

# Transient spatial attention modulates distinct components of the auditory ERP

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We recorded ERPs to pairs of externally presented tones, T<sub>1</sub> and T<sub>2</sub>, in the absence of attentional cues to determine whether attention is momentarily sustained at the location of a behaviourally relevant sound, and what effect this focusing of attention might have on the neural response to target stimuli. ERPs to T<sub>2</sub> were more negative when the preceding T<sub>1</sub> was presented on the same side of fixation than when T<sub>1</sub> was presented on the opposite side of fixation. This negative

difference consisted of an early, parietal phase and a later, frontocentral phase. These results confirm and extend previously reported effects of transient spatial attention on auditory ERPs, and they demonstrate that transient spatial attention has a distinct and robust effect on the early stages of stimulus processing in the auditory system. *NeuroReport* 12:3679–3682 © 2001 Lippincott Williams & Wilkins.

**Key words:** Attention; Audition; ERP; Event-related potential; ND; Negative difference; Parietal cortex; Spatial

## INTRODUCTION

The neural processes involved in selective attention have been studied by measuring scalp-recorded electrical activity (event-related potentials or ERPs) in response to attended and unattended sounds. Many ERP studies employed the sustained-attention paradigm, in which participants continuously monitored sounds possessing a specific feature (e.g. at a particular location or of a particular frequency) and ignored sounds possessing other features [1–5] (for reviews see [6,7]). Sounds possessing the to-be-attended feature generally gave rise to more negative ERP deflections than sounds lacking the to-be-attended feature. The earliest portion of this negative difference (Nd) overlapped the N1 component (100–130 ms) and was found to be maximal at central electrodes. A later portion of the Nd was observed in the 150–650 ms post stimulus time interval and was more frontally distributed. The early Nd appears to reflect neural activity in auditory cortex, whereas the late Nd appears to reflect neural activity in auditory cortex and modality non-specific areas of frontal cortex [8–10].

Although we often need to sustain our attention on a single auditory feature for an extended period of time, we also need to reorient our attention on a moment by moment basis in response to changes in the auditory environment. Investigators have found distinct effects of transiently oriented spatial attention on auditory ERPs using the spatial cueing paradigm [11–14]. On each of several trials, a symbolic cue (an arrow) indicated the to-be-attended ear or loudspeaker and was followed by a target tone at either the validly or invalidly cued location. A comparison of auditory ERPs elicited on valid and

invalid trials revealed an Nd (Nd1) in the 140–180 ms latency range that was larger over the parietal scalp (Pz) than over central or frontal sites (Cz or Fz). A later Nd (Nd2) was observed in the 200–350 ms latency range that was larger over frontocentral sites (Cz and Fz). The Nd1 appeared to be distinct from the more anteriorly distributed early Nd that occurs in sustained attention paradigms. Moreover, the Nd1 was found when participants attended to sounds at a particular location but not when they attended to sounds of a particular frequency [12]. Thus, the Nd1 could reflect an important characteristic of transiently oriented spatial attention.

Here, we investigated the effects of transiently oriented spatial attention on auditory ERPs using a paradigm that was different from that used previously. In our study, participants responded to sequentially presented target tones in the absence of any instructions or cues to attend to a particular location. Unlike the visual system, the auditory system lacks a central fovea [15]. Thus, we hypothesized that auditory attention might not automatically reorient to the point of visual fixation, but would instead be sustained at the location of a peripheral target until the occurrence of the next target. Indeed, prior studies indicated that attention is sustained at the location of an auditory target for > 500 ms [16] unless a central reorienting event is used to summon attention away from the target location [17,18]. Thus, we predicted that participants would respond rapidly to targets appearing at the same location as the immediately preceding target (same-side trials), and more slowly to targets appearing on the opposite side of fixation (opposite-side trials). Importantly, we tested whether the

Nd1 and Nd2 would be observed in this paradigm by comparing the ERPs on same-side trials to the ERPs on opposite-side trials. To obtain more precise information about the topography of any resulting Nds, we recorded ERPs from a high-density electrode array (62 sites). Observations of Nd1 and Nd2 components similar to previous studies would indicate that the parietal Nd1 and fronto-central Nd2 are general phenomena of transient auditory attention, and not specific to the visual cue/auditory target paradigm used previously.

## MATERIALS AND METHODS

Fifteen healthy adults participated in the experiment after giving written informed consent. Participants sat in a darkened sound-attenuating booth (background noise 35 dBA SPL) facing three horizontally arranged speakers. The center speaker was located at a distance of 105 cm and the peripheral speakers were located at 33° laterally from center. A chin rest stabilized the head and prevented head movements toward peripheral stimuli. Participants were instructed to maintain visual fixation on an LED attached to the center speaker.

Trials began with a brief flicker of the central LED to alert the participant, followed by a random delay of 800–1300 ms. A tone (1 kHz, 75 dB SPL, 50 ms duration, 2.5 ms rise/fall time) was then presented at random from one of the three speakers. The task was to press a button if this first tone ( $T_1$ ) was presented from one of the peripheral speakers and to refrain from pressing the button if  $T_1$  was presented from the central speaker. After a silent response–stimulus interval (620–1120 ms), a second tone ( $T_2$ ), identical to the first, was then presented at random from one of the three speakers. Participants responded to  $T_2$  as they did to  $T_1$ . Response times were measured using a custom I/O board with an interval timer chip.

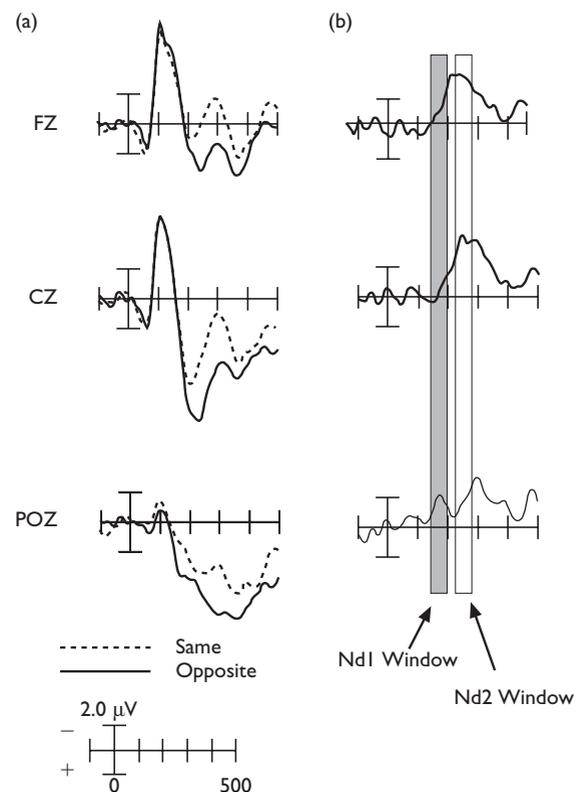
The EEG was recorded from 62 Ag/AgCl electrodes positioned at standard 10–10 scalp sites [19]. The electro-oculogram (EOG) was recorded bipolarly with electrodes placed beside and below the left eye. Electrode impedances were kept below 5 k $\Omega$ . EEG and EOG were amplified with a gain of 20000 and a bandpass of 0.1–30 Hz (–12 dB/octave; 3 dB attenuation), digitized at a rate of 250 Hz, and stored on disk for off-line averaging. Scalp voltages were referenced to the right mastoid and subsequently digitally re-referenced to averaged mastoids. The University of British Columbia human subjects review committee approved all procedures.

For each participant, ERPs to  $T_2$  (13 blocks of 27 trials) were averaged in 1200 ms epochs (including a 200 ms pre-stimulus period) for all combinations of  $T_2$  location (left and right) and  $T_1$  location (same side and opposite side). The first block of trials served as practice and did not contribute to the averaged ERPs. Eye movement, muscle, and blocking artifact were minimized in the ERP waveform by applying automatic rejection criteria to the EEG for each trial. The amplitudes of the ERPs were measured as the differences between the mean voltage within a 100 ms pre-target baseline period and the mean voltage within the 140–200 and 220–260 ms time windows, respectively. These latency windows bracketed the first two peaks in the difference waves and corresponded in latency to the Nd1 and Nd2 found in previous transient spatial attention

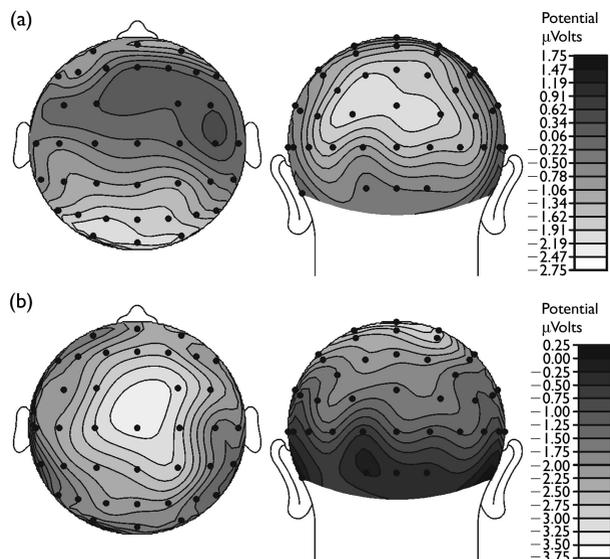
studies [13,14]. These mean amplitudes were entered into separate, repeated measures MANOVAs with electrode location (FZ, CZ, POZ) and  $T_1$  location (same side, opposite side) as factors. The data were normalized in order to assess topographical differences in the ERP amplitudes [20].

## RESULTS

Participants were significantly faster to respond to  $T_2$  on same location trials (425 ms) than on different location trials (436 ms; one-tailed  $t(14) = 2.006$ ,  $p < 0.03$ ). Figure 1 shows two prominent Nds. The first (Nd1) peaked at ~175 ms and the second (Nd2) peaked at ~250 ms. The Nd1 was largest at POZ, which led to a statistically significant interaction between electrode location and  $T_1$  location in the 140–200 ms latency window ( $F(2,28) = 6.00$ ;  $p < 0.007$ ). The Nd2 was largest at CZ and FZ, which led to a significant interaction between electrode location and  $T_1$  location in the 220–260 ms latency window ( $F(2,28) = 6.57$ ;  $p = 0.004$ ). As shown in Fig. 2, the Nd1 was distributed over the posterior scalp, whereas the Nd2 was distributed over the fronto-central scalp. Close inspection of the difference waves in Fig. 1 reveals the possible contribution of a third component located more posteriorly and centered at 300 ms latency, although no significant interaction



**Fig. 1.** (a) Grand average ERP waveforms for fifteen participants for same-side (dashed) and opposite-side (solid) stimuli at three representative electrode sites. (b) Grand average difference waves (same-side minus opposite-side) for the same participants with the Nd1 and Nd2 latency windows indicated.



**Fig. 2.** Isopotential voltage maps of the topographic distributions (a) for the Nd1 component during the 120–200 ms interval and (b) for the Nd2 component during the 220–260 ms interval. These maps were generated by computing the mean amplitude of the difference wave at 62 sites.

between electrode location and T1 location existed for the 280–320 ms latency interval ( $F(2,28) = 1.39$ ;  $p = 0.27$ ).

## DISCUSSION

The main goals of this study were to investigate the effects of transient spatial attention on neural processing of sound and to determine whether observers momentarily sustain their attention at the location of a behaviourally relevant sound after responding to it. By recording ERPs using a high-density electrode array, we were able to study both the temporal and spatial characteristics of transient spatial attention effects in audition. As in recent spatial cueing experiments [11–14], we did not find any evidence for an early Nd over the fronto-central scalp. At CZ, the T<sub>2</sub>-elicited ERPs on same side and opposite side trials progress in synchrony throughout the P1 and N1 deflections and begin to diverge only at the onset of the P2 component, ~175 ms after stimulus onset. The early modulations of the ERP due to sustained attention are thought to reflect an early selection process; thus the absence of an early, fronto-central Nd in this and other transient auditory attention studies indicates that the configuration of a low-level sensory filter [1,2,6,8] or attentional trace [3,4,7] is relatively slow and requires more time than was provided by the brief interstimulus interval in our paradigm. This notion is consistent with reports that the early Nd is not apparent during the first 30–45 s of a block of sustained attention trials [21,22].

Transient auditory attention did produce clear modulations of the ERP waveforms in the present study. Despite substantial differences in methodology, the Nd waves found here closely resembled those found in earlier spatial cueing studies [11–14]. Both approaches yielded a posterior Nd1 in the 120–200 ms latency window followed by a larger, fronto-central Nd2 in the 200–300 ms latency window. This strongly suggests that these Nd components are

representative of transient auditory attention in general and are not restricted to a specific paradigm or methodology.

Schröger and Eimer [14] suggested that the Nd1 might represent an intermediate level of selection that involves processes concerned with the spatial location of stimuli. However, the functional significance of the Nd1 is still largely unknown. The posterior distribution of this component suggests that it may result from the modulation of sensorineural activity in the parietal cortex. The parietal cortex, specifically the inferior parietal lobule, is thought to be involved in processing of spatial auditory information in humans [23]. The Nd1 might be a consequence of the attentional modulation of spatially tuned auditory neurons in the inferior parietal lobule, neurons that are critical to localizing the target in space. Alternatively, the Nd1 might reflect the modulation or recruitment of neurons in the parietal cortex that are involved in the reorienting of spatial auditory attention when the target occurs at an unattended location. This is consistent with the observation that the Nd1 arises principally on invalid trials rather than valid trials in spatial cueing experiments [14]. It is also consistent with evidence that neurons in the lateral intraparietal sulcus (area LIP) of macaques respond to auditory stimuli at a median latency of 155 ms [24], but only when that stimulus elicits an overt orienting response [25]. According to this view the Nd1 would not reflect a consequence of attentional selection, but instead would be a correlate of the selection mechanism itself.

In contrast to the differences found here between transient and sustained attention at short ERP latencies, the Nd2 was similar in latency and scalp distribution to the late Nd observed in sustained attention studies. This may represent a convergence of the neural processes underlying these two modes of attention. However, the later Nd observed here is likely to be comprised of multiple generators (both frontal and parietal). The functional correlates of these components remain to be investigated.

## CONCLUSION

Selective attention influences the perception of and neural responses to auditory stimuli, whether it is sustained at one location or shifted between locations on a trial by trial basis. There are, however, substantial differences between the electrophysiological underpinnings of these two operating modes of attention, as evidenced by the differential effects on auditory ERPs. Here, we demonstrated that transiently oriented attention has a robust effect on auditory ERPs even in the absence of attentional instructions or cues. Of considerable interest to further explorations of transient auditory attention will be the involvement of parietal cortex, possibly playing a role in the orienting of spatial auditory attention.

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