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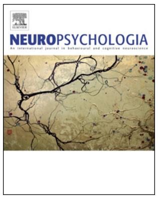

Are eyes special? Electrophysiological and behavioural evidence for a dissociation between eye-gaze and arrows attentional mechanisms

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ABSTRACT

It has been proposed that attention triggered by eye-gaze may represent a unique attentional process, different from that triggered by non-social stimuli such as arrows. To investigate this issue, in the present study we compared the temporal dynamics of the conflict processing triggered by eye-gaze and arrow stimuli. We investigated the electrophysiological activity during a task in which participants were required to identify the direction of laterally presented eye-gaze or arrow targets. Opposite behavioural effects were observed: while arrows produced the typical effect, with faster responses when they were congruent with their position, eye-gaze targets produced a reversed effect with faster responses when they were incongruent. Event-related potentials showed common and dissociable congruency modulation: whereas eye-gaze and arrows showed similar effects on earlier ERP components (P1 and N1), they led to opposite effects in later components such as N2 and P3. This represents the first electrophysiological demonstration of both early shared and later dissociable congruency effects for eye-gaze and arrow stimuli.

1. Introduction

Eye-gaze represents the most reliable stimulus for social interactions. Possibly for this reason, the role of eye-gaze perception in modulating social attention has been the major focus of an extensive number of behavioural studies (for reviews, see Capozzi and Ristic, 2018; Nummenmaa and Calder, 2009). The perception of directed eye-gaze indicates that we are the object of another person's attention, and it can have an impact in our cognitive and attentional states (i.e., the well-known *'eye-contact effect'*; Senju and Johnson, 2009). Besides, if the observed eye-gaze is averted, its direction informs us that the person is attending to something or someone else (Emery, 2000) and our ability to attend the same object another person is looking at is crucial for many aspects of everyday social functioning (e.g., Allison et al., 2000).

Importantly – and unlike non-social directional stimuli such as arrows –another person's eye-gaze might indicate more than just a direction, providing a window into their current goals and intentions (e.g., Baron-Cohen et al., 1997). This difference raises the critical issue – investigated by several behavioural, functional neuroanatomy, and electrophysiological studies – of whether the neural architecture supporting eye-gaze attentional mechanisms is different from those supporting attentional mechanisms engaged by just symbolic directional stimuli such as arrows.

In particular, a large body of literature has directly compared the attentional orienting triggered by eye-gaze and arrows stimuli using many variations of the traditional cueing paradigm (Posner, 1980). However those studies increasingly show no robust behavioural differences between eye-gaze and arrow cues (Hermens and Walker, 2010; Galfano et al., 2012; Green et al., 2013; Guzzon et al., 2010; Kuhn and Kingstone, 2009; Stevens et al., 2008; Tipples, 2008; for a review, see also Birmingham and Kingstone, 2009). On the other hand, mixed results concerning the dissociations between eye-gaze and arrow attentional mechanisms have also been reported at the neural level. While some studies reported different neural activity during attention to eye-gaze compared to arrows (e.g., Caruana et al., 2015; Hietanen et al., 2008; Joseph et al., 2014; Ristic and Giesbrecht, 2011; Tipper et al., 2008), others studies found similar patterns of activity for both types of stimuli (e.g., Brignani et al., 2009; Callejas et al., 2014; Sato et al., 2009; Tipples et al., 2012; Zhao et al., 2017). Critically, it is important to note that the majority of these studies have used the spatial cueing paradigm that, as stated above, has generally shown subtle or no behavioural differences between eye-gaze and arrows stimuli.

However, a different pattern emerges in paradigms aiming at

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investigating qualitative differences between eye-gaze and arrows. Thus, for example, by using a variant of the double-rectangle task, it has been shown that arrow cues elicit a general attentional bias towards parts of the environment, while eye-gaze cues selectively orient attention to the specific location or part of the object looked at (Marotta et al., 2012). Similarly, eye-gaze but not arrow seems to lead to the creation of an event with the looked at object, which in turn cause inhibition of return (Frischen and Tipper, 2004); an effect that is not shown by autistic children (Marotta et al., 2013).

Finally, combining a traditional eye-gaze cueing paradigm with a visual memory task, it has been observed that eye-gaze but not arrow cues enhanced memory accuracy for cued information (Dodd et al., 2012; Gregory and Jackson, 2017, 2018). Of relevance for the present study, perhaps the clearest attention dissociation between eye-gaze and no-social directional stimuli has also been recently shown when they are used as targets instead of as cues (Cañadas and Lupiáñez, 2012; Marotta et al., 2018). In particular, eye-gaze and arrow targets yielded opposite spatial interference effects when unpredictably presented to the left or right side of the fixation point and participants were required to identify their direction. Thus, arrows elicited faster responses when their direction was congruent with their position (e.g., right pointing arrows presented to the right; *typical spatial stroop*), whereas eye-gaze produced faster reaction times (RT) when it was incongruent (e.g., left looking eye-gaze presented to the right; *'reversed' spatial stroop*).

Although interesting, these findings only got indirect evidence regarding the processes contributing to the dissociation between eye-gaze and arrows attentional mechanisms. By contrast, techniques such as event-related potentials (ERPs) recordings could be critical for this purpose, since various stages of stimuli processing with different time courses can be separately analyzed. Thus, to explore the temporal dynamics of the expected attentional dissociation between eye-gaze and arrows stimuli, in the present study we recorded electroencephalogram (EEG) while participants performed a spatial interference task with either eye-gaze or arrows as target stimuli.

In particular, several ERPs may be modulated by attention across different stages of processing in the context of a *spatial interference task*. The P1 and N1 components have been generally used as indexes of early attentional allocation enhancing perceptual processing and classification of stimuli (e.g., Luck et al., 2000). The N170– related to the perceptual discrimination and categorization of stimuli (Vogel and Luck, 2000) –is also modulated by attention (Alguacil et al., 2013; Aranda et al., 2010). Note that the N170 is a component sensitive to faces and eyes stimuli as demonstrated by larger peak amplitudes observed for faces compared to other non-social objects (e.g., Bentin et al., 1996).

On the other hand, in the spatial interference task, the observed dissociation between eye-gaze and arrows might also result from differences at the response-selection stage when the response associated with the spatial position competes with the instructed response. This view suggests modulations of the fronto-central N2 component as potential index of the conflict processing and response inhibition elicited when – as in the spatial interference task – two response tendencies are simultaneously activated by the stimulus (for a review, see Folstein and Van Petten, 2008). Finally, the P3 is thought to reflect controlled allocation of capacity-limited attentional resources towards relevant situations (e.g., Nieuwenhuis et al., 2005) and it has been interpreted as reflecting the processes involved in stimulus evaluation that takes place before the implementation of the action (Friedman et al., 2001).

Therefore, by measuring ERPs such as the P1, N1, N170, N2 and P3 –as markers of different stages of information processing – we will provide a way to test the extent to which the critical behavioural dissociation expected between eye-gaze and arrows arise from early or later stages of neural processing. In particular, if the difference between the spatial conflict effects triggered by eye-gaze and arrows arise from early attention and perceptual processing of the stimuli, a dissociable congruency modulation should be observed from components such as P1, N1, and N170. In contrast, if the conflict dissociation between the two stimuli emerges from the response generation and the evaluative categorization of the stimuli, a dissociable congruency modulation should be only reflected in later components such as N2, and P3.

2. Method

2.1. Participants

A total of 28 volunteers (all right-handed; 27 women; mean age of 20.6 years, SD = 4.5) participated in the experiment. Taking as a reference the effect size of the behavioural dissociation reported in the study of Marotta et al. (2018), to achieve 95% power to detect the original effect size (η^2_p = .54), we would have needed 14 participants. However, anticipating that data from some participants would have to be excluded by noisy EEG signal, and that the size of the effect with ERP measure might be lower, we decided to collect a larger sample of 28 participants.

All participants were naïve students from the University of Granada, who participated in the experiment for course credits (0.2/Hour). All had self-reported normal or corrected-to-normal vision. Data from seven participants were excluded from the final analyses: one participant due to a technical error in data acquisition and the remaining six participants due to an excessively noisy EEG signal, leaving a final sample of 21 participants. The experiment was conducted in accordance with the ethical standards of the 1964 Declaration of Helsinki (last update: Seoul, 2008), as part of a larger research project approved by the University of Granada Ethical Committee (175/CEIH/2017).

2.2. Apparatus and stimuli

Stimuli presentation, timing, and data collection were controlled by a program written using E-prime 2.0 (Schneider et al., 2002) run on a standard Pentium 4 PC. Stimuli were presented on a 17″ wide screen monitor with a 1.024 × 768 pixel resolution. They consisted of two black arrows display and full color cropped eyes subtending a 1° x 4° degrees of visual angle at a viewing distance of 57 cm. Cropped eyes were obtained by manipulating an original face (taken from the MacBrain Face Stimulus Set; http://www.macbrain.org/faces/index.htm)[1] with Adobe Photoshop CS.

2.3. Procedure

The stimuli used and the sequence of events in each trial are illustrated in Fig. 1. Participants were seated at approximately 57 cm from the computer screen in a faintly lit room to perform the experimental task. They were required to perform a discrimination task in which they had to respond as fast and accurately as possible to the direction (left or right) indicated by the eye-gaze or arrows, while ignoring the location

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[1] Face stimulus was drawn from the MacBrain Face Stimulus Set developed by Nim Tottenham and supported by the John D. and Catherine T. MacArthur Foundation Research Network on Early Experience and Brain Development. Please contact Nim Tottenham at. tott0006@tc.umn.edu for more information concerning the stimulus set.

[2] Although only behavioural data of the participants included in the ERP analysis were reported in the Results section, the full behavioural data may be of interest to some readers. For this reason, the RTs analysis of all participants (N = 28) is presented here. The main effect of target type was significant, F (1,27) = 154.16, p$^{<}$.001, η2p = .85, with arrows showing faster RTs as compared to eye-gaze (511 ms vs. 666 ms). Moreover, target type interacted with congruency, F(1,27) = 53.05, p < .001, η2p = .66. While responses were significantly slower for incongruent than congruent trials for arrows (496 ms vs. 525 ms), F(1,27) = 29.69, p < .001, η2p = .52, they were significantly faster for incongruent than congruent trials (680 ms vs. 702 ms) for eye-gaze, F(1, 27) = 17.98, p = .001,η2p = .40. The main effect of congruency was not significant, F < 1.

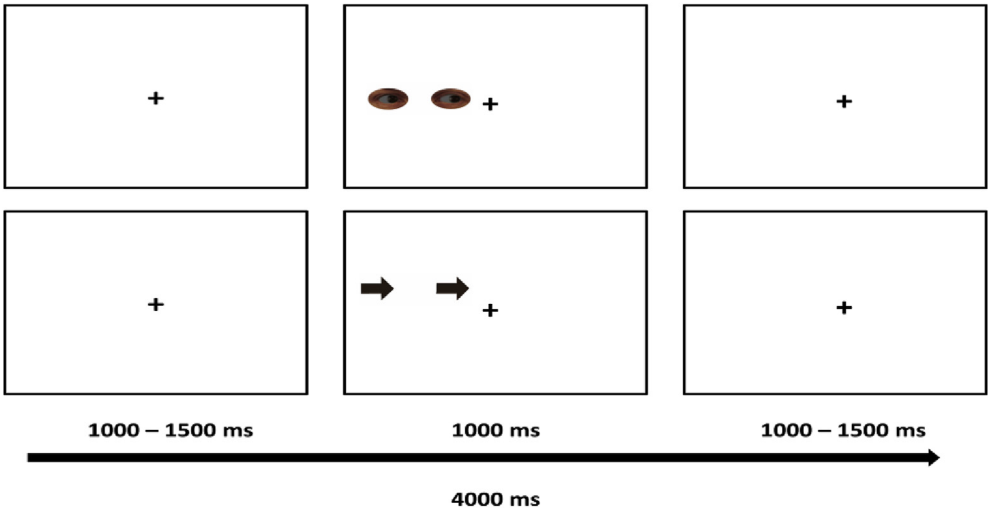

Fig. 1. Schematic view of a trial sequence, moving from the left to the right, for both the eye-gaze and the arrow target conditions. The examples represent incongruent trials.

in which the target would appear. The experiment was composed of two halves (one for each target type), each one composed of 15 practice trials followed by two experimental blocks of 64 trials each. Target direction and target location were randomly selected within each block of trials. The order of the two halves (eye-gaze/arrow) was counterbalanced across participants.

Each trial began with a black fixation cross presented in the center of a white screen which remained on the screen for a random delay between 1000 and 1500 ms. Participants were instructed to fixate the cross. Then, a pair of eyes or arrows looking/pointing to the right or to the left was presented either to the left or to the right of fixation for 1500 ms. The distance from the center of the lateral stimulus to the central fixation cross was 5° of visual angle. Participants were instructed to press the “Z” key in response to targets indicating the left, and the “M” key in response to targets indicating the right, independent of the target's location. Finally, a fixation frame (without target) was presented, for a variable duration so that the total trial time was always of 4000 ms. Feedback to incorrect key presses was provided to participants (only during practice) by presenting a 220-Hz tone for 1500 ms. Importantly, this design produced trials that were congruent (i.e., right-indicating targets presented on the right and left-indicating targets presented on the left) or incongruent (i.e., left-indicating targets presented on the right and right-indicating targets presented on the left).

2.4. Design

The experiment consisted of a two-factor repeated measure design. Target type had two levels: eye-gaze and arrow. Congruency had two levels: congruent and incongruent. Thus, the experiment consisted of 30 practice trials, which were not further analyzed, and 256 experimental trials (2 blocks of 64 trials per target type). For each participant, mean RTs and accuracy (mean percent errors) were calculated for each experimental condition.

2.5. EEG: recording and analysis

The EEG was recorded using a 128-channel Geodesic Sensor Net of Ag/AgCl electrodes (Tucker et al., 1994). The head-coverage included sensors lateral to and below both eyes, to monitor horizontal and vertical eye movements. Impedances for each channel were measured and kept < 50 KΩ before testing. All electrodes were referenced to the Cz electrode during the recording and were averaged re-referenced offline. The EEG was amplified with a band pass of .1–100 Hz (elliptic filter), and digitized at a sampling rate of 250 Hz. EEG was filtered offline by using a 30 Hz low-pass filter. Epochs were segmented from 200 ms before target appearance to 600 ms after its presentation. Segments were then baseline corrected by setting the average of the 200 ms pre-target baseline to zero. All trials containing eye movements were corrected using Ocular Artifact Removal (OAR; Gratton et al., 1983). Trials with segments containing activity greater than ± 90 µV relative to baseline, blinks, and trials with either incorrect, anticipatory (< 200 ms) or slow responses (> 1300 ms) were rejected. An average of 18.9% of trials was excluded and a minimum of 30 trials per condition was used to ensure a sufficient signal-to-noise ratio.

3. Results

3.1. Behavioural results

Data were submitted to a 2 (Target type) x 2 (Congruency) repeated measures analysis of variance (ANOVA). Partial ANOVAs were further conducted for the analysis of significant interactions. As in Marotta et al. (2018), RTs faster than 200 ms (1.5% of trials) or slower than 1300 ms (0.5%) and trials with an incorrect response (3.5%) were excluded from the RT analysis. Table 1 shows the means of mean RTs (± SD) and percentages of errors for each experimental condition.

Reaction Times.[2] The main effect of target type was significant, F (1,20) = 117.05, $p^{<}.001$, $\eta^2_p = .85$, with arrows showing faster RTs as compared to eye-gaze (525 ms vs. 691 ms). As can be observed in Fig. 2, and consistent with our previous findings (Marotta et al., 2018), target type interacted with congruency, F(1,20) = 28.91, $p < .001$, $\eta^2_p = .59$. Partial ANOVAs on each target type showed that while responses were significantly slower for incongruent than congruent trials for arrows (539 ms vs. 510 ms), F(1,20) = 18.45, $p < .001$, $\eta^2_p = .48$, they were significantly faster for incongruent than congruent trials (680 ms vs. 702 ms) for eye-gaze, F(1, 20) = 7.97, p = .011, $\eta^2_p = .28$. The main effect of congruency was not significant, F < 1.

Table 1
Mean Correct response times (RTs, in Milliseconds), standard deviations (SD) and percentages of incorrect responses errors (%IR) for each experimental condition.

Trial Type	Eye-Gaze				Arrow			
	RT	SD	%IR	SD	RT	SD	%IR	SD
Congruent	702.18	93.17	6.67	7.81	510.14	95.66	1.19	3.71
Incongruent	680.21	104.97	4.05	4.34	539.30	100.67	2.62	3.14

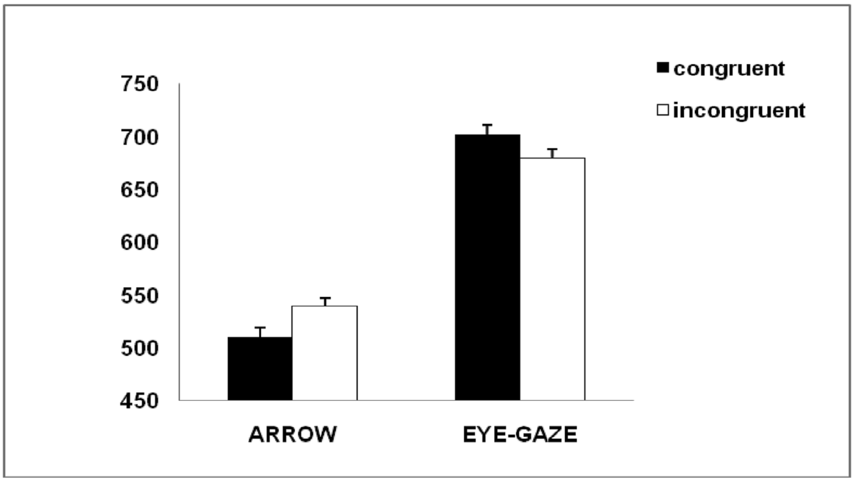

Fig. 2. Mean reaction times for each target type and congruency condition. Error bars represent standard errors of the means with between participants variance removed using Cousineau's (2005) method.

Errors.[3] The percentage of error analysis showed the same pattern of results. Thus, the main effect of target type was significant, F(1,20) = 13.44, p = .002, η^2_p = .40, with eye-gaze showing more errors as compared to arrows (5.4% vs. 2%). Consistent with the RTs analysis, target type interacted with congruency, F(1,20) = 4.54, p = .045, η^2_p = .18. Partial ANOVAs on each target type showed that while participants showed more errors for incongruent than congruent trials for arrows, F(1, 20) = 6.44, p = .019, η^2_p = .24, they showed more errors for congruent than incongruent trials for eye-gaze, although this difference was not significant, F(1, 20) = 1.80, p = .194, η^2_p = .08. The main effect of congruency was not significant, F < 1.

3.2. ERP results

ERPs locked to the appearance of the target were analyzed. Visual inspection of target-locked ERPs, based on the grand average and topographic maps according to previous literature (e.g., Eimer, 1994; Hopfinger and Mangun, 1998) revealed the presence of six main components of interest for the current study. The first component was the P1, peaking at ~140 ms in parieto-occipital electrodes. This component was followed by the N1, peaking at ~190 ms in the same parieto-occipital electrodes. The N1 component was directly followed by the N170 component, peaking at ~200 ms in temporo-occipital electrodes. We also observed the N2 component, peaking at ~250 ms in midline-frontal electrodes, followed by the P3 component, peaking at ~330 ms at central electrodes.

Based on previous studies describing the components above, we calculated the adaptive mean amplitude of each component within each trial – the average amplitude in the window 20 ms before and after the largest peak (for a similar procedure, see Chica and Lupiáñez, 2009 and Martín-Arévalo et al., 2014, 2016) using PO7/PO8, and O1/O2 for P1 and N1 components (e.g., Eimer, 1994; Martín-Arévalo et al., 2014); T9/T10, TP9/TP10, and P9/P10 for the N170 (Onitsuka et al., 2009; Tortosa et al., 2013); Cz and FCz, for the N2 component (Liotti et al., 2000; Böckler et al., 2011; Balconi and Pozzoli, 2003); and CP1/CP2 and CPz, for the P3 component (Tortosa et al., 2013; Martín-Arévalo et al., 2014). Data from grouping of electrodes in each component were collapsed since an initial analysis including electrode as a factor revealed that it did not interact with any other factors (all ps > .05). Values were analyzed using repeated measures ANOVAs, and significant interactions were further analyzed using partial ANOVAs. These analyses included the factors target type (eye-gaze and arrow) and congruency (congruent vs. incongruent trials). Note that hemisphere (left vs. right) was also included as factor in those analyses (P1, N1, and N170) where components were lateralized.

3.2.1. Early processing stages

P1 component. Only the main effect of congruency was significant, F(1,20) = 5.09, p = .035,η^2_p = .20, with congruent trials showing a larger P1 as compared to incongruent trials (see Fig. 3A). However, Congruency did not interact with Target Type, F < 1. All other main effects or interactions were not significant, all ps > .312.

N1 component. A congruency × hemisphere interaction was marginally observed, F(1,20) = 3.74, p = .067,η^2_p = .16, with incongruent trials showing a larger N1 as compared to congruent trials on the left hemisphere (see Fig. 3A). All other main effects or interactions were not significant, all ps > .218.

N170 component. The main effect of target type was significant, F(1,20) = 4.37, p = .049,η^2_p = .18, with eye-gaze showing a larger N170 as compared to arrows (see Fig. 3B). For N170 amplitude, congruency interacted with hemisphere, F(1,20) = 5.25, p = .033, η^2_p = .21, as N170 was significantly larger for incongruent than congruent trials only on the left hemisphere, F(1,20) = 5.71, p = .027(see Fig. 3C). None of the other main effects or interactions were significant, all ps > .177.

3.2.2. Late processing stages

N2 component. Neither the main effect of target type nor the main effect of congruency was significant, both ps > .145. Consistent with our previous analysis on RTs and error rates, target type interacted with congruency, F(1,20) = 41.75, p < .001, η^2_p = .68. As can be observed in Fig. 4A, while N2 was significantly larger for incongruent than congruent trials for arrows, F(1,20) = 26.67, p < .001, η^2_p = .57, N2 was significantly larger for congruent than incongruent trials for eye-gaze, F(1,20) = 5.01, p = .037, η^2_p = .20.

P3 component. Again, neither the main effect of target type nor the main effect of congruency was significant, both Fs < 1, but target type interacted with congruency, F(1,20) = 5.23, p = .033, η^2_p = .21. P3 was significantly larger for congruent than incongruent trials for

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[3] The percentage of error analysis of all participants is reported here. The main effect of target type was significant, F(1,27) = 17.95, p < .001, η2p = .40, with eye-gaze showing more errors as compared to arrows (5% vs. 2%). Target type interacted with congruency, F(1,27) = 8.22, p = .008, η2p = .23. Partial ANOVAs on each target type showed that while participants showed more errors for incongruent than congruent trials for arrows, F(1, 27) = 6.44, p = .019, η2p = .24, they showed more errors for congruent than incongruent trials for eye-gaze, although this difference was not significant, F(1, 27) = 2.96, p = .098, η2p = .08. The main effect of congruency was not significant, F < 1.

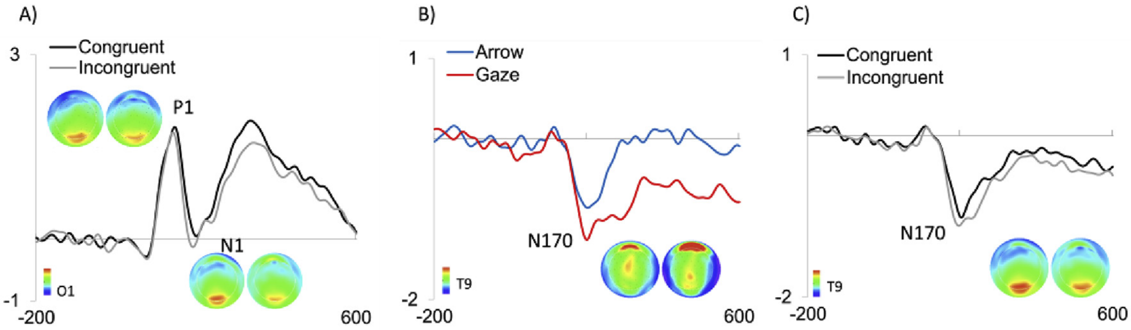

Fig. 3. (A) Mean target-locked ERP waveforms for the P1 and N1 analysis shown separately for congruent and incongruent conditions. Scalp topographic voltage maps at the moment of maximal amplitude for the P1 and N1 are also shown for each condition, respectively. (B) Mean target-locked ERP waveforms for the N170 analysis shown separately for the arrow and gaze conditions. Scalp topographic voltage maps at the moment of maximal amplitude for the N170 is also shown for each condition, respectively. (C) Mean target-locked ERP waveforms for the N170 analysis shown separately for congruent and incongruent conditions. Scalp topographic voltage maps at the moment of maximal amplitude for the N170 is also shown for each condition, respectively. Waves represent the average of responses at PO7/PO8 electrodes.

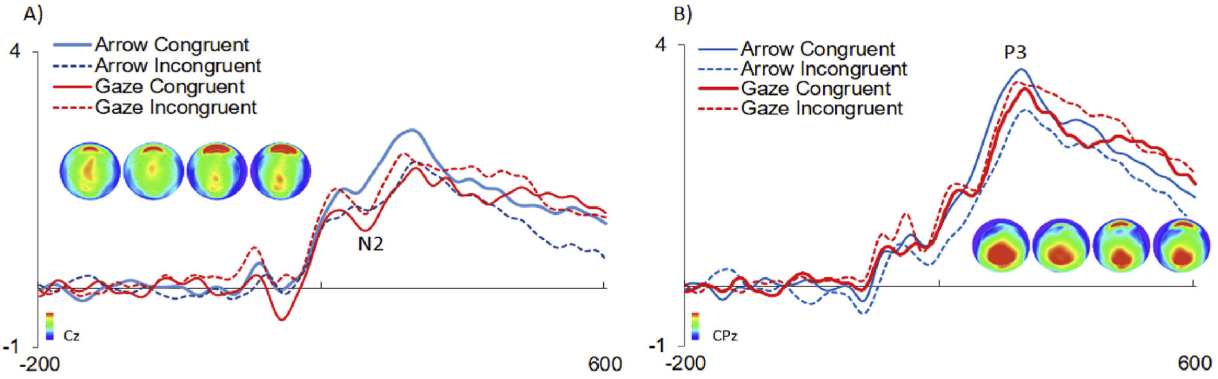

Fig. 4. (A)Mean target-locked ERP waveforms for the N2 analysis shown separately for target type and congruency. Scalp topographic voltage maps at the moment of maximal amplitude for the N2 are shown for each condition, respectively. (B)Mean target-locked ERP waveforms for the P3 analysis shown separately for target type and congruency. Scalp topographic voltage maps at the moment of maximal amplitude for the P3 is also shown for each condition, respectively. Waves represent the average of responses at PO7/PO8 electrodes.

arrows, F(1,20) = 4.90, p = .038, η^2_p = .20; in contrast, P3 amplitude was larger for incongruent than congruent eye-gaze, although this difference was not significant, F(1, 20) = 1.70, p = .206, η^2_p = .08 (see Fig. 4B).

4. Discussion

The primary focus of the current study was to conduct a direct comparison of the spatial conflict processing triggered by eye-gaze and arrows stimuli, in order to understand when the neural process critical for the observed behavioural dissociation between arrows and eye-gaze takes place. To this end, ERPs were recorded while participants performed a spatial interference task that required them to identify the direction of gaze or arrows, either congruent or incongruent with their spatial position.

Confirming previous findings (Marotta et al., 2018), behavioural data showed that eye-gaze and arrows led to opposite spatial interference effects, with arrows producing faster RTs when the arrow's direction was congruent with arrow's position, and eye-gaze producing faster responses when eye-gaze's direction was incongruent. Importantly, however, electrophysiological results suggested the presence of parallel congruency modulations for both types of stimuli at early stages of processing (P1, N1, and N170) but later dissociations according to the kind of the stimulus generating the conflict (N2 and P3).

4.1. Early processing stages

The P1 component was similarly affected by congruency with both eye-gaze and arrows stimuli. In particular, as compared to the congruent condition, the incongruent condition was accompanied by a decline in the P1 component. This may indicate that some early detection of spatial mismatch between target position and direction is occurring. Indeed, it has been suggested that such early components do not just indicate the engaging of attention, but reflect the sensory processing that arises as a result of attentional orienting (Luck, 1995).

The subsequent component significantly affected by congruency was the N170 component, its amplitude being larger for incongruent than for congruent trials. Interestingly, albeit not statistically significant, the same modulation was also observed with the N1 component. These results are in line with previous studies showing high-conflict conditions to evoke higher amplitudes of both the N1 (Kirmizi-Alsan et al., 2006) and N170 components (Baggott et al., 2011) and suggesting the presence of an enhanced early attention allocation in the incongruent condition facilitating further perceptual processing and classification of the stimuli (Vogel and Luck, 2000).

Of relevance for the present study, it is also important to note that the N170 amplitude was enhanced in response to eye-gaze as compared to arrow stimuli. This is consistent with previous studies showing that this component clearly distinguishes socially relevant stimuli, such as eyes (Taylor et al., 2001) and faces (Bentin et al., 1996), from non-social information (Hirai et al., 2005). Note, however, that the congruency effect was not different for the two target types.

4.2. Late processing stages

The N2 was the first component to reveal congruency dissociation between eye-gaze and arrows. In particular, the amplitude of the N2 component displayed larger negative amplitudes for incongruent trials with arrow stimuli. This pattern is consistent with previous evidence of N2 modulations following experimental conditions invoking conflicting response possibilities (see Folstein and Van Petten, 2008) and it implies successful solution of the spatial conflict for arrows – i.e. the monitoring of inappropriate planned responses for performing the simultaneously activated instructed response, that take place before response execution.

Paralleling the behavioural results, the reversed pattern was found for eye-gaze: the amplitude of the N2 component was larger for congruent trials. These findings might be understood in the light of evolutionary based considerations (Emery, 2000), which assume the ability to use information conveyed by the eye-gaze direction as crucial for species survival. Thus, for arrows, the incongruent condition is a merely conflicting condition, while for eye-gaze it might represent an important social situation. Indeed, it is important to note that in the incongruent condition eye-gaze is looking to the center, in the direction appropriate to make eye contact and/or to approach the participant. In contrast, in the congruent condition eye-gaze stimulus avoids the participants looking away from them. Consistent with this view, Ernst et al. (2013) showed higher N2 amplitudes when participants were required to avoid positive pictures as compared to when they had to approach them. Similarly, in the present study, we observed higher N2 amplitude in congruent than incongruent trials maybe because they respectively represent avoid and approach conditions.

The last component revealing congruency dissociation between eye-gaze and arrow stimuli was the P3. In particular, P3 displayed larger amplitude for congruent trials, but only with arrows. This result has been previously obtained in similar conflict studies with non-social stimuli (e.g., Cespón et al., 2013) and it has been related to the trial difficulty in line with studies showing P3 decrements with increasing task difficulty (e.g., Valle-Inclán, 1996). As suggested by Alguacil et al. (2013), the P3 decrement in incongruent trials might be explained by the inhibition hypothesis proposed by Polich (2007), according to which the P3 would be modulated by the inhibitory mechanisms supporting the focus of attention on the relevant elements of the task and the avoidance of extraneous information. Therefore, smaller amplitudes in the P3 have been observed in the incongruent condition because it is harder to inhibit and consequently less cognitive resources are available.

In contrast, when eye-gaze stimuli were used as targets, larger P3 amplitudes were observed in incongruent trials, although this difference was not statistically significant. Similar findings have been obtained by previous conflict studies using emotional material (Alguacil et al., 2013). Therefore, as in the case of the N2 potential, the reverse pattern of results observed with eye-gaze stimuli might be explained taking into account the social importance and the motivational value of eye-gaze direction in the incongruent condition.

Thus, both non-social (i.e., arrows) and social (eye-gaze) stimuli seem to be initially processed as directional stimuli, thus triggering either congruent or incongruent responses, and therefore producing spatial conflict. However, whereas this conflict initially generated at early stages of processing manifests afterwards in later response-selection processes in the case of arrows, an additional component must take place in the case of eye-gaze, which reverts the nature of the conflict. At later processing stages, after reaching higher semantic processing stages, the social nature of the directional eyes might involve person interrelation processes, which would convert the purely spatial conflict into a rather social approach vs. avoidance conflict. This later conflict would be reflected in the reversed N2 and P3 components observed with eyes, as compared to those observed with arrows. Future research should investigate the implications of eyes sharing some orienting mechanisms with non-social stimuli, like arrows, and adding other components of a rather social nature, and therefore specific to social stimuli like eyes.

4.3. Conclusion

To our knowledge, the present study is the first to directly compare the different processing stages in the spatial conflict triggered by eye-gaze and arrow stimuli using EEG recordings. While we found a clear dissociation between arrows and eye-gaze on behavioural data, the ERP analysis showed both shared and dissociable effects for the two types of stimuli. These results indicate a congruency effect across all the analyzed ERP components and a dissociation between eye-gaze and arrows only on late components, starting around 200 ms. This suggests that the initial attention and perceptual stages of stimuli processing tackle the conflict through similar mechanisms. On the other hand, later stages involved in cognitive control and response generation differ according to the type of stimulus generating the conflict, maybe as a consequence of the social interpretation of eyes, which is added in later processing stages to their initial processing as directional stimuli.

Authorship statement

All persons who meet authorship criteria are listed as authors, and all authors certify that they have participated sufficiently in the work to take public responsibility for the content, including participation in the concept, design, analysis, writing, or revision of the manuscript. Furthermore, each author certifies that this material or similar material has not been and will not be submitted to or published in any other publication before its appearance in the *Neuropsychologia*.

CRediT authorship contribution statement

Andrea Marotta: Conceptualization, Formal analysis. **Juan Lupiáñez:** Conceptualization, Formal analysis. **Rafael Román-Caballero:** Funding acquisition, Formal analysis. **Cristina Narganes-Pineda:** Funding acquisition, Formal analysis. **Elisa Martín-Arévalo:** Conceptualization, Formal analysis.

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Andrea Marotta on behalf of all the authors.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.neuropsychologia.2019.03.017.

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