

Title: Similarities and differences between interference from stimulus position and from direction of an arrow: behavioural and event-related potential measures.

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## ABSTRACT

Studies with stimulus-response compatibility tasks (SRC) used the stimulus position (SRC-p) and/or the direction indicated by a central arrow (SRC-d) as irrelevant dimensions. Despite behavioural differences revealed by the distributional analyses (DA), both interferences were established at similar loci on the basis of modulations in the lateralized readiness potential (LRP) and P3b components. Consequently, similar underlying mechanisms were proposed for both interferences. However, comparison of motor processes associated with each task is problematical because each involves different components. In addition, previous studies have frequently used different proportions of trials between conditions, which complicates interpretation of the results because the stimulus probability may modulate P3b. Taking these problems into account, the present study investigated the effects of interference in SRC-p and SRC-d tasks, in which the participants responded to the colour of a stimulus while ignoring the position and the direction indicated by a central arrow, respectively. The interference was greater in the SRC-p than in the SRC-d task. The DA showed that stimulus position affected the performance more quickly than the direction of the arrow. The P3b latency was longer and the P3b amplitude was smaller when stimulus position was incompatible. However, no differences in P3b were found in the SRC-d task. Moreover, both types of interference affected response-related processes (LRP-r) similarly. Therefore, the stimulus position and the direction indicated by the stimulus may share a common locus of interference (response execution), but only stimulus position affects P3b component, which constitutes a link between stimulus evaluation and the response selection.

## **1. Introduction**

In stimulus-response compatibility (SRC) tasks, participants respond to a stimulus feature (relevant dimension), while other features (irrelevant dimensions) must be ignored. SRC tasks are frequently used to study the interference caused by irrelevant dimensions that are incompatible with the relevant dimension of the stimulus or with the response. Eight types of SRC tasks are distinguished according to the overlap between the irrelevant and the relevant dimensions of the stimulus and between both dimensions of the stimulus and the response (see Zhang et al., 1999).

In type 3 SRC tasks, there is an overlap between the irrelevant dimension of the stimulus and the response. The Simon task is the most representative example of this type of tasks (for reviews see Leuthold, 2011; Lu and Proctor, 1995; Simon, 1990). In the Simon task, participants respond to a feature (e.g. the colour or the shape) of a spatially lateralized stimulus by pressing one of two buttons. The response buttons are also lateralized in the same spatial arrangement as the stimuli, and a slower reaction time (RT) is observed when the stimulus position (irrelevant for performing the task) is spatially incompatible with the side of the required response. This slowing in RT is known as the Simon effect.

The direction indicated by the stimulus has also been used as an irrelevant dimension that overlaps with the response, resulting in another type 3 SRC task. Thus, in a study carried out by Masaki et al. (2000), participants responded to the colour of a central arrow by pressing one of two buttons (arranged horizontally). The irrelevant dimension was the direction of the central arrow, which pointed left or right. A slower RT was observed when the direction of the arrow was incompatible with the hand of the required response (Masaki et al., 2000).

Previous studies have investigated the locus of interference for the stimulus position (SRC-p, also called Simon tasks) and the direction indicated by the stimulus (SRC-d) when they are incompatible with the response based on the task relevant feature (e.g., the colour). The response selection (De Jong et al., 1994; Masaki et al., 2000; Stürmer et al., 2002; Valle-Inclán, 1996a, 1996b) have been considered as a locus of interference for the SRC-p tasks. The lateralized readiness potential (LRP) is an event-related potential (ERP) that distinguishes between perceptual and motor stages of processing (see Coles et al., 1988 and Osman et al., 1995) and LRP modulations allowed to obtain insights about the interference locus of the SRC-d and SRC-p tasks in the response selection. Behavioural data suggested also that interference in Simon tasks took place in response execution stage (Ansorge and Wühr, 2004; Vallesi et al., 2005). Moreover, Masaki et al. (2000) carried out a detailed study of LRP modulations in a SRC-d task where the participants responded to colour of an arrow and ignored the direction pointed by that arrow. They concluded that SRC-d and SRC-p tasks affected motor processes in a similar way.

SRC-p and SRC-d tasks also modulated processes associated with P3b, which was proposed to reflect stimulus evaluation time (Donchin and Coles, 1988), although more recent evidence suggests that P3b reflects a link between perceptual analysis and response onset (Verleger et al., 2005). Longer P3b latencies have been reported in incompatible trials of SRC-p tasks (Leuthold and Schröter, 2006; Leuthold and Sommer, 1999; Melara et al., 2008; Ragot, 1990; Valle-Inclán et al., 1996a, 1996b; Van der Lubbe and Verleger, 2002) and SRC-d tasks (Masaki et al., 2000). A few studies have also reported reduced P3b amplitudes when the position is incompatible with the response (Leuthold and Schröter, 2006; Ragot, 1990; Valle-Inclán et al., 1996a, 1996b)

and when the stimuli moved towards the incompatible direction regarding the required response (Galashan et al., 2008).

Despite the similarities between incompatibility due to the stimulus position and incompatibility due to the direction indicated by the stimulus, behavioural and psychophysiological evidence also suggests differences between the loci of interference caused by both types of irrelevant dimensions.

On the one hand, interference in the incompatible condition is caused by the stimulus position (Lu and Proctor, 1995) and by the direction indicated by the arrow (Masaki et al., 2000); however, a facilitation effect in the compatible condition (faster RT in the compatible than in the neutral condition) was observed for the direction of the arrow (Masaki et al., 2000) while inconsistent results were observed for the stimulus position (for a review, see Simon, 1990). On the other hand, the distributional analysis (DA) (for a review see Proctor et al., 2011) has shown that the Simon effect is manifested at faster response times but usually decreases at slower RT (De Jong et al., 1994; Proctor et al., 2011), whereas the interference from the direction increases from faster to slower RT (Pellicano et al., 2009; Proctor et al., 2009). As a result, it has been suggested that stimulus position is processed more quickly than the direction indicated by the stimulus, probably because the direction requires processing of the symbolic meaning (Iani et al., 2011; Symes et al., 2005; Vainio et al., 2007).

Some electrophysiological differences between both tasks have also been reported. Both the N2 posterior contralateral (N2pc), which is related to visuospatial processing of the target (Luck and Hillyard, 1994), and the N2 central contralateral (N2cc), which is related to a mechanism that prevents cross-talk between the direction of the spatial attention and the manual response preparation (Cespón et al., 2012; Praamstra and Oostenveld, 2003), are present in Simon tasks (with stimuli in horizontal

arrangement) but not in SRC tasks based on the direction of central arrows. Therefore, some neurophysiological processes involved in SRC-p tasks are not present in SRC-d tasks. Moreover, in SRC-p tasks, the onset of the stimulus-locked lateralized readiness potential (LRP-s, a correlate of the covert response activation) overlaps with N2cc in similar regions and temporal windows (see Praamstra, 2007). Consequently, the covert response activation cannot be reliably measured in horizontal Simon tasks. Also, LRP-s cannot be compared between the tasks because differences may result from different components in each. In fact, studies comparing horizontal and vertical Simon tasks (Vallesi et al., 2005; Wiegand and Wascher, 2005) were criticized by Praamstra (2007) as they did not take into account that N2pc and N2cc are present in horizontal but not in vertical Simon tasks.

Results obtained for P3b modulation in SRC-d tasks are also controversial owing to the paradigm used in previous studies. Galashan et al. (2008) presented a larger number of compatible than incompatible and neutral trials, whereas Masaki et al. (2000) presented the same number of compatible and incompatible trials, but a larger number of neutral trials. Therefore, these experimental designs follow the structure of oddball paradigms, in which the subjective probability is known to influence P3b parameters (Duncan-Johnson and Donchin, 1977; Polich, 1990). In addition, it is known that Incompatible trials show reduced interference when they are preceded by another Incompatible trial (i-I sequence) while its interference is increased when they are preceded by Neutral (n-I sequence) or Compatible (c-I sequence) trials (Davelaar and Stevens, 2009; Spapé et al., 2011). Thus, when a reduced proportion of Incompatible trials are presented, the mentioned effects of sequence may modulate the effect of interference, and therefore the P3b component.

Summarizing, stimulus position attracts attentional resources in a fast way whereas that the direction of the arrow is processed more slowly since it is required the interpretation of its symbolic meaning (Abrahamse and Van der Lubbe, 2008; Klein and Ivanoff, 2011). Evidence for these differences in the speed of processing between both irrelevant dimensions was provided by the Distributional Analyses of the RTs (DA) (Proctor et al., 2011). Therefore, considering the above differences in behavioural results, can the loci of interference for both irrelevant dimensions (stimulus position and direction of the arrow) be considered equivalent?

To resolve these inconsistencies between behavioural and electrophysiological data it would be necessary to compare both incompatibilities (position and direction) using tasks with identical parameters. Also, it is necessary to take into account differences in ERP components involved on each task (i.e. N2pc and N2cc are present in the SRC-p but not in the SRC-d task) as well as those parameters of the task that might modulate any of the ERP components studied (e.g. P3b modulations might be caused by oddball designs and/or sequence effects).

The aim of the present study was to compare the behavioural and electrophysiological effects caused by the incompatibility of the stimulus position and the direction indicated by a central arrow for studying possible differences between both types of SRC interference. Thus, the participants performed an SRC task in which the stimulus position was the irrelevant dimension (SRC-p) and another SRC task in which the direction of a central arrow was the irrelevant dimension (SRC-d).

In order to make comparisons of motor processes between both tasks, the present study focused on the LRP-r. Since N2cc and N2pc are obtained in stimulus-locked averages, they are not expected to affect response-locked averages (Praamstra and Plat, 2001). In addition, in the present study the proportion of stimuli was matched between

conditions to exclude P3b modulations resulting from the use of different stimuli probabilities and/or sequence effects.

In the present study, we expected to find interference in the incompatible condition for both tasks. We also expected stimulus position to affect the performance at faster response times and that interference from the direction would have a greater effect at slower response times; we studied this by Distributional Analysis (DA) of the reaction times.

As regards the electrophysiological data, we expected to find larger differences between conditions on P3b latency and amplitude in SRC-p compared to SRC-d tasks if the position attracts more attentional resources than the direction indicated by the stimulus. Moreover, the responses were ordered on the basis of its speed and divided in fast and slow responses. According to studies using the DA, interference from the direction would be increased at slow responses while interference from the stimulus position would be maintained or decreased at slow responses. Thus, it was interesting to study P3b modulations in order to test if such modulations changed according to the magnitude of the interference.

Finally, we expected to obtain similar LRP-r modulations between conditions in both tasks, suggesting a common locus of interference for both incompatibilities at the response execution stage. The LRP-s onset was also studied in the SRC-d task to confirm whether the direction indicated by the stimulus also affected the response selection stage, as has been widely confirmed in Simon tasks.

## **2. Methods**

### *2.1. Participants*

Twenty-one participants (14 women, 7 men) between 19 and 28 years of age (mean age 21 years) were recruited from the local university population. The

participants volunteered to take part in the study and were paid for participating. The study received prior approval by the local ethical review board. The participants were right-handed (evaluated by the Edinburgh Handedness Inventory: Oldfield (1971)). All participants had normal or corrected to normal vision and none had any history of neurological or psychiatric disorders.

## 2.2. Stimuli

Two tasks were used in the present study: an SRC task based on the stimulus position (SRC-p) (see Figure 1, top) and an SRC task based on the direction indicated by a central arrow (SRC-d) (see Figure 1, bottom).

In the SRC-p task, a series of upward-pointing red or blue arrows was displayed on the screen against a black background, either on the left or on the right side of a white central cross, for both Compatible and Incompatible conditions. In the Neutral condition, the stimuli were upward-pointing red or blue arrows placed on the central cross. The arrow stimuli subtended  $2.87^\circ \times 1.72^\circ$  (height x width) of the visual field. In the Compatible and Incompatible conditions, the arrow stimuli were presented in parafoveal region (see Bargh and Chartrand, 2000), as the internal edge was  $2.8^\circ$  and the external edge  $4.5^\circ$  of visual angle measured from the central cross, whereas the central stimuli were presented in the foveal region. Differences in processing of the stimuli due to these eccentric positions were not expected (Cespón et al., 2012; Galashan et al., 2008; Mancebo-Azor et al., 2009). In the compatible and incompatible conditions, a geometric figure (two superimposed orthogonal bars, with the vertical bar longer than the horizontal bar, of similar size and eccentric position as the arrow) appeared in the opposite hemifield to prevent exogenous lateralization in the electroencephalogram (EEG) (see Figure 1, top).

For the SRC-d task (see Figure 1, bottom), a series of red or blue arrows pointing either left or right was displayed on the centre of the screen against a black background for the compatible and incompatible conditions. In the neutral condition, the stimuli were upward-pointing red or blue arrows placed on the central cross. The size of the arrow stimuli was identical than in the SRC-p task.

Figure 1 about here

### *2.3. Procedure*

The participants were asked to direct their gaze towards the central cross during both tasks, and were instructed to respond to the colour of the arrow as quickly as possible by pressing one of the two buttons assigned to each colour (the response pad was a Cedrus RB-834 Model). They were also instructed to ignore the position of the arrow in the SRC-p task and the direction indicated by the arrow in the SRC-d task. In both tasks, the response buttons were arranged horizontally and were pressed with the corresponding hand (right or left) so that when the arrow pointed upwards in the central position, there was no overlap between the position and the dimension of the response, and the trials were therefore considered neutral. During the experimental session, the participants carried out different tasks (they were unrelated tasks, which did not involve S-R compatibility effects), so that the SRC-p and the SRC-d tasks were not performed consecutively. This minimized the possibility of transfer effects between the tasks. The order of presentation of the tasks was also counterbalanced.

Two blocks were presented in both tasks. In the SRC-p, in each block, each of six possible types of stimuli, grouped into three conditions with the same number of trials (80 per condition), were presented at random: Compatible Position (CP, the required response was ipsilateral to the hemifield of appearance of the target), Incompatible Position (IP, the required response was contralateral to the hemifield of

appearance of the target), and Neutral Position (NP, as described above, there was no overlap between stimulus position and response). In the SRC-d, an identical procedure was followed, resulting in 3 conditions: Compatible Direction (CD, the required response was ipsilateral with respect to the direction indicated by the arrow), Incompatible Direction (ID, the required response was contralateral with respect to the direction indicated by the arrow), and Neutral Direction (ND, there was no overlap between the direction indicated by the arrow and the required response).

In both SRC tasks, the arrows were presented for 100 ms, with 2000 ms inter-trial intervals. The short duration of presentation of the stimuli, along with the simultaneous presentation of the non target stimulus in the contralateral hemifield, minimized the probability of ocular movements towards the position of the target in the SRC-p task, when stimuli were presented at eccentric locations (see Abrahamse and Van der Lubbe, 2008). In any case, HEOG was obtained in order to ensure no differences in ocular activity between the experimental conditions.

During the experimental session, participants were seated in a comfortable chair in a dimly lit, sound-attenuated, electrically shielded chamber. Each task included a practice block of 16 trials and two experimental blocks of 120 trials each, with a resting interval of 90 s between blocks. The tasks were counterbalanced so that half of the participants were instructed to respond by pressing the button on the left with the left hand, in response to the blue arrow, and the button on the right with the right hand, in response to the red arrow, whereas the other participants were given instructions to respond in the opposite way.

#### *2.4. Recordings*

Electroencephalographic activity was recorded at the following 49 active electrode sites, in accordance with the 10-10 International System: AFz, AF3, AF4,

AF7, AF8, Fz, F3, F4, F5, F6, F7, F8, FCz, FC1, FC2, FC3, FC4, FT7, FT8, FT9, FT10, Cz, C1, C2, C3, C4, C5, C6, T7, T8, CPz, CP3, CP4, TP7, TP8, TP9, TP10, Pz, P3, P4, P7, P8, P9, P10, PO7, PO8, Oz, O1 and O2. The EEG signal was passed through a 0.01–100 Hz analogue band-pass filter, and was sampled at 500 Hz. The reference electrode was placed on the tip of the nose and the ground electrode at Fpz. Simultaneously to EEG recordings, ocular movement (EOG) recordings were obtained with two electrodes located supra- and infraorbitally to the right eye (VEOG) and another two electrodes at the external canthus of each eye (HEOG). All impedances were maintained below 10 k $\Omega$ s. After signal storage, ocular artifacts were corrected off-line by use of the algorithm proposed by Gratton et al. (1983); the EEG was then segmented separately for each condition and manual response (in order to study Lateralized event-related potentials), and 1000-ms epochs (200 ms pre-stimulus baseline) were aligned to the onset of stimulus presentation whereas that response-locked epochs were established from 1000 ms before to 300 ms after the overt response. The signal was passed through a 0.01–30 Hz digital band-pass filter. Epochs with signals exceeding  $\pm 100$   $\mu$ V were automatically rejected, and all remaining epochs were inspected individually to identify those still displaying artifacts; the artifacted epochs were also excluded from subsequent averaging. Epochs were then corrected to the mean voltage of the 200-ms pre-stimulus recording period (baseline).

### 2.5. *Data analysis*

Trials with incorrect responses or RTs outside the 150-800 ms range were considered incorrect and were excluded. The RTs were ordered on the basis of their speed and divided, for each participant, on the percentile 50 into fast and slow RTs in order to considerate the speed of response in the statistical analyses. The RTs and percentage of errors (PE) were analysed. Three distributional analyses (DA) of the RTs

were carried out (Ratcliff, 1979) for each task (IP - CP; IP - NP; and NP - CP for SRC-p and ID - CD; ID - ND; and ND - CD for SRC-d) to determine if the magnitude of the interference, or of the possible facilitation, depended on the speed of response. For this purpose, the RTs were ordered on the basis of their speed, and for each participant, the RTs at the 4 Quintile Intersection Points that divided the distribution into 5 equal parts (quintiles) were selected. Also, interference was compared between SRC-p (IP - NP) and SRC-d (ID - ND) tasks according to the speed of the response.

For the ERP waveforms, P3b latency was measured at maximum positive peak with respect to baseline in the 300-500 ms interval at Fz, Cz, Pz and Oz sites in each task. The P3b amplitude was measured as the average amplitude between  $\pm 50$  ms around its peak latency. P3b analyses considered the speed of response as a main factor.

The stimulus-locked lateralized readiness potential (LRP-s) and response-locked lateralized readiness potential (LRP-r) were obtained for the SRC-d and the SRC-p tasks. The operation for obtaining LRP can be summarized by the following formula:  $[C4 - C3 \text{ (left-hand movement)} + C3 - C4 \text{ (right-hand movement)}] / 2$  (see Coles et al., 1988 for further details about the procedure for obtaining LRP).

In the present study, the LRP-s was analysed only for the SRC-d task because the N2cc/LRP overlap present in the lateralized conditions of the SRC-p task does not allow reliable measurement of the LRP-s onset (see Praamstra, 2007). Moreover, in both tasks the waveforms may be constituted by different ERP components, which preclude comparisons between the waveforms. Nevertheless, the response-locked LRP (LRP-r) was analysed in SRC-p since N2cc is observed at stimulus-locked averages but it is expected to be jittered in response-locked averages (Praamstra and Plat, 2001).

The onset latencies of the correct response preparation in LRP-s (in the SRC-d task) and in LRP-r (in the SRC-d and SRC-p tasks) were determined using the Jackknife

procedure (Miller et al., 1998). Therefore, for LRPs, 21 different grand averages for each of the experimental conditions, on each task, were computed omitting one of the participants on each grand average. Subsequently, the LRP onset was determined in the waveform of each grand average as the point in time where a 30% of the LRP peak amplitude was achieved, following previous studies with Simon-type tasks (Gevers et al., 2006; Stürmer et al., 2002). Importantly, a criterion of 30% for estimating the LRP onset was recommended by Miller et al. (1998) to maximize statistic power and avoid contamination by EEG noise when (as in the present study) a high number of participants is used (e.g. 20 participants, see Miller et al., 1998). Also, when the experimental manipulation affects the initial portion of the LRP waveform, as can be observed in the LRP-r waveforms of the present study (Figure 5, bottom), this criterion for establishing the LRP onset was also recommended (see Miller et al., 1998).

In addition, in the LRP-r waveforms of the SRC-d and SRC-p tasks, mean activity between -250 and -200 ms was compared in order to study possible differences between conditions, which could be related with a positive wave observed in the Incompatible conditions.

## *2.6. Statistical analysis*

Repeated measures ANOVAs with three within-subject factors, Task (two levels: SRC-p and SRC-d), Condition (three levels: Compatible, Incompatible, Neutral), and Speed of response (two levels: Fast, Slow) were applied to the RT and the PE data to determine any possible differences related to the experimental condition, task, and speed of response. Also, a repeated measures ANOVA with two within-subject factors, Task (two levels: SRC-p and SRC-d), and Speed of response (two levels: Fast, Slow) was carried out to compare the magnitude of the interference between both tasks according to the speed of response.

In distributional analyses, repeated measures ANOVAs with two within-subject factors, Condition (three levels: IP – CP, IP – NP and NP – CP for the SRC-p, and ID – CD, ID – ND and ND - CD for the SRC-d), and quintile intersection point (four levels: q1, q2, q3, q4) were carried out with the aim of determining whether the interference or the facilitation effects differed according to the speed of response. Also, one sample t-tests were conducted for studying if interference (i.e., IP-NP in the SRC-p task, and ID-ND in the SRC-d task) and facilitation (NP-CP in the SRC-p task, and ND-CD in the SRC-d task) were significant on each quintile intersection point.

Repeated measures ANOVAs with four within-subject factors, Task (two levels: SRC-p and SRC-d), Condition (three levels: Compatible, Incompatible, Neutral), Electrode (four levels: Fz, Cz, Pz, and Oz), and speed of response (two levels: Fast, Slow) were carried out for P3b latency and amplitude.

Repeated measures ANOVAs were carried out with two within-subject factors, Condition (three levels: Compatible, Incompatible and Neutral) and Task (two levels: SRC-p and SRC-p) to examine differences in the LRP-r onset. In the SRC-d task the covert response activation (LRP-s onset) was studied using repeated measures ANOVA with one within-subject factor, Condition (three levels: CD, ID and ND). As recommended when using the Jackknife procedure (see Ulrich and Miller, 2001), the F values were corrected according to the next formula:  $F_c = F / (n-1)^2$ , with  $F_c$  denoting the corrected F-value and n the number of participants.

Repeated measures ANOVA with two within-subject factors, Condition (three levels: Compatible, Incompatible and Neutral) and Task (two levels: SRC-p and SRC-d) was carried out to examine differences in mean activity of the LRP-r waveform, between -250 and -200 ms. In addition, one sample t-tests, on that mentioned temporal

window, were performed in both Incompatible conditions (IP and ID) to study whether that positivity differed from the baseline.

The Greenhouse-Geisser  $\epsilon$  correction for the degrees of freedom was performed where necessary, and the corresponding  $\alpha$  levels are given. When the ANOVAs revealed significant effects of the factors and their interactions, post-hoc analysis of the mean values was carried out by paired multiple comparisons (with Bonferroni corrections).

### **3. Results**

#### *3.1. Behavioural Measures*

The repeated measures ANOVA (Task x Condition x Speed of response) revealed that the Condition had significant effects on the RT ( $F(2,40) = 32.1, p < 0.001$ ) as the RT was longer in Incompatible than in Compatible trials ( $p < 0.001$ ) and in Incompatible than in Neutral trials ( $p < 0.001$ ). Task exerted a significant effect ( $F(1, 20) = 10.2, p = 0.005$ ), as the RT was longer in SRC-p than in SRC-d ( $p = 0.005$ ). The Task x Condition interaction also showed significant effects ( $F(2, 40) = 13.2, p < 0.001$ ) as in the SRC-p the RT was longer in IP than in CP ( $p < 0.001$ ) and in IP than in NP ( $p < 0.001$ ); in SRC-d the RT was longer in ID than in CD ( $p < 0.001$ ) but only marginal differences were found in ID in comparison to ND ( $p = 0.060$ ) (see Table 1). Also, responses were faster in SRC-d than in SRC-p in the Compatible condition ( $p = 0.003$ ), and the Incompatible condition ( $p = 0.001$ ). The Condition x Speed of response (see Table 2) also showed an interaction effect ( $F(1.50, 30.01) = 8.11, p = 0.003$ ), although Incompatible trials RTs were longer than Compatible ( $p < 0.001$ ) and Neutral ( $p < 0.001$ ) trials both to fast and slow responses. In addition, the Task x Condition x Speed of response also showed an interaction effect ( $F(2, 40) = 6.55, p = 0.003$ ); no differences between conditions were found in SRC-d fast responses. In slow responses,

RT was longer in ID than in CD ( $p < 0.001$ ) and ND ( $p = 0.005$ ) conditions. In SRC-p task, RT was longer in IP than in CP (fast responses:  $p < 0.001$ ; slow responses:  $p = 0.004$ ) and NP (fast and slow responses:  $p < 0.001$ ) conditions.

The repeated measures ANOVA (Task x Condition) for the percentage of errors (PE) revealed a significant effect of the Condition ( $F(2, 40) = 27.7, p < 0.001$ ) as the PE was greater in the Incompatible than in the Compatible ( $p < 0.001$ ) and than in the Neutral condition ( $p < 0.001$ ). Task exerted a significant effect ( $F(1, 20) = 5.7, p = 0.027$ ) as the PE was greater in the SRC-p than in the SRC-d task ( $p = 0.027$ ). The interaction Condition x Task revealed significant effects ( $F(2, 40) = 5.8, p = 0.006$ ) as the PE was greater in IP than in CP ( $p = 0.001$ ) and than in NP ( $p < 0.001$ ) in the SRC-p task whereas PE was greater only in ID than in CD ( $p = 0.031$ ) in the SRC-d task.

Tables 1 and 2 about here

As regards the magnitude of the effect of the irrelevant dimension in the SRC-p task (see Figure 2), the repeated measures ANOVA (Condition x Quintile Intersection Point) revealed an effect of the Condition ( $F(1.24, 24.9) = 39.96, p < 0.001$ ), as the effect was greater in IP – NP than in NP – CP ( $p < 0.001$ ) as well as in IP – CP than in NP – CP ( $p < 0.001$ ). The ANOVA did not reveal any significant effect of the factor Quintile Intersection Point.

As regards the magnitude of the effect of the irrelevant dimension in the SRC-d task (see Figure 2), the repeated measures ANOVA (Condition x Quintile Intersection Point) revealed an effect of the Quintile Intersection Point ( $F(1.54, 30.86) = 4.25, p = 0.032$ ), as the magnitude of the effect was greater in the Quintile 3 than in the Quintile 1 ( $p = 0.011$ ). The ANOVA did not reveal a significant effect of Condition, showing that facilitation and interference were present in a similar magnitude.

One sample t-tests to study on each task and quintile intersection point the interference (IP- NP, and ID-ND) and facilitation (NP-CP, and ND-CD) effects, revealed for the SRC-p task a significant interference in all the quintile intersection points ( $t_1(20) = 7.6, p < 0.001$ ;  $t_2(20) = 9.4, p < 0.001$ ;  $t_3(20) = 7.1, p < 0.001$ ;  $t_4(20) = 6.2, p < 0.001$ ) but facilitation effect was not significant in any of the quintiles. For the SRC-d task, a significant interference was found in quintile 3 ( $t_3(20) = 2.4, p = 0.027$ ) and 4 ( $t_4(20) = 2.5, p = 0.021$ ) whereas that a significant facilitation effect was found in quintile 2 ( $t_2(20) = 2.2, p = 0.040$ ), 3 ( $t_3(20) = 3.4, p = 0.003$ ), and a marginal signification was obtained in quintile 4 ( $t_4(20) = 2.1, p = 0.054$ ).

For the magnitude of the interference according to the speed of response on each task, the repeated measures ANOVA (Task x Speed of response) revealed an effect of the Task ( $F(1, 20) = 25.20, p < 0.001$ ), as the interference was greater in the SRC-p than in the SRC-d task ( $p < 0.001$ ). The Speed of response showed a significant effect ( $F(1, 20) = 6.16, p = 0.022$ ), as the interference was greater at slow than at fast RTs ( $p = 0.022$ ). Also, Task x Speed of response revealed a significant interaction effect ( $F(1, 20) = 10.98, p = 0.003$ ). Interference was greater in SRC-p than in SRC-d task ( $p < 0.001$ ) at fast responses; however, differences between both tasks were not significant at slow responses. Also, the interference was greater at slow than at fast responses ( $p < 0.001$ ) in the SRC-d task whereas such differences in the magnitude of the interference were not present in the SRC-p task.

Figure 2 about here

### 3.2. ERP Measures

The repeated measures ANOVA (Task x Condition x Electrode x Speed of response) for P3b peak latency (see Tables 1 and 2 and Figures 3 and 4) revealed a significant effect of the Task ( $F(1, 20) = 8.09, p = 0.010$ ), as latency was longer in the SRC-p than in the

SRC-d task ( $p = 0.010$ ). Also, an effect of the Condition was revealed ( $F(2, 40) = 20.33, p < 0.001$ ), as P3b latency was longer in Incompatible than in Compatible ( $p = 0.001$ ) and Neutral ( $p < 0.001$ ) conditions. In addition, Speed of response showed a significant effect ( $F(1, 20) = 28.41, p < 0.001$ ), as P3b latency was longer in trials with slow responses than in trials with fast responses ( $p < 0.001$ ). The Task x Condition interaction also showed a significant effect ( $F(2, 40) = 5.81, p < 0.001$ ) as P3b peak latency was longer in SRC-p than in SRC-d task in the Incompatible condition ( $p < 0.001$ ). In addition, the P3b latency was longer in the IP than in the CP ( $p < 0.001$ ) and NP conditions ( $p < 0.001$ ) in the SRC-p task, whereas it did not show significant differences between conditions in the SRC-d task. The ANOVA also showed an effect of the interaction Task x Condition x Speed of response ( $F(1.56, 31.23) = 7.43, p = 0.004$ ); P3b latency was longer in the SRC-p than in SRC-d task for the Incompatible condition both at fast and slow responses ( $p < 0.001$ ). In addition, P3b latency was longer in IP than in CP (fast responses:  $p = 0.011$ ; slow responses:  $p < 0.001$ ) and than in NP (fast responses:  $p = 0.003$ ; slow responses:  $p < 0.001$ ) conditions in the SRC-p task, whereas no differences between conditions were found in the SRC-d task.

The repeated measures ANOVA (Task x Condition x Electrode x Speed of response) for P3b amplitude (see Tables 1 and 2 and Figures 3 and 4) revealed a significant effect of the Condition ( $F(2, 40) = 5.95, p = 0.005$ ), as the amplitude was smaller in the Incompatible than in the Neutral ( $p = 0.017$ ) condition. The Task x Condition interaction also exerted a significant effect ( $F(2, 40) = 4.12, p = 0.023$ ). In the SRC-p task the P3b amplitude was smaller in the IP than in the CP ( $p = 0.036$ ) and NP ( $p = 0.012$ ) conditions, whereas differences between conditions in P3b amplitude were not present in the SRC-d task. The ANOVA also showed an effect of the factor Electrode ( $F(2.30, 46.00) = 31.70, p < 0.001$ ), as the amplitude was larger at Pz than at

Oz ( $p = 0.004$ ), Cz ( $p < 0.001$ ) and Fz ( $p < 0.001$ ). The P3b amplitude was also larger at Oz than at Fz ( $p < 0.001$ ), and it was larger at Cz than at Fz ( $p < 0.001$ ). An effect of the Speed of the Response was also found ( $F(1, 20) = 14.19$ ,  $p = 0.001$ ), as P3b amplitude was larger in fast than in slow responses ( $p = 0.001$ ).

Figures 3 and 4 about here

As regards LRP-r (see Table 1 and Figure 5), the repeated measures ANOVA (Task x Condition) for the LRP-r onset revealed a significant effect of the Condition ( $F_c(2, 40) = 12.1$ ,  $p < 0.001$ ) as the LRP-r onset was delayed in the Incompatible condition respect to the Compatible ( $p < 0.001$ ) and Neutral ( $p < 0.001$ ) conditions.

The repeated measures ANOVA (Task x Condition) comparing the mean activity between -250 and -200 ms in relation with the overt response, revealed an effect of the Condition ( $F(2, 40) = 30.6$ ,  $p < 0.001$ ), as mean activity was more positive in the Incompatible than in the Compatible ( $p < 0.001$ ) and Neutral ( $p < 0.001$ ) conditions. The one-sample t-tests for mean activity between -250 and -200 ms revealed a significant effect in both Incompatible conditions, that is, in IP ( $t(20) = 6.6$ ,  $p < 0.001$ ) and in ID ( $t(20) = 3.9$ ,  $p = 0.001$ ).

The repeated measures ANOVA (Condition) for the LRP-s onset in the SRC-d task did not reveal any significant effect.

Figure 5 about here

#### **4. Discussion**

In the present study, the participants carried out two stimulus-response compatibility tasks (SRC) with response to the colour of the stimuli. In one task the participants had to ignore the stimulus position (SRC based on the stimulus position, or SRC-p), and in another task, they had to ignore the direction indicated by a central arrow (SRC based on the direction of the stimulus, or SRC-d). Although both tasks

elicited interference (slower RT and higher PE in the incompatible than in the compatible conditions) and shared a common locus of interference (differences in LRP-r onset between incompatible trials compared to neutral and compatible trials as well as a transitory positive dip related to preparation of the incorrect response) in the response execution stage, the stimulus position exerted stronger interference than the direction indicated by the stimulus. This was illustrated by higher PE, interference to all responses (compared to interference only to slowed responses in SRC-d), as well as longer P3b latencies and smaller P3b amplitudes in the incompatible than in the compatible and neutral conditions only in SRC-p task. P3b results were maintained at slow responses, where the magnitude of the interference was similar in SRC-p and SRC-d tasks. Thus, P3b differences were not due to effect size. Consequently, stimulus position presented an additional locus of interference in comparison with the direction indicated by the stimulus.

Behavioural results revealed that both types of incompatibilities (SRC-p and SRC-d) elicited interference (longer RT and higher PE in the Incompatible than in the Neutral and Compatible conditions). However, greater interference was caused by the stimulus position than by the direction of the arrow, which is consistent with the findings of previous studies (Galashan et al., 2008; Wittfoth et al., 2009); a facilitation effect was only manifested in the SRC-d task.

These results were not unexpected; the presence of facilitation in compatible trials (relative to neutral trials) due to the direction indicated by the stimuli had already been reported (Galashan et al., 2008; Masaki et al., 2000); moreover, the absence of differences between Compatible and Neutral conditions in the SRC-p task were consistent with previous studies using Simon tasks with stimuli placed in horizontal arrangement (Cespón et al., 2012; Galashan et al., 2008; Praamstra and Oostenveld,

2003; but see also inconsistent results in Simon, 1990). Thus, it cannot be excluded that absence of facilitation in the SRC-p task be due to the greater complexity of the CP (where two lateralized stimuli appeared in the display) relative to the NP condition (where only a central stimulus was presented).

The DA showed a different pattern of results between SRC-p and SRC-d tasks. The interference from the stimulus position was manifested at faster RT and it was maintained at slower RT. Although the Simon effect usually decreases at slower response times (De Jong et al., 1994; Proctor et al., 2011), some studies that used the colour of the stimulus as relevant dimension showed that the interference was maintained at slower RT (Roswarski and Proctor, 1996; Wühr, 2006). According to the temporal overlap model (De Jong et al., 1994; see also Hommel, 2000), a constant interference throughout the distribution of RTs suggests that the time when participants respond to the relevant dimension (i.e. the colour) overlaps with the activation of the response to the stimulus position and this activation does not significantly decay even in the slowest responses to the colour. However, interference in SRC-d task was only manifested in slow responses, which was clearly found in the analyses of bipartition of the RT. Also, it is consistent with the results of previous studies (Pellicano et al., 2009; Proctor et al., 2009). The facilitation effect in the SRC-d task also followed the same pattern as the interference (i.e. it was not present at faster RTs although it was observed in slower responses).

The direction of the arrow did not affect the performance at faster RT, suggesting that responses to the colour occurred earlier than processing of the direction of the arrow in consistence with the temporal overlap model (De Jong et al., 1994; see also Hommel, 2000). That is, if the response to the relevant dimension is emitted before the processing of a specific irrelevant dimension then that irrelevant dimension does not

affect the performance in that specific trial. Moreover, this interpretation is consistent with the view of stimulus position orienting attention faster than the direction of the arrow (Abrahamse and Van der Lubbe, 2008; Klein and Ivanoff, 2011) since stimulus position, but not direction of the arrow, interfered in faster RTs. Some studies have attributed the slow processing of the arrow to the required semantic processing (Iani et al., 2011; Symes et al., 2005; Vainio et al., 2007).

Consequently, performance data suggest that both SRC tasks are related to an interference effect in incompatible trials, although a greater effect was found for the stimulus position than for the direction indicated by the stimulus. In addition, the interference from the position affected the performance from faster RTs while the direction of the arrow only interfered to slow RTs. The ERP results supported the existence of differences between both interference effects, providing also evidence of the cognitive processes that are the loci of interference in both tasks.

In the SRC-p task, longer P3b latency and smaller P3b amplitude were found in Incompatible than in Compatible and Neutral trials, which is consistent with previous findings showing how the Simon effect modulates P3b latency (Leuthold and Schröter, 2006; Leuthold and Sommer, 1999; Melara et al., 2008; Ragot, 1990; Valle-Inclán et al., 1996a, 1996b; Van der Lubbe and Verleger, 2002) and amplitude (Leuthold and Schröter, 2006; Ragot, 1990; Valle-Inclán, 1996a, 1996b). The present results are also consistent with the conclusion of Verleger (1997) regarding the high sensitivity of P3b latency for the Simon effect. Contrarily, P3b latency and amplitude were not affected by the experimental condition in the SRC-d task.

The results of the present study showed that P3b, which appears to reflect a link between perceptual processes and the initiation of the response (Verleger et al., 2005), was affected by incompatibility due to the stimulus position (Simon effect) but not by

incompatibility due to the direction indicated by a central arrow. Therefore, these results provided the first evidence for electrophysiological differences between both S-R incompatibilities.

The lack of modulation of the P3b latency in the SRC-d task is also consistent with the findings from studies that used semantic stimulus-response incompatibility tasks (Magliero et al., 1984; Ragot and Fiori, 1994). It could be argued that differences in P3b modulation between both tasks were due to the size effect, that is, the magnitude of the interference was greater in the SRC-p than in the SRC-d task. However, that alternative may be discarded since the results for the absence of P3b modulation in the SRC-d task remain at slow responses, where the magnitude of the interference was similar in both tasks.

The present results contrast with those of previous studies that reported modulations in P3b latency (Masaki et al., 2000) and amplitude (Galashan et al., 2008) during SRC-d tasks. The reason for these differences is probably related to differences in the experimental design. Masaki et al. (2000) reported a larger number of neutral trials than compatible and incompatible trials. Galashan et al. (2008) reported a larger number of compatible than incompatible trials, in which the effect of direction was induced by use of moving dots. In both cases, the experimental task resulted in an oddball paradigm, which has been widely related to modulate P3b amplitude. Also, Masaki et al (2000) reported an effect of interference even greater than the found at slow RTs in the SRC-d task of the present study. It might be due to the lower probability of i-I sequence, which is associated with reduced or eliminated interference in the second incompatible trial (Davelaar and Stevens, 2009; Spapé et al., 2011) in addition to the greater probability of the c-I and n-I sequences, which were associated with increased interference (Davelaar and Stevens, 2009), in the study of Masaki et al.

(2000). Therefore, in Masaki et al. (2000) the P3b modulation might be also related to the increased interference caused by sequence effects.

Regarding motor activity, LRP-r revealed interference in the incompatible condition for both tasks. This was preceded by a transitory preparation of the incorrect response in both tasks, which suggested interference in the response execution stage (Smulders and Miller, 2012) that similarly took place in SRC-p and SRC-d tasks. Also, these results are consistent with LRP-r findings in Masaki et al. (2000) using a SRC-d type task and with behavioural results from the studies of Ansorge and Wühr (2004) and Vallesi et al. (2005), which suggested that an interference locus in the response execution stage occurred in the SRC-p tasks (i.e., in the Simon tasks). Therefore, the response execution stage appears to represent a shared locus of interference for both irrelevant dimensions.

The lack of differences between both tasks in LRP-r onset suggests that N2pc and N2cc did not affect the response-locked waveforms. As this component compromises the interpretation of LRP-s in SRC-p tasks (Praagstra, 2007), it was only analysed for the SRC-d task. In this case, no differences in the onset of LRP-s between conditions were found, in contrast to results reported by Masaki et al. (2000). The discrepancies may again be explained by the greater difficulty of the task used by Masaki et al. (2000) due to the use of an oddball design. In addition to the absence of differences in P3b latency, the LRP-s results of the present study support the possibility that interference from direction, in contrast with the interference from the stimulus position, did not take place in either perceptive processes or at the response selection stage.

## **5. Conclusions**

The present study found evidence for similarities and differences between two SRC tasks: an SRC task based on the stimulus position (SRC-p) and an SRC task based on the direction of a central arrow (SRC-d). In the incompatible condition, both irrelevant dimensions caused interference, but in the compatible condition only the direction indicated by the arrow caused a facilitation effect. Furthermore, the position interfered in fast and slow responses, while the direction affected the performance only in slow responses, suggesting that position attracts attentional resources more quickly than direction. ERP results were consistent with the differences between both tasks in the pattern of behavioural data. Specifically, interference from the stimulus position was related to longer P3b latency and smaller P3b amplitude. However, P3b was not modulated in the SRC-d task. Therefore, results from P3b provided electrophysiological evidence for differences between both S-R interferences. As regards motor processes, similar effects of interference at the response execution stage (LRP-r) were found for both stimulus-response incompatibilities. Therefore, the position and the direction indicated by the stimulus may share a common locus of interference (response execution), but the position of the stimulus also affects the stimulus categorization process and, thus, the link between stimulus evaluation and the response selection.

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Figure 1: The tasks. Top: SRC task with response to the colour (red or blue), while ignoring stimulus position (SRC-p task). From left to right, the following conditions are represented according to the position-colour compatibility: Compatible Position (CP); Neutral Position (NP); Incompatible Position (IP). Bottom: Stimulus-response compatibility (SRC) task with response to the colour (red or blue), while ignoring the direction of the arrow (SRC-d task). From left to right, the following conditions are represented according to the direction-colour compatibility: Compatible Direction (CD); Neutral Direction (ND); Incompatible Direction (ID). In both tasks, participants were instructed to press the left button with the left hand when the arrow was blue and the right button with the right hand when the arrow was red. The response buttons were counterbalanced between the participants.

Figure 2: Compatibility (interference and facilitation) effects (in ms) in the Distributional Analysis of reaction times (DA) are represented for both tasks. The upper graph represents values on each quintile intersection point for the SRC-p task: IP-CP (circles); IP-NP (squares); NP-CP (triangles). The lower graph is the same graph, but depicted for the SRC-d task: ID-CD (circles); ID-ND (squares); ND-CD (triangles).

Figure 3: s-ERP for SRC-p task (left column) and for SRC-d task (right column). Solid line: compatible conditions; dashed line: incompatible conditions; dotted line: neutral conditions. Top: P3b for the SRC-p and for the SRC-d at the Pz electrode. In the SRC-p task only, longer P3b latency and smaller P3b amplitude were observed in the Incompatible than in the Neutral and Compatible conditions. Bottom: HEOG shows absence of differences in ocular movements between conditions in each task.

Figure 4: ERP waveforms for the SRC-p task (left column) and for the SRC-d task (right column) at fast (top) and slow (bottom) responses in the Pz electrode. Solid line: compatible conditions; dashed line: incompatible conditions; dotted line: neutral conditions. P3b modulations are observed for the SRC-p task, regardless the speed of the responses. In the SRC-d task P3b modulations were not evidenced even if the magnitude of the interference at slow responses was comparable to the found in the SRC-p task.

Figure 5: LRP-s and LRP-r obtained at C3/C4 electrodes pair. Solid line: compatible conditions; dashed line: incompatible conditions; dotted line: neutral conditions. Top: LRP-s waveforms are represented for SRC-p (left) and SRC-d (right) tasks. Analysis for the SRC-d task showed absence of incorrect preparation as well as absence of differences in the onset latency of the preparation of the correct response for the ID condition. Bottom: LRP-r waveforms for SRC-p (left) and SRC-d (right). Both tasks showed signs of interference in the response execution for the incompatible condition (delayed LRP-r onset in the incompatible conditions).

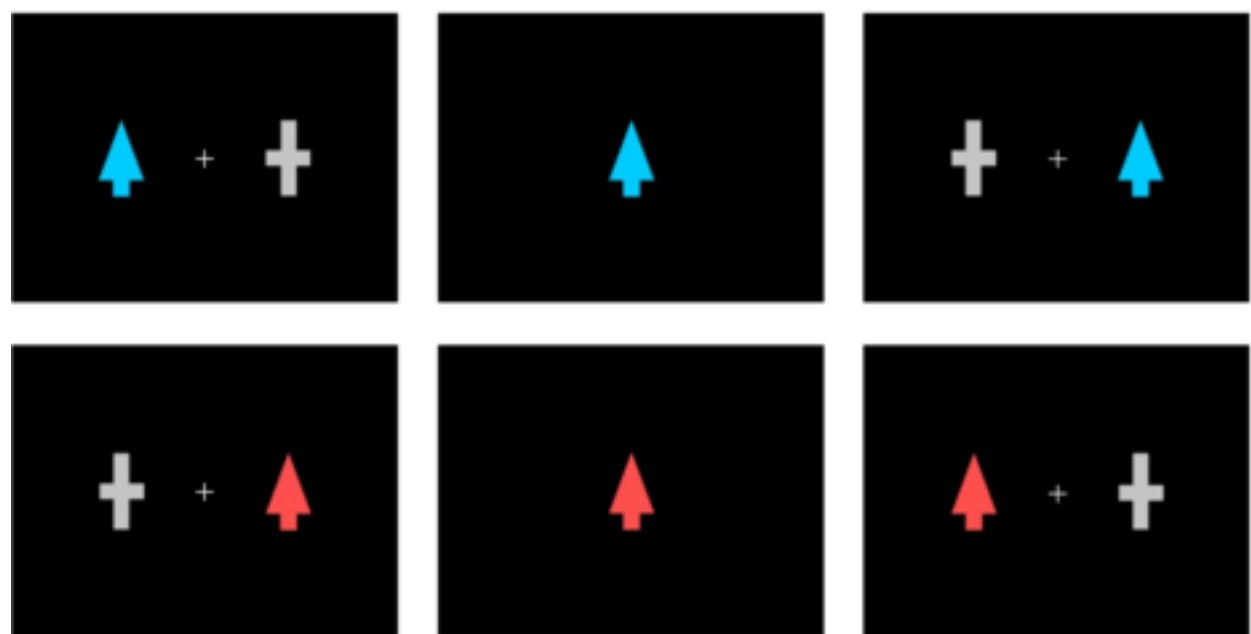
	RT	PE	P3b lat	P3b amp	LRP-r onset	LRP-s onset
<b>SRC-P</b>						
CP	431 (48)	4.6 (3.4)	362 (40)	13.4 (5.9)	-181 (2.7)	
NP	422 (44)	3.1 (2.9)	350 (52)	14.4 (7.6)	-181 (2.9)	
IP	461 (47)	10.5 (6.7)	413 (48)	12.1 (7.5)	-134 (2.6)	
<b>SRC-D</b>						
CD	380 (35)	2.6 (2.4)	353 (41)	12.1 (5.3)	-182 (3.0)	192 (2.7)
ND	392 (39)	3.8 (4.5)	351 (39)	12.6 (5.9)	-181 (2.8)	189 (2.4)
ID	404 (37)	5.3 (4.2)	349 (50)	12.0 (5.9)	-133 (2.4)	191 (2.8)

Table 1: Values in each Condition on each task (Compatible Position –CP- Incompatible Position –IP- Neutral Position –NP- for the stimulus-response compatibility (SRC) task based on the stimulus position (SRC-p) and Compatible Direction –CD- Incompatible Direction –ID- and Neutral Direction –ND- for the SRC task based on the direction of the arrow (SRC-d)) for reaction time (RT, in milliseconds), percentage of errors (PE), P300 (P3b) peak latency (in milliseconds); P3b averaged amplitude (in microvolts); onset of response-locked lateralized readiness potential (LRP-r). Also, for the SRC-d: onset of the LRP-s.

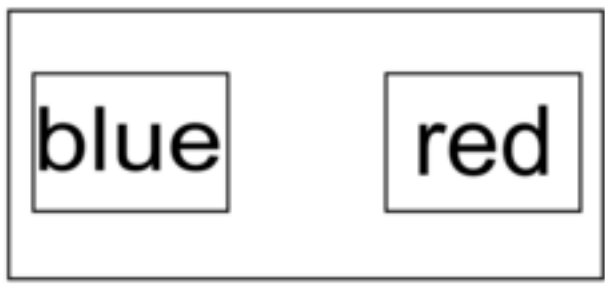
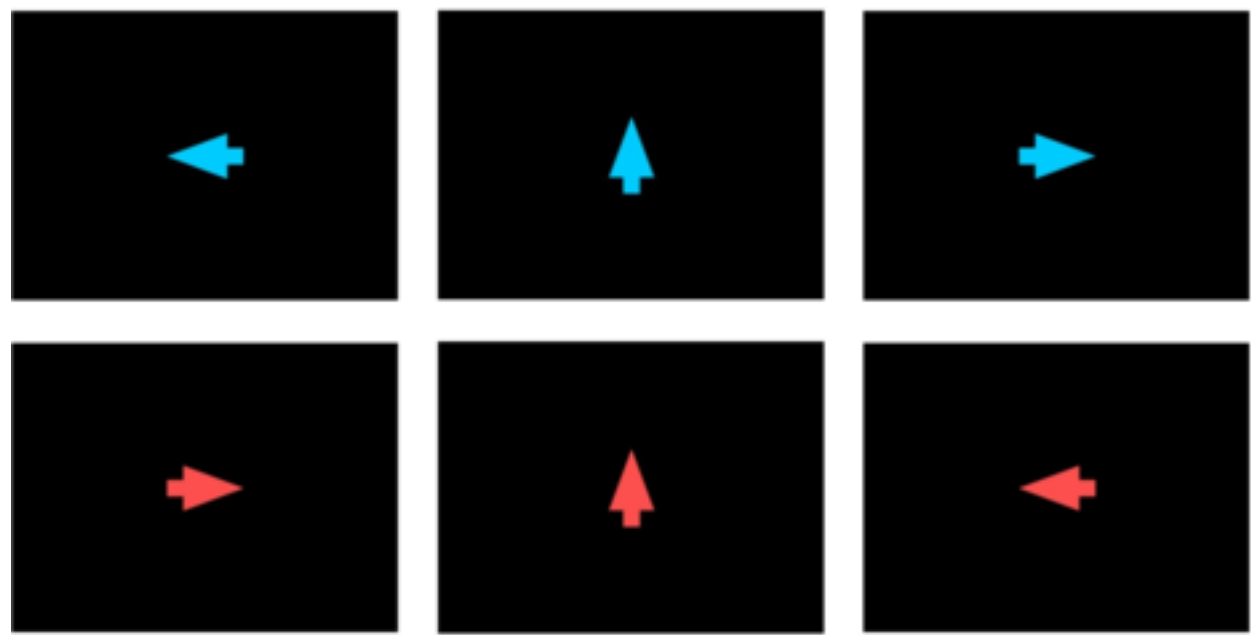
	Fast RT	Slow RT	Fast P3b lat	Slow P3b lat	Fast P3b amp	Slow P3b amp
<b>SRC-P</b>						
CP	340 (40)	524 (60)	350 (35)	380 (58)	15.4 (6.5)	12.2 (6.4)
NP	327 (34)	517 (61)	352 (52)	375 (55)	15.4 (7.4)	14.0 (8.6)
IP	366 (42)	556 (57)	382 (58)	449 (50)	12.6 (7.9)	11.3 (7.0)
<b>SRC-D</b>						
CD	302 (28)	459 (68)	341 (41)	366 (48)	13.0 (6.8)	11.8 (5.5)
ND	307 (34)	477 (66)	349 (48)	363 (41)	13.8 (5.6)	11.7 (5.7)
ID	303 (29)	503 (48)	345 (53)	374 (48)	13.4 (6.4)	11.2 (6.6)

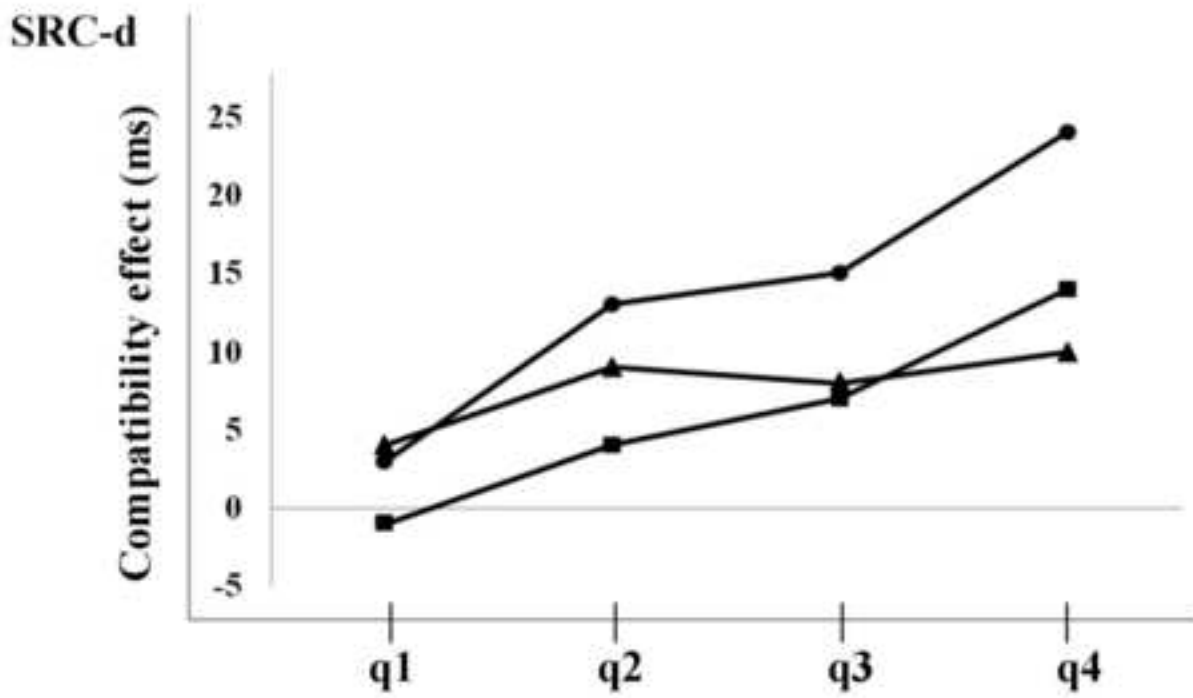
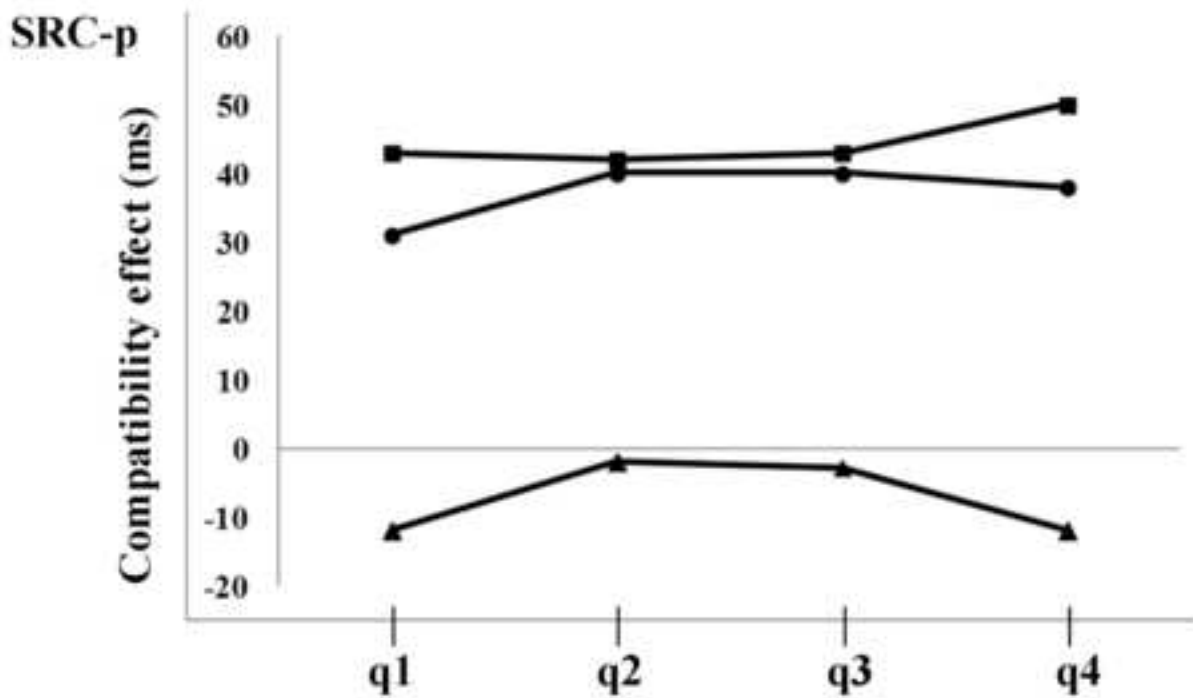
Table 2: Values in each Condition on each task (Compatible Position –CP- Incompatible Position –IP- Neutral Position –NP- for the stimulus-response compatibility (SRC) task based on the stimulus position (SRC-p) and Compatible Direction –CD- Incompatible Direction –ID- and Neutral Direction –ND- for the SRC task based on the direction of the arrow (SRC-d)) divided on the Percentile 50 according to the speed of the response. The Table shows, for fast and slow responses separately, RT (in milliseconds), P3b peak latency (in ms), and P3b averaged amplitude (in  $\mu\text{V}$ ) ( $\pm 50$  ms around peak latency).

### SRC-p



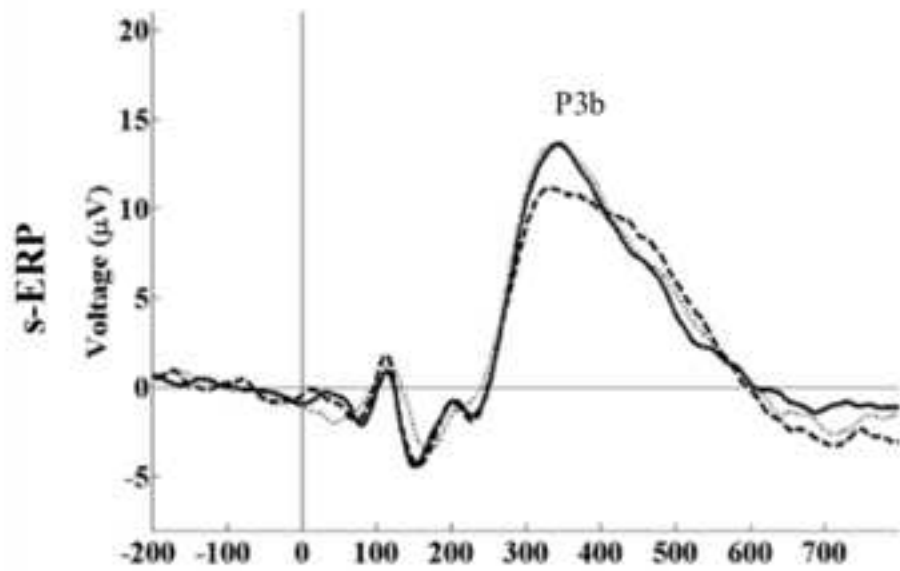
### SRC-d



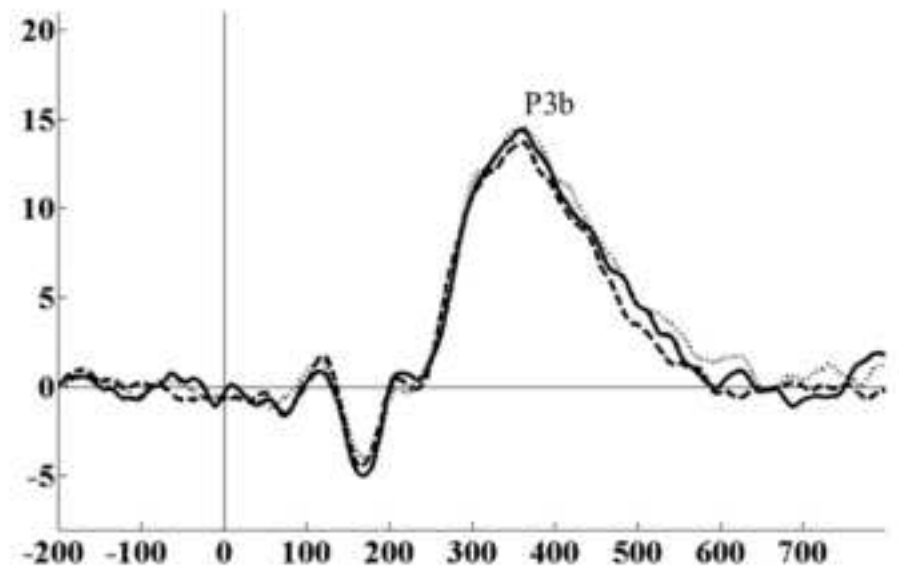


Figure(s)  
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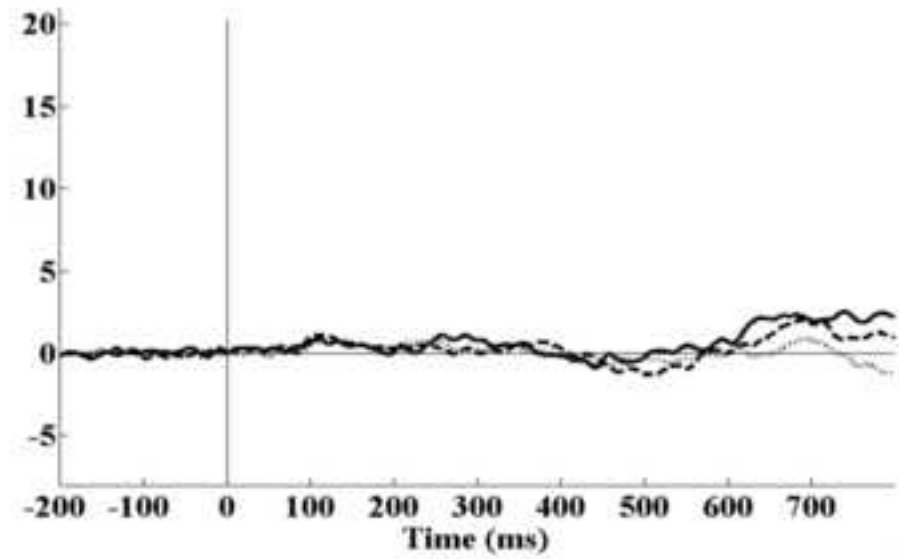
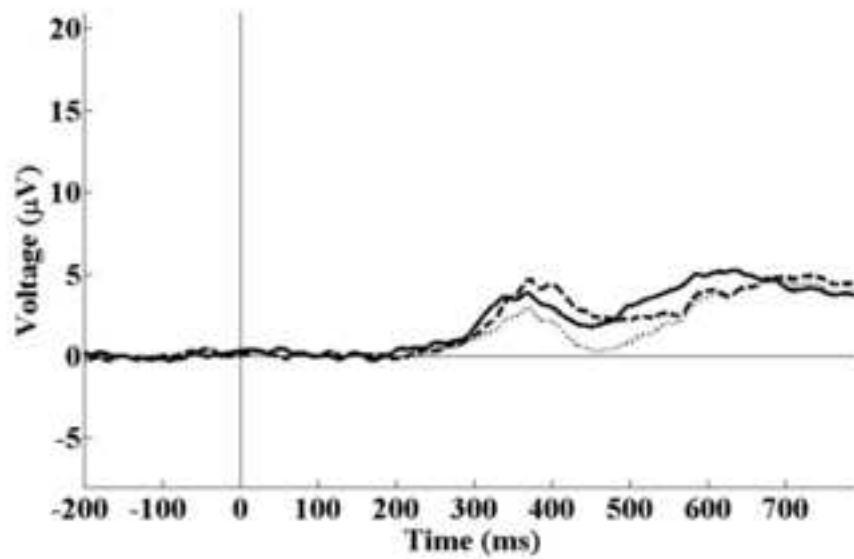
SRC-p

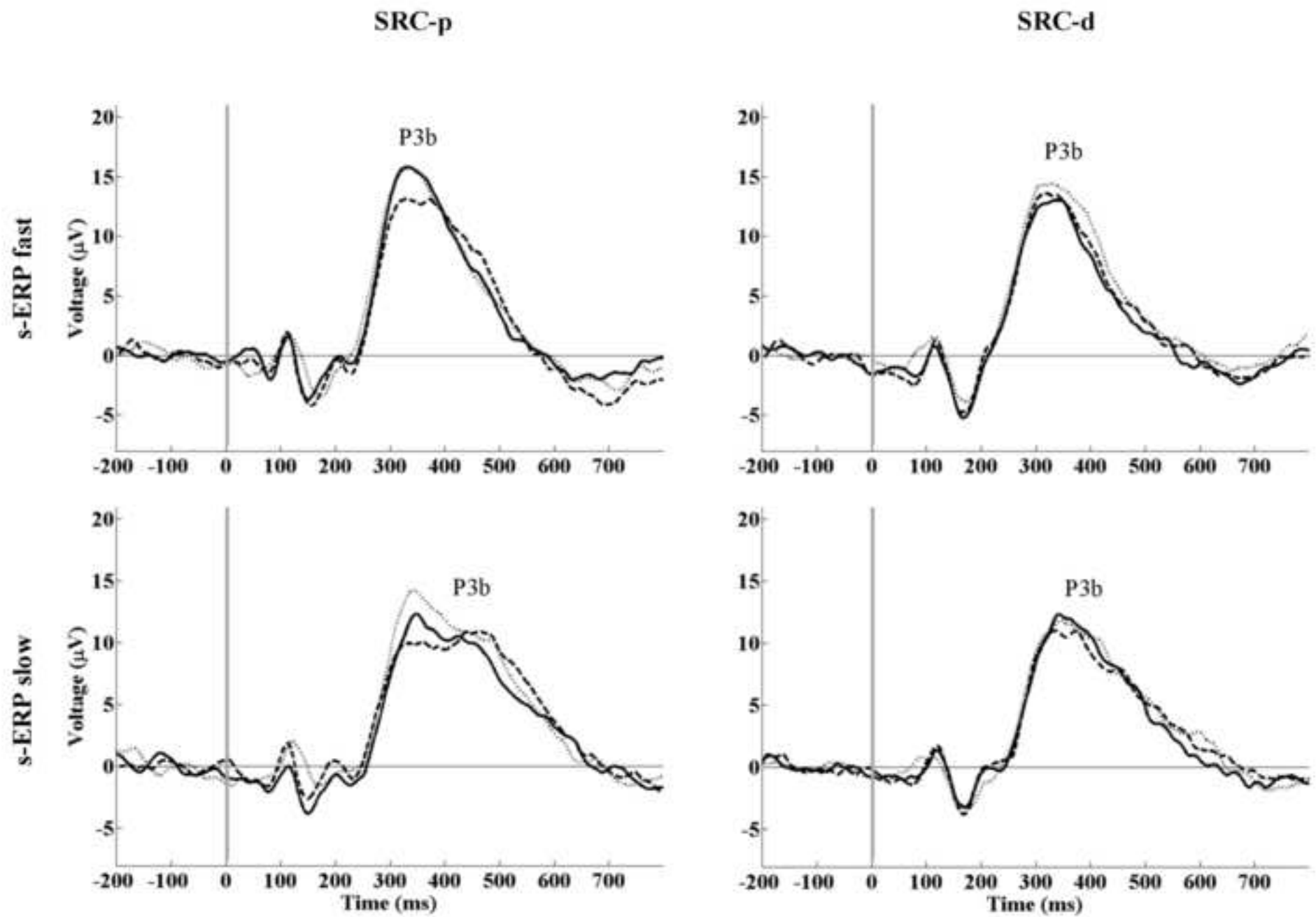


SRC-d



HEOG





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