



The Simon effect modulates N2cc and LRP but not the N2pc component

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ABSTRACT

Previous studies have reported that the horizontal arrangement of the stimuli in Simon tasks elicits three different components: LRP, N2pc and N2cc. Although N2cc may play a key role in Simon tasks, as it is involved in preventing responses based on stimulus position, modulation of the N2cc component according to the experimental conditions has not previously been investigated because of N2cc/LRP overlap in similar regions and temporal window. The aim of the present study was to investigate how the Simon effect modulates N2pc, N2cc and LRP components. For this purpose, participants were asked to respond to an arrow according to its colour. Three conditions, which depended on the congruency between stimulus position and the required response, were analysed: compatible position (CP), incompatible position (IP), and neutral position (NP). The LRP peak latency was delayed in IP with respect to CP and NP conditions. Lateralized minus neutral position (L–NP) subtractions were carried out to remove the common motor activity and isolate the N2cc and N2pc components in the lateralized conditions. The N2cc amplitude in L–NP waveforms was larger in IP than in CP, in accordance with the greater effort required to monitor selection of the correct response in the first condition. eLORETA analysis also revealed greater premotor activity at 150–200 ms in IP and CP, than in NP, which was attributed to the N2cc component present in IP/CP conditions. Evidence of functional dissociation between N2pc and N2cc components was obtained, because N2cc, but not N2pc, was affected by the experimental conditions.

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1. Introduction

The Simon task is a stimulus–response compatibility task (SRC) (Kornblum and Stevens, 2002), in which participants must respond to 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 stimuli being irrelevant to the task. In those cases in which the required response is on the opposite side to the stimulus (incompatible condition), a type of interference known as the Simon effect is produced (for reviews see Leuthold, 2011; Lu and Proctor, 1995; Simon, 1990). The interference is manifested by a slower reaction time (RT) in the incompatible condition than in the compatible condition, in which the response side is ipsilateral with respect to the stimulus position.

Analysis of the lateralized readiness potential (LRP) revealed that the Simon effect occurs during the response selection stage (Valle-Inclán, 1996). The LRP is an event-related potential (ERP) associated with motor activity, and it allows distinction between interference produced during motor stages and interference produced during perceptual stages of processing (Gratton et al., 1988; for a review of different ways of obtaining LRP, and its functional significance, see Eimer, 1998). However,

it has been shown that the location of the stimuli produces lateralized modulations that overlap with motor activity.

When the stimuli are presented in a horizontal arrangement, the eccentric location induces asymmetry in the exogenous ERP N1 (at around 180 ms) (Valle-Inclán, 1996, Experiment 1). This asymmetry can extend to central regions, thus affecting measurement of the LRP. To avoid such asymmetry, some researchers have presented a non-target stimulus in the contralateral hemifield (Valle-Inclán, 1996, Experiment 2). However, such stimulus configuration requires visuospatial selection of the relevant stimulus, which elicits a component named N2 posterior contralateral (N2pc). N2pc is observed at parieto-occipital electrode sites contralateral to the stimulated hemifield, between 200 and 300 ms, and represents visuospatial processing of the relevant stimulus (Luck and Hillyard, 1994; Woodman and Luck, 1999, 2003). N2pc may be accompanied by a deflection of the same polarity at central electrodes (N2 central contralateral–N2cc), which would hinder evaluation of the motor activity (Valle-Inclán, 1996 Exp. 2; Wascher and Wauschkuhn, 1996). N2cc has been suggested to play an important role in preventing cross-talk between the direction of the spatial attention and the manual response preparation (Praamstra, 2006, 2007; Praamstra and Oostenveld, 2003).

The N2cc wave was first interpreted as volume conduction from posterior areas, i.e. from N2pc activity (Valle-Inclán, 1996 Experiment 2; Wascher and Wauschkuhn, 1996). However several studies have shown that N2pc and N2cc are different components. Using a

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biophysical model, Oostenveld et al. (2001) showed that the amplitude recorded at central electrodes in the temporal window of the N2pc was too large to be explained by volume conduction from N2pc sources. Also, in the latter and other studies (Praagstra and Oostenveld, 2003; Praagstra and Plat, 2001), the use of source reconstruction techniques enabled identification of activity peaks at central and at parieto-occipital regions, thus indicating the existence of two different components. Moreover, Van der Lubbe et al. (2001) showed that lateralization at central electrodes did not occur parallel to the N2pc, suggesting different sources of activity for central and parieto-occipital waves. Finally, some studies have shown functional dissociation between N2pc and N2cc, since both were differentially affected by experimental manipulation of the tasks (see Praagstra, 2006; Praagstra and Oostenveld, 2003).

The scalp distribution of the N2cc, as well as the conditions under which it was elicited, suggest that N2cc is associated with activation of the dorsal premotor cortex (dPM) (see Praagstra and Oostenveld, 2003). In fact, the dPM is involved in selection of movements according to learned associations in spatial tasks (Rushworth et al., 2003). In addition, visual and motor signals were found to interact in the dPM (Wise et al., 1996, 1997; for a review on dPM, see Abe and Hanakawa, 2009).

In order to prevent overlap between N2pc/N2cc and the motor activity, some researchers have used a vertical arrangement of stimuli and responses (de Jong et al., 1994; Stürmer et al., 2002; Valle-Inclán, 1996, Experiment 3). Using this arrangement, N2cc and N2pc are not elicited. Nonetheless, in our opinion (see also Leuthold, 2011), it is important to examine the N2cc in the Simon task, as it may reflect a mechanism of cognitive control.

The present study involved a Simon task with lateralized stimuli. The positions of the stimuli were compatible (compatible position, CP), incompatible (incompatible position, IP) or central (neutral position, NP) with respect to the required response. The stimuli were presented in a horizontal arrangement to determine whether the location modulated only motor processes (analysed via LRP), as maintained in previous studies (de Jong et al., 1994; Stürmer et al., 2002; Valle-Inclán, 1996, Experiment 3), or also other cognitive processes, specifically the visuospatial processing of the relevant stimulus (which has been related to N2pc) and the cognitive control that prevents execution of the response based on stimulus position (which has been related to N2cc).

In order to clarify the existence of these effects, two procedures were carried out to isolate the N2cc and N2pc components from the motor activity. Firstly, the NP waveform was subtracted from the CP and the IP waveforms, as central stimuli elicit LRP but not N2cc and N2pc components. Also, analyses were carried out to discount the possibility that the differences in motor activity between lateralized and NP conditions affected the lateralized minus neutral position (L–NP) waveforms. Secondly, the CP and the IP conditions were compared with the NP condition using eLORETA source analyses (Pascual-Marqui, 2007, 2009).

In the waveforms in which N2cc and N2pc were isolated (i.e. when the motor activity is subtracted), we expected to find a larger N2cc amplitude in the IP than in the CP condition, as the cognitive control for monitoring selection of the response based on the relevant dimension (the colour of the arrow) should be greater in the IP than in the CP condition. On the basis of e-LORETA estimations, we expected to find higher activity in premotor areas during the N2cc time interval in the CP and IP than in the NP. We did not expect to find any differences in the N2pc component between CP and IP, as the Simon effect does not appear to take place in the visuospatial processing of the relevant stimulus. Therefore, another aim of the present study was to obtain new evidence of the functional dissociation between N2pc and N2cc components. Finally, with respect to the modulation of the motor activity by the stimulus position, we expected to find longer LRP peak latency in the IP than

in the CP and NP conditions, consistent with the slower RT in the IP condition.

2. Methods

2.1. Participants

Nineteen participants (14 women, 5 men) between 19 and 28 years old (mean age: 21 years old) were recruited from the local university population. Four participants (3 women) were not included in some of the ERP analyses because of an insufficient number of artefact-free epochs in some of the conditions. 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. Eighteen of the participants were right-handed and one was ambidextrous (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

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 \times width) of the visual field. In the compatible and incompatible conditions, the visual stimuli were presented 3.1° (visual angle) from the centre of the screen at the centre of the stimulus. The lateralized (CP and IP) and central stimuli were presented in parafoveal and foveal regions respectively (see Bargh and Chartrand, 2000), although differences in stimulus processing due to this eccentricity were not expected (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 Fig. 1).

2.3. Procedure

The participants were asked to direct their gaze towards the central cross during the task, 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. They were also instructed to ignore the position of the arrow. A cross appeared in the centre of the screen and remained in view throughout the task. The response buttons were arranged horizontally and were pressed with the corresponding hand (right or left) so that when the arrow was in the central position, there was no overlap between the position and the dimension of the response, and the trials were therefore considered neutrals. In each block, each of six possible types of stimuli, grouped in three conditions with the same number of trials (80 per condition) were presented at random: compatible position (CP, the response required was ipsilateral to the hemifield of appearance of the target), incompatible position (IP, the required response was contralateral to the hemifield of the appearance of the target), and neutral position (NP, as described above, there was no overlap between stimulus position and response). The arrows were presented for 100 ms, with inter-trial intervals of 2000 ms. The possibility of ocular movements towards the position of the target when this was presented at eccentric locations was minimised by the short duration of presentation of the stimuli and the simultaneous presentation of the non target stimulus in the contralateral hemifield (see Abrahamse and Van der Lubbe, 2008).

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