Effects of auditory distraction on electrophysiological brain activity and performance in children aged 8–13 years

VALENTINA GUMENYUK,a OLEG KORZYUKOV,a KIMMO ALHO,b CARLES ESCERA,c AND RISTO NÄÄTÄNENA

a Cognitive Brain Research Unit, Department of Psychology, University of Helsinki, Finland
b General Psychology Division, Department of Psychology, University of Helsinki, Finland
c Neurodynamics Laboratory, Department of Psychiatry and Clinical Psychology, University of Barcelona, Catalonia, Spain

Abstract

Distractibility was investigated in three age groups of children (8–9, 10–11, and 12–13 years) with event-related brain potentials (ERPs) and performance measures in a forced-choice visual task. Distraction was reflected by increased reaction times (RTs) and decreased performance accuracy in the visual discrimination task following presentation of unexpected novel sounds. The amplitude of the late portion of the P3a elicited by novel sounds was largest for the youngest group and showed a centrally dominant scalp distribution and smallest for the oldest group with a frontal scalp distribution. A frontally dominant late negativity (LN) that was largest in the youngest group followed the P3a. Correlation between the RT increase caused by the distracting novel sounds and the amplitude of the LN elicited by these sounds suggested that the LN is associated with the degree of attention engaged by the distracting sounds.

Descriptors: P3a, Late negativity, Development, Attention, Distraction, Auditory event-related potentials

In his famous passage, William James wrote: “Everyone knows what attention is. ... Focalization, concentration of consciousness are of its essence. It implies withdrawal from some things in order to deal effectively with others, and is a condition which has a real opposite in the confused, dazed, scatterbrained state which in French is called distraction ...” (James, 1890, pp. 403–405). Similarly, Tecce, Savignano-Bowman, and Meinbresse (1976) considered distraction as a process that directs attention toward task-irrelevant stimuli and interferes with the selection of the task-relevant stimuli. Tecce’s criteria for distraction were: (1) evidence that the distracting stimuli have been processed and (2) evidence that the primary task has been impaired.

At the behavioral level, distraction is usually observed as deterioration of performance in the current task caused by stimuli extraneous to the task (Escera, Alho, Winkler, & Näätänen, 1998; Escera, Yago, & Alho, 2001; Grillon, Courchesne, Ameli, Geyer, & Braff, 1990; Woods, 1992). Electrophysiologically, distraction appears to be indicated by the elicitation of the P3a component of the event-related brain potential (ERP) in adults (Escera et al., 1998; Escera, Alho, Schröger, & Winkler, 2000; Knight & Scabini, 1998; Näätänen, 1992; Squires, Squires, & Hillyard, 1975) and in children (Courchesne, 1990; Cycowicz & Friedman, 1997; Gumenyuk et al., 2001). The main advantage of ERPs is that they provide noninvasive information about brain activity with a high time resolution, and for certain categories of subjects such as children, the ERPs are a particular suitable tool for studying the development of cognitive processes.

The association of the P3a with involuntary orienting of attention is suggested by results showing that a large P3a positivity with a fronto-central maximum is elicited by behaviorally distracting environmental novel sounds, such as telephone ringing or dog barking occurring among monotonously repeating tones (Woods, 1992). Previous studies (Alho et al., 1998; Escera et al., 1998; see Escera et al., 2001, for a review) indicated that, in adults, this P3a has two subcomponents: an early P3a (eP3a) component, with its peak latency around 200 ms and a centrally dominant amplitude distribution over the scalp, and a late P3a (lP3a) component, peaking at around 300 ms with a frontal scalp maximum. Thus, the eP3a component overlaps with the P2 component of the auditory ERP, and therefore it might be argued that it was caused by an enhanced (nonrefractory) P2 in response to the physical features of novel sounds (Näätänen & Picton, 1987). However, in combined recordings of ERPs and
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Sokolov, Sprinks, Näätänen, & Lyytinen, 2002). However, Friedman, Cycowicz, & Gaeta, 2001; Knight, 1996; Luria, 1973; events for subsequent behavioral action (Escera et al., 2000; orienting of attention to novel events and evaluation of these in neurological patients (Baudena, Halgren, Heit, & Clarke, 2000). Attenuated P3a responses to novel auditory, visual, and somatosensory stimuli in patients with lesions of the dorsolateral prefrontal cortex provide evidence for the role of the prefrontal cortex in P3a generation (Knight 1984, 1990). This is also supported by intracranial P3a recordings in the prefrontal cortex in neurological patients (Baudena, Halgren, Heit, & Clarke, 1995). Therefore, the P3a to novel stimuli might serve as a probe of frontal lobe functions, especially those associated with orienting of attention to novel events and evaluation of these events for subsequent behavioral action (Escera et al., 2000; Friedman, Cycowicz, & Gaeta, 2001; Knight, 1996; Luria, 1973; Sokolov, Sprinks, Niätäinen, & Lyytinen, 2002). However, elastic sound was either a sinusoidal tone of 600 Hz (50 dB above each participant’s subjective hearing threshold. The 200 ms and was binaurally presented through headphones at the auditory stimuli preceding the visual stimuli were recorded. Auditory–visual stimulus pairs were presented at a constant rate of one pair every 1.7 s (Figure 1). Each sound had a duration of 200 ms and was binaurally presented through headphones at 50 dB above each participant’s subjective hearing threshold. The sound was either a sinusoidal tone of 600 Hz (p = .80) or a complex “novel” sound presented randomly (p = .20) with the exception that at least three tones occurred between any two successive novel sounds. The novel sounds were drawn from a pool of 160 different environmental sounds, such as those produced by a hammer, rain, door, car horn, and so forth. Each novel sound was presented only once during the experiment. The visual stimuli were 32 different white-line drawings (16 animals and 16 nonanimals) extending 9 cm horizontally and 9 cm vertically, presented for 300 ms and starting at 300 ms after the onset of the preceding sound. The visual stimuli were displayed in...
a random order in the center of a black computer screen located approximately 130 cm from the participant’s eyes.

The children were instructed to ignore the sounds, to focus their gaze on a white fixation cross (1 cm × 1 cm) continuously presented in the center of the screen, and to respond in the visual discrimination task as accurately as possible by pressing one response button with their right thumb to an animal image appearing on the screen and another button with their left thumb to a nonanimal image. Before the main experiment, each child participated in one or two practice blocks in the visual task without auditory stimuli. The main experiment consisted of eight 3-min experimental blocks with 1–2 min pauses between the blocks.

Electrode Placement and Recording Techniques
The electroencephalogram (EEG; 0.1–100 Hz, sampling rate 500 Hz) was recorded from frontal (Fp1, Fp2, F7, F3, Fz, F4, and F8), central (C3, Cz, C4), temporal (T3, T4, T5, T6), parietal (P3, Pz, P4), and occipital (O1, O2) scalp sites and from the left and right mastoids (LM and RM, respectively). Voltage changes caused by eye movements and blinks were monitored with recordings from the forehead sites (Fp1, Fp2) and from additional electrodes placed at the left and right canthi. The common reference electrode was placed at the tip of the nose. All impedances were maintained below 10 KΩ. ERPs were obtained separately for the tones and novel sounds by averaging EEG epochs over an 800-ms period starting 100 ms before each sound onset. These EEG epochs were digitally band-pass filtered at 1–30 Hz. Epochs during which extracerebral artifacts caused the EEG or electrooculograms to exceed ±100 µV at any electrode were excluded from further processing. Also, the epochs for the first four stimuli of each block and the epochs for tones occurring right after a novel sound were excluded. For each child, averaged ERPs for tone and novel consisted of at least 380 and 130 acceptable EEG epochs, respectively.

Data Analysis

Behavioral data. A correct button press occurring between 200 and 1,500 ms after visual stimulus onset was classified as a hit. Mean hit reaction times and rates of hits, wrong responses, and response omissions were determined for each child separately for visual stimuli following tones and novel sounds. Calculations of novel minus tone differences in the RTs and in the hit, wrong-response, and omission rates provided an index of the effects of novel sounds on behavior. Statistical significance of between-group differences in these performances was studied with repeated-measures analyses of variance (ANOVAs).

Electrophysiological data. The short 300-ms interval between each sound onset and the onset of the following visual stimulus resulted in an overlap of visual ERPs and the late auditory ERP components elicited at later than 300 ms from sound onset. To remove the effects of visual ERPs from the P3a and LN responses to novel sounds, the P3a and LN amplitudes were measured from ERP difference waves obtained by subtracting ERPs to tones from those to novels (cf. Escera et al., 1998) as mean voltages over 150–250 ms (eP3a), 250–350 ms (lP3a), and 450–550 ms (early LN), and 550–650 ms (late LN) from sound onset in relation to the mean difference-wave amplitude during the 100-ms prestimulus baseline.

The statistical significances of between-group differences in the P3a and LN amplitudes were studied with ANOVAs and Newman–Keuls post hoc tests. An alpha level of .05 was used for all statistical tests. Greenhouse–Geisser corrections were used in reporting p values when appropriate. Moreover, Spearman’s rank–order correlation coefficients were calculated to evaluate the relationship between the effects of novel sounds on the RT and on the amplitudes of difference-wave ERPs.

The scalp distributions of the P3a and LN responses were statistically analyzed after voltage normalization. This normalization was done separately for each child and for each difference wave ERP time range by dividing the amplitude at each electrode by the square root of the sum of the squared amplitudes at all electrodes (McCarthy & Wood, 1985). The normalized ERP amplitudes were compared with four-way ANOVAs including the following factors: Group (young vs. middle vs. old), Phase (early vs. late P3a or LN), Frontality (frontal electrodes F3, Fz, and F4 vs. central electrodes C3, Cz, and C4 vs. parietal electrodes P3, Pz, and P4), and Laterality (left-hemisphere electrodes F3, C3, and P3 vs. midline electrodes Fz, Cz, and Pz vs. right-hemisphere electrodes F4, C4, and P4).

Results

Behavioral Data
All children were highly cooperative and for each child, the percentage of correct responses to the visual stimuli was higher than 70% in each block (Table 1). The high motivation of children to perform the experimental task was also indicated by their genuine interest to their performance level, which was reported to them after each block.

Comparison of the hit rate between the age groups yielded significant group differences, $F(2,21) = 6.49, p < .006$. Subsequent Newman–Keuls tests revealed that while the middle and old groups did not differ significantly from each other, the young
Effects of auditory distraction on children between groups were found. Omissions were low and no significant differences within or between groups showed less correct responses, \( p < .006 \), after novel sounds than the older groups.

In the young group, comparisons of the novel–tone RT and hit-rate differences with zero revealed significant, \( F(1,7) = 5.52, p < .05 \), prolongations of RT and a significant decrease in performance accuracy in the visual task, \( F(1,7) = 34.36, p < .006 \), following novel sounds (see Table 1). In the middle and old groups, such comparisons showed only significant decreases in the hit rate, \( F(1,7) = 7.00, p < .03 \), \( F(1,7) = 13.88, p < .007 \), respectively. The percentages of wrong responses and omissions were low and no significant differences within or between groups were found.

<table>
<thead>
<tr>
<th>Performance</th>
<th>Stimuli</th>
<th>Young Mean (SD)</th>
<th>Middle Mean (SD)</th>
<th>Old Mean (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>RT (ms)</td>
<td>Novel</td>
<td>530 (162)</td>
<td>546 (150)</td>
<td>515 (114)</td>
</tr>
<tr>
<td></td>
<td>Tone</td>
<td>497 (134)</td>
<td>493 (96)</td>
<td>458 (110)</td>
</tr>
<tr>
<td></td>
<td>Difference</td>
<td>33 (28)</td>
<td>53 (54)</td>
<td>57 (4)</td>
</tr>
<tr>
<td>Hit rate (%)</td>
<td>Novel</td>
<td>77 (11)</td>
<td>88 (9)</td>
<td>89 (7)</td>
</tr>
<tr>
<td></td>
<td>Tone</td>
<td>81 (9)</td>
<td>91 (8)</td>
<td>92 (6)</td>
</tr>
<tr>
<td></td>
<td>Difference</td>
<td>-4 (2)</td>
<td>-3 (1)</td>
<td>-3 (1)</td>
</tr>
<tr>
<td>Wrong-response rate (%)</td>
<td>Novel</td>
<td>9 (5)</td>
<td>5 (3)</td>
<td>4 (2)</td>
</tr>
<tr>
<td></td>
<td>Tone</td>
<td>7 (9)</td>
<td>4 (4)</td>
<td>3 (1)</td>
</tr>
<tr>
<td></td>
<td>Difference</td>
<td>2 (4)</td>
<td>1 (1)</td>
<td>1 (1)</td>
</tr>
<tr>
<td>No-response rate (%)</td>
<td>Novel</td>
<td>14 (11)</td>
<td>7 (14)</td>
<td>7 (8)</td>
</tr>
<tr>
<td></td>
<td>Tone</td>
<td>12 (10)</td>
<td>5 (13)</td>
<td>5 (6)</td>
</tr>
<tr>
<td></td>
<td>Difference</td>
<td>2 (1)</td>
<td>2 (1)</td>
<td>2 (2)</td>
</tr>
</tbody>
</table>

Note: Difference = novel minus tone.

Figure 2 displays the grand-averaged ERPs elicited by the auditory–visual stimulus pairs. In the middle and old groups, both tones and novels elicited an auditory N1 component peaking around 100 ms from sound onset. The young group showed a very small auditory N1, presumably due to immaturity of the auditory cortex (Courchesne, 1990; Ponton et al., 2002). However, the visual N1 response was quite prominent in all age groups. A P3a response was elicited by novel sounds in each age group.

Figure 3a presents the frontal (Fz) and vertex (Cz) novel–tone ERP difference waves averaged across the subjects for each age group. In the young group, the early phase of P3a (eP3a) peaked at 180 ± 30 ms, in the middle group at 170 ± 45 ms, and in the old group at 200 ± 25 ms. The late phase of P3a (lP3a) had respective peak latencies of 315 ± 30, 309 ± 32, and 311 ± 27 ms after novel sound onset. There were no significant between-group differences in the latencies of eP3a or lP3a.

Significant Group × Phase × Frontality, \( F(4,42) = 3.27, p < .02 \), and Phase × Frontality interactions, \( F(2,42) = 31.36, p < .001 \), revealed by ANOVAs for the eP3a and lP3a amplitudes (measured over 150–250 ms and 250–350 ms, respectively) indicated that the eP3a was largest over the fronto-central scalp in all groups and inverted in polarity over the posterior and temporal scalp areas (Figure 3b), whereas the lP3a did not invert its polarity and showed distribution differences between the groups (Figures 3b and 4). A further comparison of the lP3a amplitude at Cz electrode yielded significant differences between the young, middle, and old groups (9.4 µV vs. 8.7 µV vs. 5.4 µV, respectively, \( F(2,21) = 3.59, p < .04 \), and subsequent Newman–Keuls tests revealed that the lP3a amplitude was significantly smaller, \( p < .05 \), in the old than the young or middle groups, whereas there was no significant difference in the IP3a amplitude between the young and middle groups (see Figures 3b and 4).

In all groups, a frontally dominant LN at the latency of 400–700 ms followed the P3a (Figure 3). The young group showed a larger LN amplitude than the middle and the old groups (mean amplitude measured over the F4, Fz, and F3 electrodes at 450–650 ms: -6.6 µV, -3.6 µV, and -2.7 µV, respectively, \( F(2,21) = 6.26, p < .01 \), whereas there was no significant difference between the middle and the old groups.

**Correlations between ERPs and Performance**

In the young group, there was a significant negative correlation between the novel–tone RT difference and the amplitude of the late phase LN (measured over 550–650 ms, \( r = -0.8, p < .04 \) at the frontal (F3, Fz, and F4) electrodes, that is, the larger (more negative) the late LN the larger the RT prolongation caused by novel sounds (Figure 5). The middle and old groups showed no such correlations between behavioral indices and ERPs.

**Discussion**

In line with previous studies on ERPs to novel sounds in adults (Alho et al., 1998; Escera et al., 1998; Friedman & Simpson, 1994; Knight, 1984) and children (Gumenyuk et al., 2001), the present study in the 8–13-year-olds showed a P3a response that might be associated with Pavlov’s “What-is-it” orienting/
investigative response (Ruff & Rothbart, 1996; Sokolov, Sprinks, Näätänen, & Lyytinen, 2002). Orienting has been described as including a passive shift of attention away from the current task (Öhman, 1979). In the present study, such a shift of attention was caused by novel sounds, as indicated by the prolongation of RT and decrease in the performance accuracy in the visual task following novel sounds. The present results also corroborate the recent studies in adults (Escera et al., 1998) and children (Gumenyuk et al., 2001) showing that the P3a is a composite response with two different phases: an early P3a (eP3a) and late P3a (lP3a), which was followed by the late negativity (LN). Horizontal EOG was recorded with electrodes attached to the left (LEOG) and right (REOG) canthi. (b) P3a and LN scalp-distribution maps for each group of children. The maps demonstrate average voltage at 200 ms (early P3a), 300 ms (late P3a), 500 ms (early phase of LN), and 600 ms (late phase of LN). Small open circles on the schematic scalp depict locations of electrodes; large filled circles depict the Fz and Cz electrode positions.

Moreover, the late P3a can be distinguished from the P300 or P3b component to target stimuli by its shorter latency and more frontal scalp distribution (Ford, Roth, & Kopell, 1976; Squires et al., 1975).

The orienting/investigate system quickly develops during the first year of life and leads infants to be particularly responsive to novelty (Richards, 1988). However, responsiveness to novelty is linearly decreased in the amount of attention devoted to novel events during familiarization and habituation procedures, possible because children learn about such events more and more quickly (Colombo, Freeseman, Coldren, & Frick, 1995). Present ERP results suggest age-related differences in orienting to novel sounds: The late P3a was largest in the young group and smallest in the old one. Thus, our data suggest that activity of orienting system caused by environmental novel sounds develops...
at least until 13 years in children with a normal developmental course of attentional functions.

Another late component that has been linked with distraction processes is the frontally distributed LN (latency approximately 400–700 ms), which could be an index of the reorienting of diverted attention back to the task-relevant stimulus after temporary distraction [reorienting negativity (RON); Schröger & Wolff, 1998]. In adults, the RON has been interpreted as reflecting the reorienting of attention back to the main/current task after behavioral distraction (Berti & Schröger, 2001; Escera et al., 2001; Schröger & Wolff, 1998). The LN response observed in the young children of present study can also be explained in this context. A correlation between the RT prolongation and LN might indicate that reorienting attention back to the visual task after distracting sounds is more effortful in the young children than in older ones.

Alternatively, the LN response might reflect some other processes, for example, those related to the further evaluation of the distracting sounds (Nääätänen, Simpson, & Loveless, 1982). Whatever is the current interpretation to the LN in children, like the P3a, the LN response was decreased in amplitude with age, which might be due to different capabilities in controlling attention in different age groups. Such an assumption corresponds to the developmental literature (Pearson & Lane, 1990), which suggests age-related development in auditory reorienting ability in children from 8 to 11 years, whereas 11-year-old children already have nearly adult-level reorientation ability.

In conclusion, the present study suggests that the brain responses related to the processing of distracting novel information might reflect an age-related ability to resist switching of attention to distracting events and to keep attention focused on the main task in a distracting environment.

REFERENCES


(RECEIVED August 29, 2002; ACCEPTED May 29, 2003)