BRIEF REPORT

Early posterior ERP components do not reflect the control of attentional shifts toward expected peripheral events

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Abstract

Previous experiments investigating ERP correlates of anticipatory attention shifts triggered by central symbolic cues have identified a contralateral "early directing attention negativity," which was assumed to be generated by processes involved in the control of spatial orienting. Here we demonstrate that this component is not directly linked to the control of attentional shifts, but instead reflects the selection of task-relevant aspects of cue stimuli. In contrast, later ERP components triggered during covert attentional shifts are insensitive to physical cue attributes, and thus appear to be genuine electrophysiological correlates of covert attentional control mechanisms.

Descriptors: Visual-spatial attention, Attentional orienting, Attentional control, Event-related brain potentials

Research in selective attention has recently focused on preparatory control states, which arise prior to onset of sensory stimulation, and bias perceptual processes in favor of stimuli presented at attended locations (for review, see Corbetta & Shulman, 2002). Several studies have measured event-related brain potentials (ERPs) elicited during covert shifts of visual attention to identify electrophysiological correlates of attentional control processes that occur in response to a cue directing attention to the left or right side. Harter, Miller, Price, LaLonde, and Keyes (1989) measured ERPs triggered by a central arrow cue indicating the side of an upcoming visual event. An early negative deflection at posterior electrodes contralateral to the direction of the induced attentional shift ("early directing attention negativity," EDAN) was followed by a contralateral positivity at posterior electrodes ("late directing attention positivity," LDAP; see also Hopf & Mangun, 2000; Nobre, Sebestyen, & Miniussi, 2000; Yamaguchi, Tsuchiya, & Kobayashi, 1994). In addition, an enhanced negativity at frontal electrodes contralateral to the direction of an attentional shift ("anterior directing attention negativity," ADAN) has also been observed (Hopf & Mangun, 2000; Nobre et al., 2000).

These lateralized effects have been assumed to reflect the control of visual-spatial orienting. However, recent experiments from our lab (cf. Eimer & van Velzen, 2002; Eimer, van Velzen, &

Driver, 2002) have demonstrated that ADAN and LDAP are not only elicited during visual-spatial orienting, but also when attention is directed towards expected locations of auditory or tactile events, suggesting that these components reflect attentional control at a supramodal level (see Eimer et al., 2002, for further discussion). Importantly, these recent studies have consistently failed to find any evidence for a posterior early directing attention negativity. Its absence in studies investigating attentional control in audition and touch could indicate that the EDAN is only elicited during shifts of visual-spatial attention. There is, however, an alternative explanation. Most studies that reported an EDAN have used centrally presented arrow cues to elicit leftward or rightward attentional shifts (Harter et al., 1989; Hopf & Mangun, 2000; Yamaguchi et al., 1994). Although the physical difference between a left and right arrow is modest, this difference may still cause a lateralization of early visual responses to the cue, which may have been responsible for the EDAN effects.

This possible confound was recognized and addressed by Nobre et al. (2000). Instead of arrow cues, they used symmetrical cue stimuli to summon rightward or leftward attentional shifts. Green and red arrowheads were presented simultaneously, arranged to form a diamond shape, with either red or green arrowheads indicating the direction of an attentional shift. A posterior EDAN was observed between 160 and 360 ms after cue onset, thereby apparently ruling out the hypothesis that this component reflects a lateralized visual response to asymmetric attentional cues.

However, although the cues used by Nobre et al. (2000) were symmetrical in shape, they were *not* symmetrical with respect to the location of the relevant arrowhead. Arrowheads directing

attention to the right were always presented to the right of fixation, and arrowheads directing attention to the left on the left side. It is well known that relevant stimuli presented together with irrelevant distractors elicit an enhanced negativity over contralateral posterior electrodes. This "N2pc" component was first described by Luck and Hillyard (1994) in a visual search paradigm. Later studies (Eimer, 1996; Wijers, Lange, Mulder, & Mulder, 1997) demonstrated that the N2pc can also be observed when stimulus arrays consist of only two elements, that is, when a relevant and an irrelevant stimulus are presented on either side of fixation (as was the case for the cue stimuli used by Nobre et al., 2000).

The present experiment aimed to resolve the question of whether the EDAN reflects processes involved in the control of cued attentional shifts or whether it arises because of asymmetrical cue stimulus arrays. On each trial, a central cue was followed after 700 ms by a peripheral visual, auditory, or tactile event. Participants had to shift attention to the cued side to detect infrequent visual targets presented there, and ignore visual stimuli at the uncued side, as well as all auditory and tactile events

regardless of their location. Auditory and tactile stimuli were included to make the task context comparable to our previous studies (Eimer et al., 2002; Eimer & van Velzen, 2002) where no EDAN was observed.

Cue stimuli were similar to the stimuli used by Nobre et al. (2000). Two differently colored arrowheads were presented simultaneously to the left and right of fixation. One color was relevant, and the direction of an attentional shift was indicated by the relevant arrowhead. Importantly, two different cue stimulus arrangements were used (Figure 1, top panel). In compatible cue arrays, arrowheads were pointing outwards, and the relevant side was ipsilateral to the cued attention shift (this replicates the cueing procedure used by Nobre et al., 2000). In incompatible cue arrays, arrowheads pointed inwards, and the relevant side was contralateral to the direction of the required attention shift.

If the early directing attention negativity was in fact an N2pc elicited contralateral to the relevant side of the cue stimulus array, this effect should be strongly modulated by the difference between compatible and incompatible cue arrays. If the EDAN component was genuinely related to the control of cued
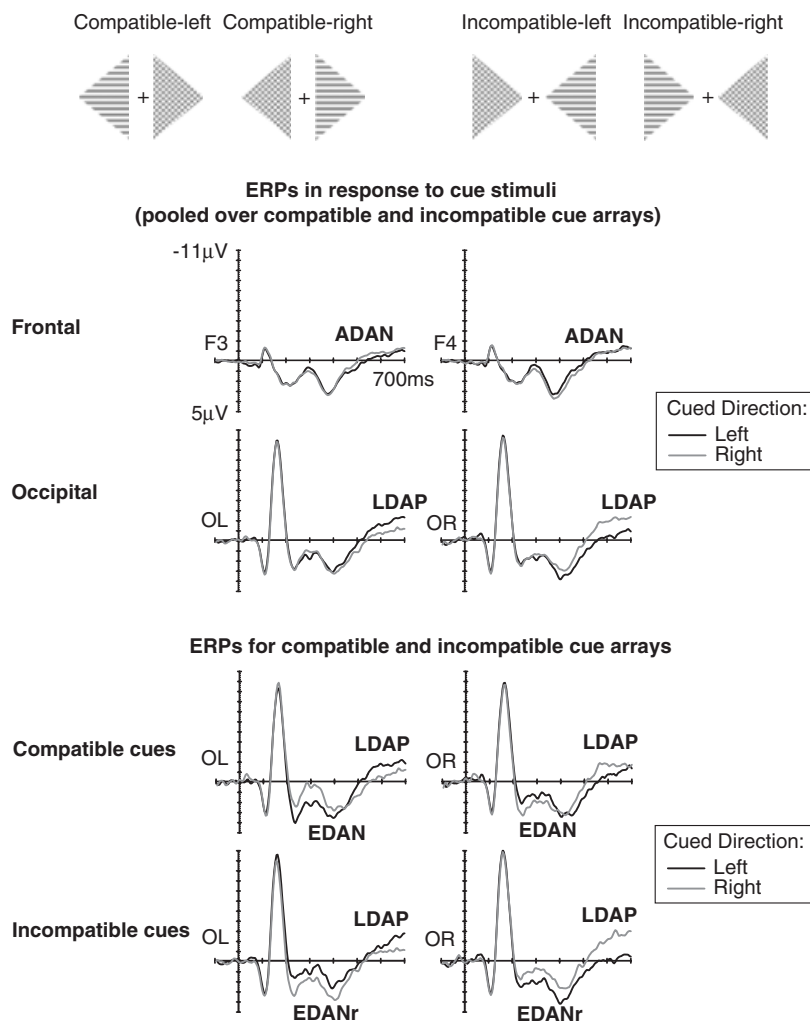
Figure 1. Top panel: Illustration of the cueing procedure used in the present study. Horizontal patterns symbolize the task-relevant color, checkerboard patterns the irrelevant color. The relevant arrowhead was located ipsilateral (compatible arrays) or contralateral (incompatible arrays) to the cued attentional shift. Middle panel: ERPs elicited at left and right anterior (F3, F4) and posterior (OL, OR) electrodes in the 700-ms interval following cues directing attention the left or right side, pooled across compatible and incompatible cue arrays. Bottom panel: ERPs elicited at left and right occipital electrodes (OL, OR) in response to compatible and incompatible cue arrays.

attentional shifts, it should be unaffected by the relative location of the task-relevant part of the cue.

Methods

Participants

Sixteen paid volunteers participated in the experiment. Four were excluded because of insufficient eye fixation control (see below). Thus 12 participants (6 women) aged 21–30 years (mean age: 24.8 years) remained in the sample. Ten participants were right-handed, two left-handed, and all had normal or corrected vision.

Stimuli and Apparatus

Participants sat in a dimly lit booth, wearing a head-mounted microphone. Cue stimuli were two adjacent triangles presented on a computer screen placed at a viewing distance of 55 cm. Together, these two triangles covered a visual angle of $3.5° \times 2.5°$. One of the triangles was red, the other blue, and they pointed either outwards or inwards. A central fixation cross, located in the space between the two triangles, was continuously present. Two tactile stimulators, two LED ensembles (total angular size: 2.4°), and two loudspeakers were placed in close spatial register, each 25° to the left or right, at a viewing distance of about 45 cm from the participant's eyes.

Procedure

Eight experimental blocks of 72 trials were run. Each trial started with the presentation of a central cue (100 ms duration), followed after 700 ms by an auditory, tactile, or visual peripheral stimulus (200 ms duration). Intertrial interval was 1,000 ms. The task was to respond vocally (by saying "yes") whenever a visual target was presented at the cued location (left or right). Visual events on the uncued side were to be ignored, as were all tactile or auditory events on either side. Visual nontargets were 200-ms illuminations of one LED ensemble. For visual targets, this stimulation was turned off for 50 ms after 75 ms, and then turned on again for 75 ms. Tactile stimuli were presented using 5-V solenoids, driving a metal rod with a blunt conical tip that touched to the outside of either index finger for 200 ms. White noise (62 dB) was present to mask sounds made by the tactile stimulators. Auditory stimuli were bursts of white noise (200 ms duration, amplitude 80 dB SPL) presented from one of the two loudspeakers.

For half of the participants, blue triangles indicated the attended location, whereas red triangles were relevant for the other half of the participants. Outward pointing (compatible) and inward pointing (incompatible) cue arrangements (Figure 1, top panel) were equiprobable and randomly distributed in each block. On 60 trials, auditory, tactile, or visual nontargets were presented with equal probability and in random order on the left or right side at cued or uncued locations. In the remaining randomly intermingled 12 trials, visual targets were presented on the left or right side. Eight targets were presented on the cued side (and thus required a response); the other four were presented on the uncued side (requiring no response). Participants were instructed to maintain central eye fixation throughout the trials. Training blocks were run until task performance and eye movement control were satisfactory.

Recording and Data Analysis

EEG was recorded with Ag-AgCl electrode and linked-earlobe reference from 23 scalp electrodes. Horizontal EOG was recorded bipolarly from the outer canthi of both eyes. The impedance for all electrodes was kept below 5 kΩ. Amplifier bandpass was 0.1 to 40 Hz, digitization rate was 200 Hz, and no additional filters were applied to the averaged data. Averages were computed for the 700-ms interval following cue onset relative to a 100-ms precue baseline, separately for all four combinations of cued direction (left vs. right) and cue arrangement (compatible vs. incompatible), but collapsed across trials containing peripheral visual, auditory, or tactile stimuli. Trials with blinks, horizontal eye movements, or muscle artefacts were excluded. Averaged HEOG waveforms were scored for systematic deviations of eye position. Four participants were excluded due to residual HEOG deflections exceeding $\pm 2 \mu V$.

Based on previous findings (cf. Eimer et al., 2002; Harter et al., 1989), three successive latency windows were defined relative to cue onset (150–350 ms, 350–500 ms, 500–700 ms). ERP mean amplitudes obtained within these latency windows were analyzed using repeated measures ANOVAs, separately for lateral anterior (F7/8, F3/4, FC5/6), lateral central (C3/4, T7/8, CP5/6), and lateral posterior sites (OL/R, P3/4, P7/8) for the factors of electrode site, hemisphere (left vs. right), cue arrangement (compatible vs. incompatible), and cued direction (left vs. right). In these omnibus analyses, the presence of an EDAN component, as well as the presence of other lateralized effects sensitive to the direction of an attentional shift should be reflected by Cued Direction × Hemisphere interactions. Lateralized effects found to be affected by cue arrangement (as indicated by Cue Arrangement × Cued Direction × Hemisphere interactions) were assessed separately for compatible and incompatible cues.

Results

Behavioral Measures

Mean vocal reaction time was 629 ms. Participants missed 24% of all visual targets at cued locations. False alarms to nontargets occurred on less than 3% of all trials. None of these measures was affected by cue arrangement.

ERPs Elicited in the Cue–Target Interval

Figure 1 (middle panel) shows ERPs in response to cues directing attention to the left or right side, collapsed across both cue arrangements, at frontal and occipital electrodes. An ADAN and a LDAP are visible. No Cued Direction × Hemisphere interaction was present at posterior electrodes between 150 and 350 ms, $F(1,11) < 0.2$, demonstrating that the EDAN was absent when data were pooled across compatible and incompatible cue arrays. Between 350 and 500 ms, the presence of the ADAN was confirmed by a significant Cued Direction × Hemisphere interaction at frontal electrode pairs, $F(1,11) = 13.98, p < .003$. In the 500–700-ms interval, a reliable LDAP effect was observed for posterior electrode pairs, $F(1,11) = 22.39, p < .001$. A Cued Direction × Hemisphere interaction was also present frontally, $F(1,11) = 13.98, p < .003$, reflecting the later portion of the ADAN.

Importantly, a highly significant three-way interaction (Cued Direction × Hemisphere × Cue Arrangement, $F(1,11) = 17.2, < .002$) was found at posterior electrodes in the 150–350-ms interval. The basis of this interaction is revealed in Figure 1

(bottom panel), which shows ERPs elicited during leftward and rightward attentional shifts at lateral occipital electrodes, displayed separately for compatible and incompatible cue arrays. Starting about 150 ms after cue onset, an enhanced negativity contralateral to the direction of an attentional shift (EDAN) was elicited with compatible cues. In contrast, a reversed EDAN effect (enhanced negativity *ipsilateral* to the cued side; EDANr) was observed for incompatible cues. When considered relative to the side of the relevant arrowhead (which was ipsilateral to the cued side in compatible arrays, but contralateral in incompatible arrays), enhanced negativities were elicited contralaterally for both cue arrays. In addition, Figure 1 (bottom panel) also shows that an enhanced positivity contralateral to the cued direction (LDAP) is elicited in the final 200 ms of the cue–target interval for both cue arrangements.

Follow-up analysis conducted separately for ERPs elicited in response to compatible and incompatible cue arrays in the 150–350-ms interval showed Cued Direction × Hemisphere interactions for both cue types, both $F(1,11) > 12.3$, both $p < .005$, demonstrating that early lateralized effects were triggered by compatible as well as by incompatible cues. In contrast, the frontal ADAN effect was not significantly affected by cue arrangement. The posterior LDAP interacted marginally with cue arrangement (Cued Direction × Hemisphere × Cue Arrangement: $F(1,11) = 3.9$, $p < .08$), but follow-up analysis confirmed that the LDAP was present for compatible as well as incompatible cues, both $F(1,11) > 14.7$, both $p < .003$.

Discussion

The present study investigated lateralized ERP components elicited in response to cues directing attention to one side, which are assumed to reflect processes involved in the control of covert attentional shift. More specifically, we wanted to resolve the question of whether the EDAN component observed in several previous ERP studies of attentional cueing is an electrophysiological correlate of processes underlying shifts of spatial attention (as suggested by Harter et al., 1989; Hopf & Mangun, 2000; Nobre et al., 2000), or merely reflects asymmetries in the cueing procedures used in these earlier studies.

On each trial, a cue stimulus consisting of two arrowheads in different colors presented to the left and right of fixation instructed participants to direct attention to the left or right side in anticipation of infrequent visual targets presented at the cued location. The direction of the attentional shift was signaled by the arrowhead in the relevant color, and this arrowhead was presented either ipsilateral (compatible arrays) or contralateral (incompatible arrays) to the required attentional shift.

When ERPs in response to the cues were pooled across cue arrangements, ERP lateralizations sensitive to the direction of an attentional shift consisted of a frontal ADAN and a posterior LDAP component, consistent with earlier observations (cf. Eimer et al., 2002; Hopf & Mangun, 2000; Nobre et al., 2000), and confirming the hypothesis that these components are linked to the control of covert attentional orienting towards anticipated events on the left versus right side. To further confirm that the cueing procedure used in this study was effective in triggering attentional shifts, we analyzed attentional modulations of early ERP components (P1, N1) elicited at lateral occipital electrodes (OL, OR) by visual nontarget stimuli. As expected, significant effects of attentional cueing were found both for the P1 (measured between 100 and 130 ms poststimulus,

$F(1,11) = 5.5$, $p < .04$) and the N1 (measured between 160 and 200 ms poststimulus, $F(1,11) = 12.7$, $p < .01$), reflecting larger P1 and N1 components for visual stimuli presented at cued (attended) relative to uncued (unattended) locations.

Most importantly, with ERP data pooled across cue arrangements, no indication for an earlier posterior EDAN component was found. The reasons for this failure to replicate an effect that has been present in several earlier ERP studies of spatial cueing (cf. Harter et al., 1989; Hopf & Mangun, 2000; Nobre et al., 2000; Yamaguchi et al., 1994) became obvious when ERPs were analyzed separately for compatible and incompatible cue arrangements. Now, an enhanced negativity contralateral to the direction of an attentional shift was observed between 150 and 300 ms after cue onset when the cue arrangement was compatible, and thus analogous to the cueing procedure used by Nobre et al. This replicates the EDAN effect reported by Nobre et al., as well as by earlier studies using arrow cues. However, a reversed lateralized effect (EDANr) was observed in response to incompatible cue arrays, where an enhanced negativity was elicited ipsilateral to the side of an attentional shift (Figure 1, bottom panel). Naturally, these early lateralized effects were canceled when ERPs for compatible and incompatible cue arrangements were pooled.

This pattern of results is fully in line with the predictions derived from the hypothesis that the "early directing attention negativity" observed previously reflects an N2pc elicited contralateral to the relevant side of a cue stimulus. According to this hypothesis, this effect should reverse direction for incompatible relative to compatible cue arrangements, in the present experiment, and that was precisely what was observed. The N2pc has been interpreted as reflecting the spatial filtering of irrelevant information (Luck & Hillyard, 1994), or, alternatively, the detection and selection of task-relevant stimuli (Eimer, 1996). It is therefore not surprising that this component is elicited when attentional cue arrays contain relevant and irrelevant parts on the left and right side of fixation (as in Nobre et al., 2000, and the current study). Under these conditions, the N2pc appears to reflect the selection of the relevant side of the cue. The fact that this happens regardless of the direction of the attentional shift signaled by these cues (Figure 1, bottom panel) provides compelling evidence that this component is not linked to attentional control processes involved in the orienting of attention towards anticipated peripheral events. N2pc components are also likely to be triggered by arrow cues, where the arrowhead is the most salient and informative aspect. Thus, EDAN effects previously reported in response to attentional arrow cues (cf. Harter et al., 1989; Hopf & Mangun, 2000; Yamaguchi et al., 1994) may similarly reflect N2pc components triggered contralateral to the side of the arrowhead.

What implications do the present results have for our understanding of ERP modulations elicited during covert attentional shifts and their interpretation as correlates of preparatory attentional control processes? The fact that the frontal ADAN and the posterior LDAP component were present when attention was directed toward the location of relevant visual events and the similarity of these effects to the effects previously observed during shifts of auditory and tactile attention (cf. Eimer et al., 2002; Eimer & van Velzen, 2002) suggests that these components reflect anterior and posterior attentional control processes that are at least partially supramodal. The fact that the earlier posterior EDAN component was absent in the pooled ERP data, and reversed polarity with

incompatible relative to compatible cue arrays, demonstrates that this component does not reflect processes involved in the preparatory orienting of attention. In contrast, the EDAN (which appears to be an N2pc in disguise) indicates processes involved in selecting task-relevant aspects of attentional cue stimuli, and should not be interpreted as an electrophysiological correlate of covert attentional shifts triggered by such cues.

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