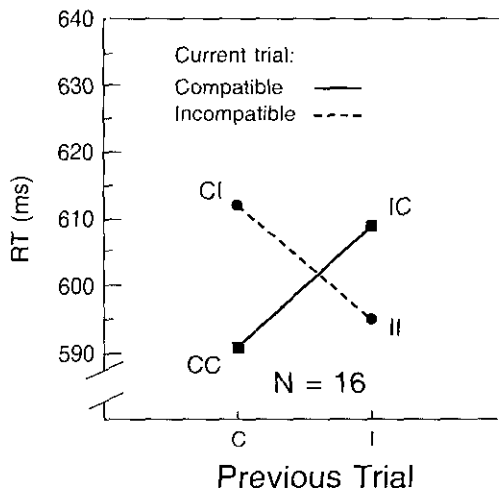
The RT analyses included only those sequences with correct responses in the two consecutive trials. The trials were classified according to compatibility between the trials N and N-1, yielding four types of sequences: compatible-compatible (CC), compatible-incompatible (CI), incompatible-compatible (IC), and incompatible-incompatible (II). Figure 7 displays the mean RTs for each of the four sequences. The Simon effect (compatible < incompatible) is present only if the preceding trial was compatible, and an inversion of the Simon effect (compatible > incompatible) is produced if the preceding trial was incompatible. This inversion of the Simon effect contradicts the supposition of an automatic activation of the compatible response; instead, it suggests that strategic factors are crucial in the production of the effect. More specifically, it suggests the existence of a repetition effect of spatial stimulus-response compatibility (SRC).

To test this SRC-repetition effect, we reemployed the procedure of an experiment that attained Simon effects at about 50 ms (Valle-Inclán, 1996a, Experiment 3). Sixteen students participated voluntarily. The stimuli were arrows pointing up or down, presented randomly above or below the point of fixation, for a period of 50 ms. Responses were made by pressing the keys of a computer keyboard that was placed perpendicular to the screen. The "upper" key was the number 5 and the "lower" key, number 6, both of the numerical keyboard. The keys were pressed with the index fingers of each hand, and the assignment of key to hand was counterbalanced among the subjects. The subjects' task consisted of pressing the "upper" key if the arrow pointed up and the "lower" key if the arrow pointed down.

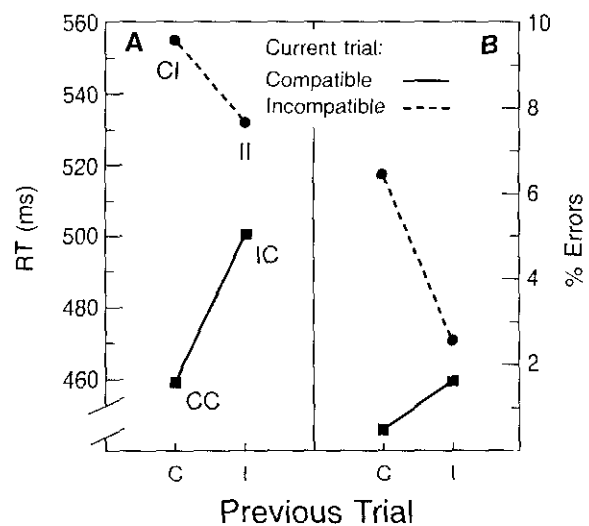Figure 7. Sequential dependencies in a Simon task (from Valle-Inclán, Hackley, & McClay, 1998).

Figure 8. Sequential dependencies in a Simon task after Valle-Inclán (1996, Experiment 3). The panel on the left contains the mean RT and the right panel shows the mean percentage of errors. C = Compatible; I = Incompatible; CC = Compatible-Compatible; CI = Compatible-Incompatible; IC = Incompatible-Compatible; II = Incompatible-Incompatible.

The trials were classified according to the compatibility between the preceding trial and the current trial, just as in the experiment of Valle-Inclán et al. (1998). The compatible trials had faster RTs (487 msec) than the incompatible trials (549 msec), $F(1, 15) = 109.92$, $p < .0001$, and a lower percentage of error (1.17% and 5.17%, respectively), $F(1, 15) = 17.95$, $p < .0001$. The results of the analysis of sequential compatibility are shown in Figure 8. The left panel includes the mean RTs for each of the four sequences of compatibility (CC, CI, IC, II), and the right panel contains the averages of percentage of error for each of the conditions (to obtain this measure, only sequences in which the first trial had been answered correctly were included). A strong SRC-repetition effect (CC < IC and II < CI) was observed in RT and percentage of error, although the Simon effect did not become inverted after incompatible trials, as in Valle-Inclán et al. (1998). Figure 8 shows that the greatest contribution to the Simon effect was produced by the difference between CC (459 msec) and CI (555 msec) although there was also a contribution in the difference between IC (501 msec) and II (532 msec). Interaction between compatibility in the preceding trial and in the current trial was very strong, $F(1, 15) = 113.1$, $p < .0001$, just as the main compatibility effect for the current trial, $F(1, 15) = 117.51$, $p < .0001$.

These results suggest that subjects expect repetition of S-R compatibility (trials CC and II). If, instead of repetition, alternation is presented (CI or IC), the RTs are longer and precision diminishes. The results also indicate that the SRC-repetition effect is greater when trial N-1 is compatible (difference between CC and CI, 96 msec) than when it is incompatible (difference between II and IC, 31 msec). The causes for this asymmetry are not known, but we believe that it may be a consequence of overestimation of the number of compatible trials. In turn, this overestimation could be caused by daily experience, where spatial compatibility is the norm (Valle-Inclán, Hackley, & de Labra, 2000).

3. The Locus of the Accessory Effect

The accessory effect is another of the tasks in which irrelevant information affects the processing of relevant information, but, in this case, there is no conflict between two responses. In a choice-RT task with visual targets, if an irrelevant noise (that calls for no response, gives no information about which is the correct response, and provokes no blinking reflex) is presented on some trials, RT is shorter for those trials with noise (accessory stimulus) than for those without (see Nikerson's classic revision, 1973).

Explanations for this effect have been offered for each of the three stages of information processing of Figure 2. It has been suggested that the accessory effect reflects intersensory facilitation (Stein, London, Wilkinson, & Price, 1996), an increase in the speed with which the response is

selected (Posner, 1978), and an increase in the speed with which the response is prepared and executed (Sanders, 1980). In view of these conflicting explanations, it is difficult to see how behavioral data alone could localize the processing stage. However, use of the LRP makes it perfectly possible to divide the RT in two and note whether the accessory effect is produced in one half or the other.

Hackley and Valle-Inclán (1998, 1999) applied this reasoning and found that the facilitation is produced before response selection ends; that is, the entire behavioral effect is reflected in the stimulus-locked LRP, and there are no traces of facilitation in the response-locked LRP. One can conclude that the accessory effect occurs either during the perceptive processing or during response selection. The next step is to demonstrate in which one of the two the behavioral effect originates. This is no easy task. The fundamental problem lies in the confusion of visual and auditory ERPs on trials with an accessory stimulus. Separating the two contributions requires some sophistication in the experimental design and in the treatment of data, but this does not appear to be impossible to achieve.

Another interesting outcome from the work of Hackley and Valle-Inclán (1999) is the utilization of blinking latency. It is known that subjects tend to blink on finishing a trial (Stern, Walrath, & Goldstein, 1984), and this holds for trials that require a response ("go trials") and for those that do not require a response ("no-go trials"). This means that, even in the trials for which the subject does not have to press a key, the recording of blinks allows one to know when the subject has finished processing the stimulus and has decided not to respond (see Figure 3 of Hackley & Valle-Inclán, 1999). We would like to call attention to this finding, which provides for measuring 'RT' in trials where there is no response.

4. Concluding Remarks

The research summarized in this paper provides an example of the way in which physiological measures can be used to test information-processing models of human brain functioning. We have focused on one physiological measure, the LRP, that yields an index of differential activation between left and right motor cortex. Unlike other ERPs, the neural generators of the LRP are relatively well known, and its functional significance is clear, or, at least, is understood more clearly than any other ERP.

Using the LRP, we showed that: (a) The Simon effect is due, at least in part, to response interference produced by activation of the compatible response on incompatible trials (Valle-Inclán, 1996a, 1996b); (b) the activation of the compatible response should not be considered an automatic, stimulus-driven process (Valle-Inclán & Redondo, 1998); and (c) the observed behavioral facilitation in the accessory effect is produced before the response selection ends (Hackley & Valle-Inclán, 1998, 1999).

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