Title: N2pc is modulated by stimulus-stimulus, but not by stimulus-response incompatibilities.

Authors: [a]Cespón, J., [a]Galdo-Álvarez, S., and [a]Díaz F.

[a] Laboratorio de Neurociencia Cognitiva, Departamento de Psicoloxía Clínica e Psicobioloxía, Facultade de Psicoloxía, Universidade de Santiago de Compostela, 15782 Santiago de Compostela, Galiza, Spain.

Corresponding author: Jesús Cespón

Tel.: +34 981 563100 Ext.: 13732

Fax number: +34 981 528071

E-mail addresses:

jesus.cespon@usc.es (Jesús Cespón)

santiago.galdo@usc.es (Santiago Galdo-Álvarez)

fernando.diaz@usc.es (Fernando Díaz)

ABSTRACT

Studies of the N2pc in Simon-type tasks have revealed inconsistent results. That is, N2pc was only modulated when a stimulus-stimulus (S-S) overlap covaries with the stimulus-response (S-R) overlap. The present study aimed to establish whether N2pc is modulated by the S-R or by the S-S overlap. Therefore, we designed a Simon task requiring response to a colour stimulus (an arrow) with two irrelevant dimensions (position and direction). The following conditions were thus generated: Compatible Direction-Compatible Position (CDCP); Incompatible Direction-Compatible Position (IDCP); Compatible Direction-Incompatible Position (CDIP); and Incompatible Direction-Incompatible Position (IDIP). In IDCP and CDIP, both irrelevant dimensions conveyed contradictory spatial information (S-S incompatibility), while compatibility between both irrelevant dimensions occurred in CDCP and IDIP (the direction indicated was compatible with stimulus position). The N2pc amplitude was smaller in IDCP and CDIP than in CDCP and IDIP, what suggests that N2pc was modulated by S-S incompatibility and not by S-R incompatibilities.

1. Introduction

The Simon task is a type 3 stimulus-response compatibility task (SRC) (for a classification of SRC types, see Zhang et al., 1999) in which the participants respond to a feature (e.g. colour, shape, etc.) of spatially lateralized stimuli by pressing one of two buttons. The response buttons are also lateralized in the same spatial arrangement as the stimuli, with the position of the stimulus irrelevant to the task. In those cases in which the required response is on the opposite side to the stimulus (incompatible condition), an interference effect known as the Simon effect is produced (for reviews, see Leuthold, 2011; Lu and Proctor, 1995; Simon, 1990). The interference is manifested by a longer reaction time (RT) in the incompatible condition than in the compatible condition.

The temporal locus of the interference in SRC tasks, particularly in the Simon task, is of great interest. The high temporal resolution of the event-related potentials (ERP) allows this locus to be established. The lateralized readiness potential (LRP) is an ERP component that is widely used to investigate the temporal locus of the Simon effect (see Gratton et al., 1988). Analysis of the LRP has revealed that the temporal locus of the Simon effect occurs at the response selection stage (De Jong et al., 1994; Stürmer et al., 2002; Valle-Inclán, 1996); interference has also been reported at the response execution stage (Ansorge and Wühr, 2004; Vallesi et al., 2005). Similar loci of interference have been observed in another SRC task, in which the direction indicated by a central arrow was considered an irrelevant dimension when the participants were responding to the colour of the arrow (Masaki et al., 2000).

It is possible that visuospatial processing of the stimulus plays an important role in the Simon task because the stimuli are spatially lateralized. The N2pc (negativity posterior contralateral) is an ERP component related to the visuospatial processing of the stimulus (Luck and Hillyard, 1994; Woodman and Luck, 1999, 2003). The sources of N2pc have been localized in extraestriate visual areas (Hopf et al., 2000; Luck et al., 1997), and the component has been observed at 200-250 ms, as enhanced negativity at posterior electrodes contralateral to the hemifield in which the stimuli were presented (Eimer, 1996). The importance of studying the N2pc component in this type of task was highlighted in a recent review of electrophysiological studies of the Simon effect (Leuthold, 2011), although studies addressing modulation of the N2pc by the Simon effect are scarce and show inconsistent results.

In some studies using Simon tasks, N2pc modulations were not observed in relation to the experimental condition (Cespón et al., 2012; Praamstra, 2006; Praamstra and Oostenveld, 2003; Van der Lubbe and Verleger, 2002). However, Valle-Inclán (1996, Exp. 2) observed a larger N2pc amplitude in the incompatible condition than in the compatible condition. This suggested that, in addition to the interference observed in response-related processes, interference took place at stimulus processing stages in the Simon effect.

The discrepancies in the results regarding N2pc modulation may have been caused by a stimulus-stimulus overlap (S-S) in the Simon task used by Valle-Inclán (1996), which was not present in the tasks used in the other studies mentioned. In the study carried out by Valle-Inclán (1996), the participants responded to the direction indicated by a lateralized arrow and ignored the stimulus position. Thus, in addition to the overlap between the irrelevant dimension and the response, there was also an overlap between the relevant dimension (the direction of the arrow pointing to the right or to the left) and the irrelevant dimension of the stimulus (the position of the arrow, which was placed on the right or on the left of the screen). However, in the previously mentioned studies, the relevant dimension, which was a letter (Praamstra and Oostenveld, 2003; Van der Lubbe and Verleger, 2002), a coloured arrow pointing upwards (Cespón et al., 2012), or a square containing horizontal bars (Praamstra, 2006), did not overlap with the irrelevant dimension (stimulus position) (e.g. a specific letter is not compatible or incompatible with a right or left side position, unlike arrows pointing to the right or to the left. For a review on the dimensional overlap, see Zhang et al., 1999).

It is known that the stimulus position and the direction pointed by an arrow may orient spatial attention (Klein, 2004; Klein and Ivanoff, 2011). Consequently, when the arrow is in the opposite hemifield with respect to where it is pointing, conflicting spatial information may be produced, causing a decline in the allocation of spatial attention to the stimulus position, which would be reflected by changes in the N2pc.

In the type of task used by Valle-Inclán (1996), it is not possible to dissociate S-S and S-R effects since the S-S incompatibility is always accompanied by S-R incompatibility and the S-S compatibility is always accompanied by the S-R compatibility (Juncos-Rabadán et al., 2008). Therefore, the N2pc modulation could not be attributed to S-R incompatibility (Simon effect) or to S-S incompatibility. However, Valle-Inclán (1996) observed a larger N2pc amplitude in the incompatible condition than in the compatible condition and interpreted this as interference at a perceptual processing stage. Although some studies have related increased N2pc amplitude to greater difficulty in suppressing the non-target stimulus (Luck et al., 1997), the N2pc was related to target processing (Eimer, 1996) in tasks in which a single contralateral non-target is presented. Furthermore, recent evidence supports the idea that the N2pc amplitude is smaller when the allocation of attentional resources to the target is less efficient (Hilimire et al., 2009; 2010; Telling et al., 2009).

The aim of the present study was to determine whether the S-S incompatibility affected allocation of the visuospatial attention to the target stimulus. For this purpose, it was necessary to dissociate S-S and S-R incompatibilities, and therefore we designed a task in which the participants were asked to respond to the colour of an arrow, but to ignore the position and the direction pointed by the arrow. As a result of the combination of both irrelevant dimensions, the task included four conditions (Figure 1a): compatible direction/compatible position (CDCP), in which S-R compatibility based on the stimulus position was accompanied by S-S compatibility (compatible position S-R/compatible S-S); incompatible direction/compatible position (IDCP), in which S-R compatibility based on the stimulus position was accompanied by S-S incompatibility (compatible position S-R/incompatible S-S); compatible direction/incompatible position (CDIP), in which S-R incompatibility based on the stimulus position was accompanied by S-S incompatibility (incompatible position S-R /incompatible S-S); and incompatible direction/incompatible position (IDIP), in which S-R incompatibility based on the stimulus position was accompanied by S-S compatibility (incompatible position S-R/compatible S-S) (the task stimuli are illustrated in Figure 1a and a diagram of the experimental design is shown in Figure 1b).

According to recent views of N2pc modulations, a smaller N2pc amplitude is expected when the difficulty in allocating attentional resources to the target stimulus increases. Three alternative hypotheses were considered in the present study. Firstly, if the S-S incompatibility interferes with the allocation of attention to the target stimulus, then a smaller N2pc amplitude would be expected in incompatible S-S (IDCP and CDIP, in which incompatibility between the position and the direction was present, i.e. the arrow was placed in the opposite hemifield with respect to where it was pointing) than in compatible S-S (CDCP and IDIP conditions) (Hypothesis 1, see Figure 1c). Secondly, if the Simon effect causes a decline in visuospatial attention to the target stimulus, then a smaller N2pc amplitude would be expected in the incompatible position

S-R (CDIP and IDIP, in which the position was incompatible with the response) than in the compatible position S-R (CDCP and IDCP conditions) (Hypothesis 2, see Figure 1d). A third possibility is that the direction of the arrow modulates the N2pc component. In this case, a smaller N2pc amplitude would be expected in incompatible direction S-R (IDCP and IDIP, in which the direction was incompatible with the response) than in the compatible direction S-R (CDCP and CDIP conditions) (Hypothesis 3, see Figure 1e).

2. Methods

2.1. Participants

Twenty one participants (14 women) between 19-28 years of age agreed to take part in the study and were paid for their participation. The study received prior approval by the local ethical review board. Twenty participants were right-handed and one was ambidextrous, as 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 and procedure

A red or blue arrow pointing either left or right was displayed on a screen against a black background. The screen was placed 100 cm in front of the participants. The arrow stimuli subtended 2.87º horizontally and 1.72º vertically in the visual field and were presented in parafoveal region (the internal edge was 2.29º and the external edge 5.16º of visual angle with respect to a central cross: see Bargh and Chartrand, 2000). A geometric figure of similar morphology (see Figure 1a) and eccentricity was presented in the opposite hemifield with respect to the position of the arrow. Both stimuli were presented for 125 ms (2000 ms inter-trial intervals).

The participants were instructed to direct their gaze to the central cross throughout the task and to respond to the colour of the arrow by pressing one of two horizontally arranged buttons. The following experimental conditions were generated: compatible direction-compatible position (CDCP), incompatible direction-compatible position (IDCP), compatible direction-incompatible position (CDIP), and incompatible direction-incompatible position (IDIP) (see Figure 1a). After a practice block of 24 trials, 320 trials (80 per condition) were presented in two blocks (90 s inter-block interval). The response button assigned to each colour of the arrow was counterbalanced among participants, who were instructed to respond as quickly and accurately as possible.

2.3. EEG recordings

Forty-nine active electrodes were used for the EEG recordings, 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 analog bandpass filter and was sampled at 500 Hz. The reference electrode was placed on the tip of the nose and the ground electrode at Fpz. Recordings of vertical ocular movement (VEOG) and horizontal ocular movement (HEOG) were obtained with two electrodes located supra- and infraorbitally to the right eye and two electrodes at the external canthus of each eye, respectively. Impedances were maintained below 10 kΩs. After signal storage, ocular artifacts were corrected off-line by use of the algorithm proposed by Gratton et al. (1983). The signal was filtered at 0.01–30 Hz digital band-pass. Epochs exceeding ±100 µV were automatically rejected, and all remaining epochs were individually inspected to identify those still displaying artifacts; these epochs were also excluded from subsequent averaging. Epochs were then corrected to the mean voltage of the 200-ms pre-stimulus recording period (baseline).

2.4. Data analysis

Trials with incorrect responses or RTs outside the 100-1000 ms range were excluded from the analysis. The RTs and the Percentage of Errors (PE) were calculated.

Epochs were established between -200 and 800 ms associated with presentation of the stimulus. Following previous studies (e.g. Kiss et al., 2008), in the present study a two-step procedure was used to remove epochs with horizontal ocular artifacts. Firstly, trials with large horizontal eye movements (larger than ± 30 μV) were removed. Secondly, averaged HEOG waveforms showing residual eye movements (HEOG activity exceeding ± 3 μV) were eliminated. Three participants were excluded from further analyses because they displayed residual horizontal ocular movements in all conditions. The number of averaged epochs in each experimental condition was as follows: CDCP (61 averaged epochs / 19 excluded epochs), IDCP (56 averaged epochs / 24 excluded epochs), CDIP (57 averaged epochs / 23 excluded epochs), and IDIP (58 averaged epochs / 22 excluded epochs). The N2pc component was determined in relation to the hemifield of the target presentation, as follows: [PO8 – PO7 (left hemifield) + PO7 – PO8 (right hemifield)] / 2 (see Luck and Hillyard, 1994). The latency of N2pc was measured as the largest negative peak between 200-270 ms, determined by inspection of the grand averages. Amplitudes of N2pc were calculated as the mean value between 200-270 ms (i.e. the usual procedure for measuring N2pc amplitude, e.g. Woodman and Luck, 1999).

Incompatibility from the position modulates motor (Valle-Inclán, 1996) and negativity central contralateral (N2cc) (Cespón et al., 2012) components, and incompatibility from the direction also modulates motor activity (Masaki et al., 2000). As these modulations and those of the N2pc amplitude occur in a similar temporal window, the procedure for obtaining N2pc was applied at central electrodes, [C4 – C3 (left hemifield) + C3 – C4 (right hemifield)] / 2, to test for possible effects of volume conduction from central regions on the N2pc. The N2cc amplitudes were calculated as the mean value between 200-270 ms (note that the wave recorded at central electrodes is labelled as N2cc, although it is actually constituted by overlapping between N2cc and motor activity (LRP) (Praamstra, 2007)).

2.5. Statistical analysis

The RT, Percentage of Errors (PE), and ERP data were analyzed by ANOVA, with the stimulus-stimulus compatibility (S-S) (two levels: Compatible and Incompatible) and the stimulus-response compatibility based on the stimulus position (S-R) (two levels: Compatible and Incompatible) as within-subject factors. Therefore, S-S or S-R effects due to the stimulus position would be revealed by a main effect, while S-R effects due to the direction indicated by the arrow would be revealed by an S-S x S-R interaction effect (see Figure 1b, showing a diagram of the design).

Repeated measures ANOVAs were used to determine whether there were any differences in the RTs, the PE, the N2pc peak latency and averaged amplitude, and the N2cc averaged amplitude in relation to the experimental conditions. Two within-subject factors were considered: S-S (two levels: Compatible and Incompatible) and S-R (two levels: Compatible and Incompatible). When the ANOVAs revealed significant effects due to the factors and their interactions, post hoc paired multiple comparisons of the mean values were carried out (with Bonferroni correction).

Figure 1 about here

3. Results

3.1. Behavioural measures

For the RT (see Table 1), the repeated measures ANOVA (S-S x S-R) revealed a significant effect of the S-R factor ($F(1, 17) = 143.4$, $p < 0.001$, $\eta^2_\rho = 0.894$), as the RTs were shorter in compatible S-R trials (CDCP/IDCP) than in incompatible S-R trials (CDIP/IDIP) ($p < 0.001$, $\eta^2_\rho = 0.894$). An S-R x S-S interaction effect was observed ($F (1, 17) = 11.8$, $p = 0.003$, $\eta^2_\rho = 0.411$); specifically, when the S-R was compatible, the RT was longer when the S-S was also incompatible ($p = 0.009$, $\eta^2_\rho = 0.342$) (i.e. the RT was longer in IDCP than in CDCP). In addition, when the S-S was compatible, the RT was longer when the S-R was also incompatible ($p < 0.001$, $\eta^2_\rho = 0.861$) (i.e. the RT was longer in IDIP than in CDCP). For PE (see Table 1), the repeated measures ANOVA (S-S x S-R) revealed an effect of the S-R factor ($F (1,17) = 47.6$, $p < 0.001$, $\eta^2_\rho = 0.737$), as the PE was higher in incompatible S-R trials (CDIP/IDIP) than in compatible S-R trials (CDCP/IDCP) ($p < 0.001$, $\eta^2_\rho = 0.737$).

3.2. ERP

For the N2pc latency, the repeated measures ANOVA (S-S x S-R) did not reveal any significant effect. For the N2pc amplitude, the repeated measures ANOVA (S-S x S-R) revealed a significant effect of the S-S factor ($F (1, 17) = 8.9$, $p = 0.008$, $\eta^2_\rho = 0.344$), as the N2pc amplitude was smaller when S-S was incompatible (IDCP/CDIP) than when it was compatible (CDCP/IDIP) ($p = 0.008$, $\eta^2_\rho = 0.344$) (see Table 1 and Figures 1f and 2a).

For the amplitude of N2cc, the repeated measures ANOVA (S-S x S-R) revealed an effect of the S-R factor ($F (1, 17) = 24.5$, $p < 0.001$, $\eta^2_\rho = 0.591$), as the N2cc amplitude was larger when the stimulus was compatible (CDCP/IDCP) than when the stimulus was incompatible (CDIP/IDIP) with the response ($p < 0.001$, $\eta^2_\rho = 0.591$) (see Figure 2b).

(Figure 2 and Table 1 about here)

4. Discussion

In the present study, two type 3 S-R incompatibilities (the direction indicated by the arrow and the stimulus position, left or right) were combined in the same task. Both irrelevant dimensions were also incompatible with each other in the IDCP and CDIP conditions (stimulus-stimulus incompatibility). Incompatibility from the position caused an interference effect (i.e. longer RT, higher PE) as did the incompatibility from the direction (causing longer RT). The electrophysiological results showed that N2pc was smaller in incompatible S-S (CDIP and IDCP) than in compatible S-S (CDCP and IDIP). This suggests the existence of S-S interference in the allocation of attentional resources to the target stimulus. The results of applying the N2pc formula to data obtained at central electrodes strongly suggest that N2pc results are not the consequence of ERP modulations occurring at central regions.

The reaction time (RT) revealed strong interference when the position of the stimulus was incompatible with the required response (longer RTs in incompatible position S-R -CDIP and IDIP- than in compatible position S-R –IDCP and CDCP). Furthermore, the RT revealed an interference effect when the direction was incompatible with the required response (longer RTs in incompatible direction S-R -IDCP and IDIP- than in compatible direction S-R -CDCP). Moreover, the S-S incompatibility did not increase the RT. Behavioural interference from the S-S incompatibility might have been masked by the strong interference, caused by the stimulus position, which takes place in response-related processes (Valle-Inclán, 1996). The Percentage of Errors (PE) was higher when the position was incompatible (in incompatible position S-R), but not when the direction indicated by the arrow was incompatible with the response (in incompatible direction S-R). There was also no effect of any interaction between both S-R incompatibilities (in IDIP). Overall, these results are consistent with the results of a previous study using a similar task (Wittfoth et al., 2009).

As regards the ERP results, the N2pc peak latency did not differ between the four conditions. However, the amplitude of N2pc was smaller in the incompatible S-S than in the compatible S-S conditions. These findings revealed interference in the visuospatial processing of the target stimulus, caused by S-S incompatibility. In other words, in the incompatible S-S conditions (IDCP and CDIP), the direction indicated by the arrow and the position of the arrow conveyed contradictory spatial information (the arrow was pointing to the opposite hemifield with respect to its location). Thus, the irrelevant dimensions induced opposing changes in spatial attention, so that the ability to allocate attentional resources to the target stimulus was reduced in these conditions. These findings are consistent with the N2pc modulation generated by high-level properties of the display (Eimer and Kiss, 2007; Telling et al., 2009). The present results also showed that S-S incompatibility may affect the processing of the target stimulus, even when both dimensions (position and direction of the arrow) were irrelevant, unlike the conclusion made on the basis of behavioural data (see type 6 tasks in Zhang et al. 1999).

The smaller N2pc amplitude was not caused by S-R incompatibility due to the stimulus position. In that case, the amplitude of N2pc would have been smaller in incompatible position S-R (IDIP and CDIP, in which the stimulus position was incompatible with the response) than in compatible position S-R (CDCP and IDCP, in which the stimulus position was compatible with the response). The lack of N2pc amplitude modulation by S-R compatibility due to the stimulus position is consistent with the results of previous studies (Cespón et al., 2012; Praamstra, 2006; Praamstra and Oostenveld, 2003; Praamstra and Plat, 2001; Van der Lubbe and Verleger, 2002).

Furthermore, the smaller N2pc amplitude was not caused by the S-R incompatibility due to the direction indicated by the arrow. In that case, the N2pc amplitude would have been smaller in incompatible direction S-R (IDCP and IDIP, in which the direction indicated by the arrow was incompatible with the response) than in compatible direction S-R (CDCP and CDIP, in which the direction pointed by the arrow was compatible with the response). Therefore, the present results allow us to exclude the possibility that the N2pc amplitude modulation was caused by any S-R incompatibility.

Previous studies showed that incompatibility due to the position of the stimulus modulates the motor activity (Valle-Inclán, 1996) as well as the N2cc (Cespón et al., 2012) when both ERP components were recorded at central regions. In addition, motor activity was also modulated by incompatibility due to the direction of the arrow (Masaki et al., 2000). Therefore, in the present study, it would be possible to relate differences in N2pc amplitude to differences in volume conduction from central regions. However, in the same temporal interval in which N2pc was measured, the amplitude of the wave recorded at central electrodes (using the N2pc derivation) was larger in compatible position S-R (CDCP and IDCP) than in incompatible position S-R (CDIP and IDIP) conditions. Taking into account that the N2pc amplitude was larger in compatible S-S (CDCP and IDIP) than in incompatible S-S (CDIP and IDCP), these results are inconsistent with the hypothesis of N2pc being modulated by volume conduction from the ERP components recorded at central regions.

It could be argued that differences in N2pc amplitude in the present task may be due to differences in the asymmetrical shape of the arrow, i.e. in incompatible S-S the arrowhead was pointing inwards while in compatible S-S the arrowhead was pointing outwards. Although the eccentricity of the arrow was the same in every condition (see method), the arrowhead (i.e. the most informative portion of the arrow) was placed at a less eccentric position relative to the central cross in incompatible S-S than in compatible S-S (between 2.86 and 5.16 degrees of visual angle in compatible S-S, and between 2.29 and 4.59 degrees of visual angle in incompatible S-S). Several studies have shown that when the eccentricity of the stimulus increases, the N2pc amplitude decreases (Schlaghecken et al., 2001; Schaffer et al., 2011). However, the results of the present study show the opposite, i.e. that the N2pc amplitude was smaller when the arrowheads were closer to the central cross (incompatible S-S) than when the arrowheads were further away from the central cross (compatible S-S). Therefore, in the present study, the N2pc modulation appears to be explained by the S-S incompatibility, but not by the eccentricity of the arrowhead.

In accordance with the recent literature concerning N2pc (Hillimire et al., 2009; 2010; Telling et al., 2009), we interpreted the smaller N2pc amplitude as reflecting diminished target processing due to the S-S interference; however, Valle-Inclán (1996, Exp. 2) related the larger N2pc amplitude in the incompatible condition to an interference effect. This interpretation would be consistent with the ambiguity resolution theory (see Luck et al., 1997), which related increased N2pc amplitude to greater allocation of resources for suppressing the non-target stimulus. These contrary interpretations about the N2pc modulations may be due to differences in the experimental design of the studies. Thus, in the study carried out by Valle-Inclán (1996), the stimuli (target and non-target) were presented with a very narrow degree of eccentricity (1º of visual angle from the centre of the target to the centre of the contralateral non-target stimulus), whereas in the present study, target and non-target stimuli were separated by a visual angle of 7.5º. It is therefore possible that in the present study, N2pc basically reflected processes associated with identification of the target, whereas in the task used by Valle-Inclán (1996) the N2pc may have reflected processes associated with identification of the target as well as processes associated with suppression of the distracting stimulus (see Hickey et al., 2009).

In summary, in the present study the participants carried out a Simon task with response to the colour of a lateralized arrow. The irrelevant dimensions were the position and the direction indicated by the arrow, which overlapped with the response (S-R overlaps). In addition, both irrelevant dimensions overlapped with each other (S-S overlap). Both types of S-R incompatibility caused an interference effect in the behavioural data, but they did not modulate N2pc parameters. Moreover, the N2pc amplitude was smaller in incompatible S-S than in the compatible S-S conditions. Therefore, N2pc modulations showed that the S-S incompatibility, and not the S-R incompatibilities, reduced the ability to allocate attentional resources to the target stimulus.

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FIGURE CAPTIONS

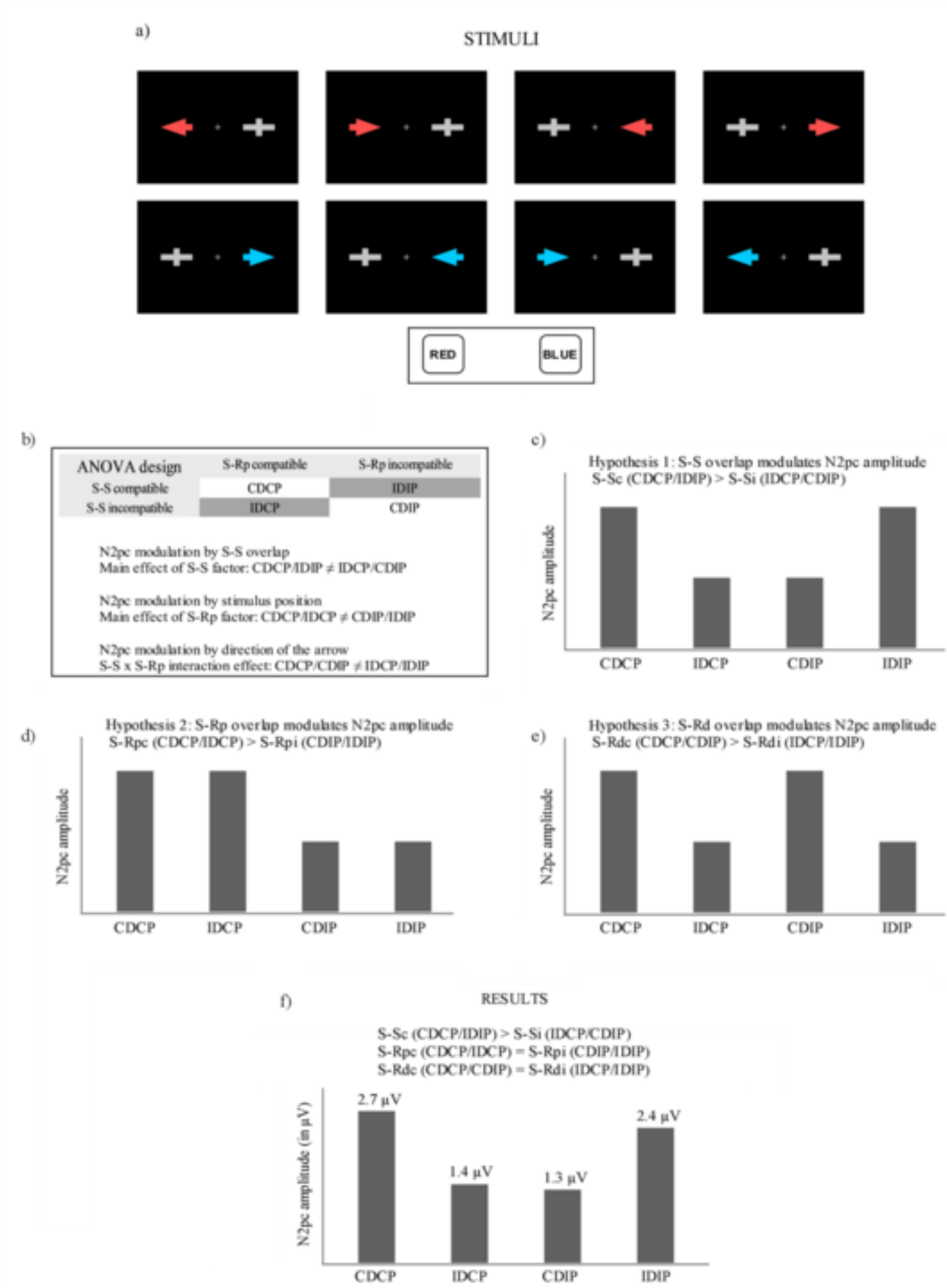
Figure 1: a) Diagram showing the task and stimuli presented. Participants were instructed to respond by pressing the left button with their left hand when a red arrow appeared and the right button with their right hand when a blue arrow appeared, so that the conditions presented (from left to the right columns) were respectively: compatible direction/compatible position (CDCP); incompatible direction/compatible position (IDCP); compatible direction/incompatible position (CDIP); and incompatible direction/incompatible position (IDIP). The response buttons were counterbalanced among participants. b) ANOVA design. The main factors were stimulus-stimulus (S-S) and stimulus-response compatibility based on the position (S-Rp). Effects of direction of the arrow (S-Rd) would be revealed by S-S x S-R interaction effects (note that the white diagonal line = compatible direction, and the grey diagonal line = incompatible direction). c) Pattern of results expected if stimulus-stimulus (S-S) modulates N2pc amplitude. d) Pattern of results expected if stimulus-response based on the stimulus position (S-Rp) modulates N2pc amplitude. e) Pattern of results expected if stimulus-response based on the direction pointed by the arrow (S-Rd) modulates N2pc amplitude. f) Results of N2pc amplitude showing that S-S overlaps (and not S-R overlaps) modulated the amplitude of N2pc.

Figure 2: Grand averages for: a) N2pc in PO7/PO8 electrodes; b) N2cc in C3/C4 electrodes; c) HEOG. Solid lines: Stimulus-Stimulus compatibility; dashed lines: Stimulus-Stimulus incompatibility; grey lines: Stimulus-Response compatibility due to position; black lines: Stimulus-Response incompatibility due to position. N2pc amplitude was smaller in incompatible S-S (IDCP and CDIP) than in compatible S-S (CDCP and IDIP); N2cc amplitude (overlapping with motor activity) was smaller in incompatible position S-R (CDIP and IDIP) than in compatible position S-R (CDCP and IDCP). HEOG did not reveal any differences in ocular movement to the stimulus position based on the experimental condition.

Table(s)

CONDITION	CDCP	IDCP	CDIP	IDIP
Reaction Time	404 (39)	416 (42)	450 (41)	455 (44)
Percentage of Errors	3.1 (3.4)	3.5 (3.1)	8.7 (7.2)	9.9 (4.6)
N2pc Peak Latency	237 (20)	230 (26)	236 (26)	241 (17)
N2pc Amplitude	-2.7 (1.9)	-1.4 (1.8)	-1.3 (2.3)	-2.4 (1.8)
N2cc Amplitude	-2.2 (1.3)	-1.6 (0.8)	-0.6 (0.9)	-0.4 (1.3)

Table 1: Values in each Condition (Compatible Direction and Compatible Position –CDCP-, Incompatible Direction and Compatible Position –IDCP-, Compatible Direction and Incompatible Position –CDIP-, Incompatible Direction and Incompatible Position -IDIP) for reaction time (RT, in milliseconds), percentage of errors (PE), averaged amplitude (in microvolts) of N2pc between 200-270 ms; peak latency (in milliseconds) of N2pc; and averaged amplitude (in microvolts) of N2cc between 200-270 ms.


a)
STIMULI
RED
BLUE
b)
ANOVA design
S-Rp compatible
S-Rp incompatible
S-S compatible
CDCP
IDIP
S-S incompatible
IDCP
CDIP
N2pc modulation by S-S overlap
Main effect of S-S factor: CDCP/IDIP ≠ IDCP/CDIP
N2pc modulation by stimulus position
Main effect of S-Rp factor: CDCP/IDCP ≠ CDIP/IDIP
N2pc modulation by direction of the arrow
S-S x S-Rp interaction effect: CDCP/CDIP ≠ IDCP/IDIP
c)
Hypothesis 1: S-S overlap modulates N2pc amplitude
S-Sc (CDCP/IDIP) > S-Si (IDCP/CDIP)
N2pc amplitude
CDCP
IDCP
CDIP
IDIP
d)
Hypothesis 2: S-Rp overlap modulates N2pc amplitude
S-Rpc (CDCP/IDCP) > S-Rpi (CDIP/IDIP)
N2pc amplitude
CDCP
IDCP
CDIP
IDIP
e)
Hypothesis 3: S-Rd overlap modulates N2pc amplitude
S-Rdc (CDCP/CDIP) > S-Rdi (IDCP/IDIP)
N2pc amplitude
CDCP
IDCP
CDIP
IDIP
f)
RESULTS
S-Sc (CDCP/IDIP) > S-Si (IDCP/CDIP)
S-Rpc (CDCP/IDCP) = S-Rpi (CDIP/IDIP)
S-Rdc (CDCP/CDIP) = S-Rdi (IDCP/IDIP)
N2pc amplitude (in µV)
2.7 µV
1.4 µV
1.3 µV
2.4 µV
CDCP
IDCP
CDIP
IDIP

Figure(s)
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