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N2pc is modulated by stimulus–stimulus, but not by stimulus–response incompatibilities

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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

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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 (Fig. 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 Fig. 1a and a diagram of the experimental design is shown in Fig. 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 Fig. 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 Fig. 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 Fig. 1e).

2. Methods

2.1. Participants

Twenty-one participants (14 women) between 19 and 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 2.87° horizontally and 1.72° vertically in the visual field and were presented in parafoveal region (the internal edge was 2.29° and the external edge 5.16° of visual angle with respect to a central cross: see Bargh and Chartrand, 2000). A geometric figure of similar morphology (see Fig. 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 Fig. 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 analogue 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 kΩ. After signal storage, ocular artefacts were corrected offline 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 artefacts; 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).