

## Age-related differences in distraction and reorientation in an auditory task

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### Abstract

Behavioral and event-related potential measures of distraction and reorientation were obtained from children (6 years), young (19–24 years) and elderly adults (62–82 years) in an auditory distraction-paradigm. Participants performed a go/nogo duration discrimination task on a sequence of short and long (50–50%) tones. In children, reaction times were longer and discrimination ( $d'$ ) scores were lower than in adults. Occasionally (15%), the pitch of the presented tones was changed. The task-irrelevant feature variation resulted in longer reaction times and lower  $d'$  scores with no significant differences between the three groups. Task-irrelevant changes affected the N1 amplitude and elicited the mismatch negativity, N2b, P3 and reorienting negativity (RON) sequence of event-related brain potentials. In children, the P3 latency was the same as in young adults. However the RON component was delayed by about 100 ms. In the elderly, P3 and RON were uniformly delayed by about 80 ms compared to young adults. This pattern of results provides evidence that distraction influences different processing stages in the three groups. Restoration of the task-optimal attention set was delayed in children, whereas in the elderly, the triggering of involuntary attention-switching required longer time.

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### 1. Introduction

In many everyday situations, maintaining high-level performance in a given task requires focusing on the task-relevant aspects of the environment while disregarding the irrelevant ones. Although goal-directed behavior is primarily governed by top-down control, infrequent unpredictable events are automatically detected (Näätänen, 1992) and can trigger an orienting response (Sokolov, 1963; Schröger, 1997). Orienting towards unexpected task-irrelevant stimuli is advantageous in an evolutionary sense, because these may carry information that is crucial for survival. However, distraction from one's current task usually leads to tempo-

rary deterioration of performance in that task (Escera et al., 2000).

Normal functioning of the cognitive system is characterized by a good balance between maintenance of goal-directed behavior and involuntary orientation (passive attention, James, 1890; Escera et al., 2000). The balance, however, shifts during maturation and aging. Children and elderly adults are more susceptible to distraction than young adults, a fact often attributed to weaker inhibition efficiency related to immature or deteriorated frontal lobe functions (Van der Molen, 2000; Hasher et al., 2007). However, several processes participate in the distraction-orientation-refocusing cycle and, therefore, changes occurring in the course of human life may affect different functions involved in the interplay between voluntary and passive attention.

In the present study, we investigated processes contributing to goal-directed and orienting-related activities in three age-groups (early school-age children, young and elderly

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adults) with the goal to assess the effects of development and aging on the various processes.

### 1.1. A three-stage model of distraction

Current understanding of the interplay between distraction caused by unexpected events and control processes governing goal-directed behavior can be described in the framework of a *three-stage model of distraction* (Escera et al., 2000; Friedman et al., 2001; Näätänen, 1990, 1992; Polich and Criado, 2006; Schröger, 1997; Schröger and Wolff, 1998b).

The *first* stage of the model features processes, which continuously monitor and “model” the temporal aspects of the sensory environment without the involvement of voluntary control processes (Schröger, 1997; Näätänen, 1990; Winkler, *in press*). Modeling the environment is mainly based on the extraction of regularities from recent stimulation, whereas monitoring is based on the detection of discrepancies between the predictions of the model and incoming stimuli (Winkler, *in press*; Winkler et al., 1996). Regularity extraction and deviance-detection is an economic solution to the monitoring problem, as it minimizes the demand on capacity-limited control processes in relatively stable environmental stimulus configurations. Small deviations from the detected regularities usually lead to model-updates, which can be handled within the first processing stage (Näätänen and Winkler, 1999; Winkler, *in press*; Winkler et al., 1996). In contrast, major deviations can trigger higher-order processes leading to an involuntary change in the allocation of attention (Näätänen, 1990; Schröger, 1997; Escera et al., 1998). That is, gradual changes in the environment occurring over a longer period of time may go unnoticed, whereas the same change occurring rapidly may catch one’s attention.

The processes of involuntary attention-switching constitute the *second stage* of the distraction model. Distraction is understood as a transition from a selective attention set which is optimal with respect to performing a given task, to a different, probably suboptimal set (with respect to performing the original task), which might allow for more efficient processing of the distracting task-irrelevant event (Escera et al., 2000; Polich, 2003; Schröger et al., 2000).

Processes at the *third stage* of the model are responsible for restoring the optimal attention-set for the task at hand (reorientation), that is, they directly subserve the voluntary re-establishing of the selective attention set appropriate for the primary task (Munka and Berti, 2006). These processes probably take place only if the task is still relevant at the point when the distracting event has been evaluated. Response execution based on task-relevant information may take place before as well as after the optimal attention-set has been restored.

In summary, the first stage can be described as filtering the task-irrelevant stimulation with automatic identification of events that violate the detected sensory regularities. Such events may trigger the involuntary attention-switching mechanisms of the second stage. The third stage encompasses

mechanisms that compensate the effects of involuntary orientation to task-irrelevant aspects of the environment by restoring the task-optimal attention-set.

### 1.2. ERP correlates of the three processing stages

The three-stage model receives important support from the analysis of event-related potentials (ERPs) elicited in the *oddball* paradigms. In the oddball paradigm, occasional irregular stimuli are presented within the sequence of a repeating stimulus. The repeating stimulus is termed the *standard*, whereas the stimuli violating the repetition are termed *deviants*. The ERPs elicited in the oddball paradigm reflect many of the processes taking place during the three stages of the distraction-orientation-refocusing cycle. Some of the ERP components are elicited whether or not attention is directed towards the oddball stimulus sequence (corresponding to automatic/involuntary stimulus processing), other ERP components are elicited mainly when participants perform a task related to the oddball sequence. We start our description of the distraction-related ERP components with the ERP components elicited irrespective of the direction of focused attention, which are typically studied in the passive task condition in which participants perform a task that is not related to the oddball sequence.

In the *passive* oddball paradigm, deviants elicit the modality-specific (auditory, visual and somatosensory) mismatch negativity (MMN), peaking 100–200 ms after the onset of deviance (Czigler et al., 2002; Näätänen et al., 1978; Shinozaki et al., 1998). As MMN can be elicited even if participants do not attend the stimuli, it is assumed to reflect a pre-attentive deviance detection process (Näätänen, 1990; Sussman et al., 2003b). In terms of the three-stage model, MMN reflects an important process in the first stage, one which detects irregular unattended stimuli.

In paradigms utilizing easily discriminable, salient deviants, MMN is often followed by the P3a, a fronto-central positivity peaking at about 300 ms (Friedman et al., 2001) from deviation onset. However, P3a-like activity can also be elicited without a preceding MMN (Rinne et al., 2006), e.g., by rare salient stimuli. P3a is assumed to reflect the activation of an attention-switching mechanism, which is an important step of involuntary orienting of attention (Escera et al., 2000; Friedman et al., 2001; Knight and Scabini, 1998; Schröger, 1996). Thus P3a would index processes in the second stage of the distraction model. However, there is no general consensus on the precise role of the P3a *within* the second processing stage (see Dien et al., 2004).

In *active* oddball paradigms (in which participants perform a task related to the stimulus sequence) a number of additional components can be observed.

When the oddball sequence is attended, MMN is overlapped/ followed by the N2b component peaking around 200 ms (Näätänen and Gaillard, 1983; Ritter and Ruchkin, 1992). N2b probably reflects a modality-specific process: the controlled registration of the occurrence of an infrequent

deviant tone (as opposed to its automatic detection reflected by the MMN, see Ritter et al., 1992).

The N2b is followed by the P3 components, which typically peak between 300 and 400 ms (for a recent review, see Polich and Criado, 2006). Apart from the already mentioned fronto-central P3a, a centro-parietal, later P3-variant, termed P3b, is elicited when the participant is required to respond to a target deviant. When the discrimination of the target and standards is easy, the P3 component is characterized by a central topography, however, difficult discrimination tasks result in later and more parietal P3b. It has been proposed, that P3b reflects a memory function, which maintains and updates the working-memory representation of the stimulus context on the occurrence of the deviant (Donchin and Coles, 1988, but see Verleger, 1988).

When a task-irrelevant deviant distracts the participant from the primary task, a late frontal negativity is elicited 400–600 ms after the onset of the deviation (Schröger et al., 2000; Schröger and Wolff, 1998a,b). As this component is thought to reflect recovery from distraction, it is referred to as Reorienting Negativity (RON). The processes indexed by RON constitute the third stage of the distraction model. A similar negativity termed *late difference negativity* (LDN, for a summary, see Cheour et al., 2001) is often found in children in passive oddball paradigms. LDN may be homologous to the reorienting negativity (RON, Wetzel et al., 2006) or reflect higher-order processing of sound change (Čeponienė et al., 2004).

### 1.3. A simple paradigm for studying distraction

The present study presented a variation of the stimulus paradigm designed by Schröger and Wolff (1998a,b). Therefore this paradigm is described in detail in the following.

Distraction is often studied using a variation of the oddball paradigm, in which stimuli vary in two features, one task-relevant and the other task-irrelevant. Participants perform a two-alternative choice or Go/NoGo task on every trial based on the task-relevant property of the stimuli (e.g. stimulus duration). The two levels of the task-relevant feature are presented equiprobably. In contrast, the task-irrelevant feature (e.g. pitch) is delivered with unequal probabilities as in an oddball paradigm (e.g., 90% of one level, the standards and 10% of the other level, the deviants).

Differences in the processing of deviants and standards are manifested both by ERPs and by indices of task performance. Compared to standards, deviants elicit negativities in the 100–250 ms post-stimulus interval (N1 effect [Näätänen and Picton, 1987; Jacobsen et al., 2003], MMN, and N2b) followed by the P3a (300–400 ms) and RON (400–600 ms). Responses to deviants are delayed compared to standards, and participants make more mistakes on deviant trials.

The notion that RON reflects the recovery of the task-optimal attention set (reorientation) is supported by results of Sussman et al. (2003a), who have shown that a visual cue reliably signaling the occurrence of the deviant feature

(the level of the task-irrelevant stimulus feature) eliminates both P3a and RON. This finding can be interpreted as the suppression of the distracting effect of the expected deviant event. Furthermore, larger deviance results in higher P3 and RON amplitudes (Yago et al., 2001). RON exhibits the same topography for visual and auditory stimuli, which suggests that the underlying process is modality-independent (Berti and Schröger, 2001). Escera et al. (2001) suggested that RON is the sum of two subcomponents: one is time-locked to the onset of the deviation, and the other is time-locked to the onset of the target.

### 1.4. Effects of maturation and aging on distraction-related ERPs and behavioral indices

For a summary on developmental changes in attention-related ERP components see Ridderinkhof and van der Stelt (2000).

MMN latency and amplitude seems to decrease (or at least not increase) with growing age (Csépe, 1995; Kraus et al., 1993; Kurtzberg et al., 1995; Lang et al., 1995) in children. It has to be noted that MMN elicitation is often less robust in children when deviance-magnitudes are small (see Rääkkönen et al., 2003). Even positive deviant-minus-standard differences in the MMN latency range were found (see Morr et al., 2002; Maurer et al., 2003), probably due to an overlap of the P3a (Kushnerenko et al., 2002).

It is generally found that the latency of P3 decreases with growing age in children up to an age of about 9–10 years (see, e.g. Zenker and Barajas, 1999; Batty and Taylor, 2002).

Distraction-related behavioral and ERP-effects in 5–6 year old children were found to be generally similar to that of in adults in the Schröger-Wolff-paradigm (Wetzel et al., 2004), however, Wetzel et al. (2006) showed that the distraction-related response-delay decreased with age (across 6–9, 10–13, and 19–29 year old groups of participants). These authors found no age-related P3a effects, but the RON amplitude was smaller in 6–9 year old than in 10–13 year old children. RON elicitation was also delayed by about 70 ms in the 10–13 year old group compared to young adults. Wetzel et al. (2006) also found that P3a and RON were elicited even in a passive condition in children but not in adults, which may imply that RON and the LDN are the same component. In school-age children, Gumenyuk et al. (2001) found that deviants (occasional novel environmental sounds embedded in a sequence of pure-tone standards) elicited an early and a late P3 with 200 and 300 ms peak latency, respectively. The early but not the late P3 (probably P3a) exhibited a polarity inversion at the mastoids suggesting that its generators lie in the auditory cortex. P3 was followed by a late negativity (RON), which was larger in younger (7–10 years) than older (11–13 years) children.

In the elderly, the MMN amplitude is often lower than in young adults (e.g. Bertoli et al., 2002; Cooper et al., 2006; Czigler et al., 1992; Gaeta et al., 1998; Jääskeläinen et al., 1999; Woods, 1992; but see Amenedo and Diaz, 1998b,

Pekkonen et al., 1996). N2b elicitation is delayed in the elderly (Amenedo and Diaz, 1998a,b). It has been shown that P3a and P3b is delayed and elicited with lower amplitude in the elderly (see, e.g. Polich, 1997; Czigler et al., 2006; Fjell and Walhovd, 2004). Mager et al. (2005) found that the P3 was delayed in middle-aged adults compared to young adults, but there was no difference in the RON-latency. Response-delays to deviants did not differ between the two groups. In an auditory-visual distraction paradigm (odd-even categorization task for visually presented numbers with a synchronous auditory oddball sequence), Andrés et al. (2006) found a larger behavioral distraction-effect for the elderly than for young adults. However, age-related increase of distraction effects is not unequivocal (for a review see Madden and Langley, 2003).

The present study investigated distraction and reorientation-related processes as indexed by behavioral and ERP measures in early school-age children, young and elderly adults using an auditory distraction paradigm. The uniqueness of the present approach is that the same paradigm was used in all three age groups, thereby allowing a direct comparison between the response patterns.

## 2. Methods

### 2.1. Participants

Three groups participated in the experiment: a group of early school-age children, a group of young adults and a group of elderly adults. The study was approved by the Ethical Committee of the Institute for Psychology of the Hungarian Academy of Sciences.

Forty children from the 103 low-social risk, middle-class Hungarian families of the longitudinal Budapest Infant–Parent Study (Lakatos et al., 2000) participated in the experiment at the age of 6 years (24 boys and 16 girls). Signed informed consent was obtained from the parents for participating in the experiment. The children had normal hearing as reported by their parents. Due to too low number of artifact-free epochs (less than 25 epochs in at least one stimulus category), data from 22 children were excluded from the analysis leaving 9 boys' and 9 girls' data to be analyzed. The relatively high rejection rate was mainly the result of the children losing interest in performing the task, which led to aborting the experiment earlier in a number of cases. In other cases an exceeding number of movement and ocular artifacts led to too low numbers of artifact-free epochs.

Nine young adults (5 females, 19–24 years of age, mean 21.2 years) were recruited through a part-time job agency. Nine elderly participants (7 females, 62–82 years of age, mean 68.4 years) were recruited through advertisements in newspapers. None of the participants reported any history of neurological problems, and they did not take medications affecting the central nervous system. Participants gave written informed consent after the nature of the experiment was

Table 1

Mean absolute hearing threshold levels (and standard deviations) in the young and elderly adult groups

|         | Mean absolute threshold (dB SPL) |                  |                   |                   |                   |
|---------|----------------------------------|------------------|-------------------|-------------------|-------------------|
|         | 250 <sup>a</sup>                 | 500 <sup>a</sup> | 1000 <sup>a</sup> | 2000 <sup>a</sup> | 4000 <sup>a</sup> |
| Young   | 11.1 (5.2)                       | 14.7 (6.9)       | 8.3 (5.1)         | 10.8 (3.6)        | 10.6 (5.6)        |
| Elderly | 14.7 (6.9)                       | 12.2 (4.7)       | 12.5 (4.3)        | 15.0 (5.3)        | 25.6 (18.0)       |

<sup>a</sup> Frequency (Hz)

explained to them. Before the experiment, participants' hearing was assessed with an audiometer (Mediroll SA-5, see Table 1). Only data from participants with pure-tone frequency thresholds not higher than 20 dB SPL in the frequency range used in the experiment (636–2310 Hz) were analyzed. No pathological asymmetry (i.e., a threshold difference of 15 dB or more) was found between the two ears in any of the participants. For 250 and 500 Hz, *t*-test with separate variance estimates showed no significant differences between the two adult groups ( $t[16] = 1.26$ ;  $p = 0.22$ ;  $t[16] = 0.82$ ;  $p = 0.42$ ). At 1000 and 2000 Hz, a tendency was found ( $t[16] = 1.86$ ;  $p < 0.1$ ;  $t[16] = 1.96$ ;  $p < 0.1$ ), whereas at 4000 Hz, the difference was significant ( $t[16] = 2.39$ ;  $p < 0.05$ ), showing better hearing in the young adult group.

### 2.2. Stimuli and procedure

Tone sequences were presented through loudspeakers positioned symmetrically 40 cm from the left and right sides of the participants' head. The sequences consisted of complex tones with three harmonic components. The frequencies (and relative intensities) of the three components were 700 Hz (0 dB), 1400 Hz (−3 dB), and 2100 Hz (−6 dB) for the standards (85%); 636 Hz (0 dB), 1272 Hz (−3 dB), and 1908 Hz (−6 dB) for the low deviants (7.5%); and 770 Hz (0 dB), 1540 Hz (−3 dB), 2310 Hz (−6 dB) for the high deviants (7.5%). The intensity of the tones was 68 dB (A-weighted) measured at the head. The duration of the stimuli was 150 (target, short) and 600 ms (non-target, long), both including 2.5–2.5 ms rise/fall times. The stimulus onset asynchrony (SOA) was 1600 ms.

Participants were instructed to listen to the tones and press a response button (held in their right hand) as fast as possible for short but not for long tones (a Go/NoGo task). After each stimulus block, participants were informed about their performance (overall hit and false alarm rates).

The sequences were pseudo-randomized with the following constraints: (1) deviants were always followed by at least one standard tone. (2) No micro-sequences longer than three stimuli with the same duration were allowed (thus for example, after three short tones, the fourth tone was always a long tone). These “predictable” tones (i.e. the tones immediately following a micro-sequence of three short or long tones) were always standards. This manipulation was necessary to maintain the applicability of the paradigm in children, who tended to repeat the same response after a longer repetitive sub-



sequence in a pilot experiment. These constraints were not explicitly revealed to the participants.

For young and elderly participants 12 stimulus blocks were presented, whereas 5–10 blocks were presented to the children, depending upon how long they kept their interest in the experiment. Each stimulus block consisted of 104 stimuli.

### 2.3. Behavioral analysis

Responses to standard trials immediately following a deviant trial, and predictable trials (see constraint 2, above) were excluded from the analyses. Only responses in the 200–1500 ms interval following the onset of the short stimuli were accepted as correct. Reaction times and  $d'$  values were calculated for each stimulus type, separately.  $d'$  values were corrected when the hit or false alarm rate was 1 or 0 by replacing it with  $1 - (1/2N)$  or  $1/2N$ , respectively (where  $N$  is the number of targets, i.e., the number of short stimuli) to avoid infinite values in the calculations (Macmillan and Creelman, 1991). Measurements were analyzed by ANOVAs using the factors: group (elderly, young adults and children) and stimulus type (deviant and standard). All significant effects are described in Section 3.

### 2.4. EEG recording and analysis

EEG was recorded using Ag/AgCl electrodes with a Synamps amplifier (Neuroscan Inc.), DC-40 Hz. The sampling rate was 250 Hz.

For children, the electrodes were attached to the Fz, Cz positions according to the 10–20 system, and the left and right mastoids (Lm and Rm, respectively). Vertical and horizontal eye-movements were monitored with an electrode attached to the FPz location (10–20 system) and an electrode attached near the outer canthus of the right eye, respectively.

For the young and elderly adult participants, electrodes were placed at the F3, Fz, F4, C3, Cz, C4, P3, Pz, P4 locations (10–20 system) and the left and right mastoids (Lm and Rm, respectively). Horizontal eye-movements were monitored with a bipolar montage of two electrodes placed lateral to the outer canthi of the two eyes; vertical eye-movements were monitored with electrodes placed above and below the right eye.

The common reference electrode was placed on the tip of the nose for all participants.

EEG was bandpass filtered offline (2–20 Hz). Epochs were 1200 ms long, including 200 ms pre-stimulus interval. The average signal amplitude measured during the 200 ms pre-stimulus interval was used as the baseline value. Epochs with the signal range exceeding 100  $\mu$ V on any channel as well as epochs with temporally adjacent sampling points showing a voltage difference exceeding 12  $\mu$ V on any channel (corresponding to a temporal derivative of 3  $\mu$ V/ms) were discarded from the analyses. Epochs corresponding to short and long standards and short and long deviants were averaged separately. Epochs corresponding to standards immediately

following a deviant, and to predictable stimuli were excluded from the analysis. Difference waveforms were calculated by subtracting from the deviant response the one elicited by the corresponding standard, separately for short and long tones.

Based on previous results (see Section 1), we assumed that the deviant-minus-standard difference waveform would exhibit negativities between 100 and 250 ms, followed by positivities in the 300–450 ms and late negativities in the 400–600 ms interval. These were identified on the group average difference waveforms. The amplitude of each component was measured as the average signal in a 40 ms long window centered on the highest peak of the given component in the group-average waveform.

Amplitudes were statistically analyzed separately for short (target, i.e., Go) and long (non-target, i.e., No-Go) stimuli by ANOVAs of stimulus type (deviant and standard)  $\times$  electrode. For children, Fz, Cz, Lm and Rm leads, for adults F3, Fz, F4, C3, Cz, C4, P3, Pz, P4, Lm and Rm leads were included in the analyses. A subsequent ANOVA was carried out separately for each group comparing the deviant-minus-standard difference waveforms between short (target, i.e., Go) and long (non-target, i.e., No-Go) stimuli. Subtracting responses elicited by stimuli of identical duration and target status eliminates the ERP responses directly related to sound duration and target status in the task while retaining the electric brain responses elicited by distraction. Therefore, this comparison reveals interactions between distraction and duration/target status. For the analysis of peak latencies, individual peaks were identified and their latency measured. In those participants (mostly in children), whose response showed multiple peaks in the measurement interval, the peak closest to the group average peak was measured. Peak latency analysis of the N2 component elicited by standards was carried out in a mixed, group (young adults and elderly adults)  $\times$  duration (short and long) ANOVA. P3- and RON-latencies were analyzed in a mixed, group (children, young adults and elderly adults)  $\times$  component (P3, RON) ANOVA for short tones. Greenhouse–Geisser corrections were applied where appropriate. Partial  $\eta^2$  are reported. All significant effects are described in the following section.

## 3. Results

### 3.1. Behavioral data

Group-average reaction times calculated from the onset of the tones, hit rates, false alarm rates and  $d'$ s are presented in Table 2.

The group  $\times$  stimulus type ANOVA of reaction times showed a main effect of group:  $F(2,33) = 21.10$ ,  $p < 0.001$ ,  $\eta^2 = 0.56$ ; and a main effect of stimulus type:  $F(1,33) = 25.73$ ,  $p < 0.001$ ,  $\eta^2 = 0.44$ . Tukey HSD test showed that children's responses were slower than those of the other two groups ( $p < 0.001$  for both comparisons), but there was no significant RT difference between the young and elderly groups.

Table 2

Mean reaction times, hit rates, false alarm rates and  $d'$  scores for standards and deviants (and the corresponding standard deviations) in the child, young and elderly adult groups

|                | Reaction time (ms) |           | Hit rate (%) |         | False alarm rate (%) |         | $d'$        |             |
|----------------|--------------------|-----------|--------------|---------|----------------------|---------|-------------|-------------|
|                | Stand.             | Dev.      | Stand.       | Dev.    | Stand.               | Dev.    | Stand.      | Dev.        |
| Children       | 704 (87)           | 739 (90)  | 86 (9)       | 78 (18) | 12 (11)              | 14 (13) | 2.56 (0.85) | 2.11 (0.69) |
| Young adults   | 518 (108)          | 552 (123) | 99 (2)       | 98 (3)  | 1 (1)                | 2 (2)   | 5.24 (0.71) | 4.50 (0.68) |
| Elderly adults | 504 (59)           | 550 (61)  | 99 (1)       | 99 (1)  | 1 (1)                | 1 (1)   | 5.30 (0.60) | 4.71 (0.39) |

The stimulus type effect showed that responses were slower for deviants.

The group  $\times$  stimulus type ANOVA of the  $d'$ s showed a main effect of group:  $F(2,33) = 76.23$ ,  $p < 0.001$ ,  $\eta^2 = 0.82$ ; and a main effect of stimulus type:  $F(1,33) = 31.54$ ,  $p < 0.001$ ,  $\eta^2 = 0.49$ . Tukey HSD test showed that children's  $d'$  was significantly lower than that of the other two groups ( $p < 0.001$  for both comparisons), but no significant difference was found between the young and elderly groups. The stimulus type effect showed that  $d'$ s were lower for deviants.

In summary, responses were slower and  $d'$  was lower for deviants than for standards, but the deviant versus standard differences did not differ between the groups (as no interactions were found between the factors), even though children showed, in general, lower performance rates and slower reaction times than the two adult groups of participants. Since the lack of group differences for the distraction effects may be somewhat surprising, individual response patterns for short standard and deviant sounds are illustrated in Fig. 1.

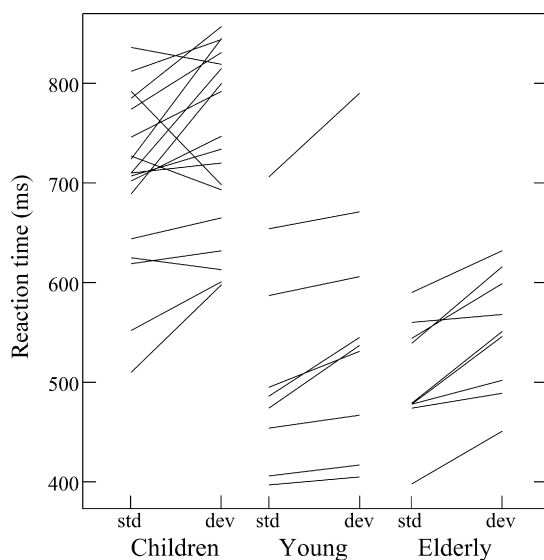


Fig. 1. Mean reaction times for target (short) standards and deviants separately for each participant (children: left; young adults: center; elderly participants: right). Reaction times were measured from the onset of the target tones (i.e., subtract 150 ms to refer it to the moment when the target could be detected). Each line represents data from a single participant, the left endpoint denoting the mean RT for standards, the right endpoint the mean RT for deviants.

### 3.2. ERPs

An overview of the group average ERP waveforms is presented in Fig. 2. Responses elicited by short and long deviants are separately overplotted by those to standards at midline electrodes and the average of the mastoid signals (CM). Fig. 2 shows that although there are many differences in the timing and amplitude of the ERP responses between the three groups, the general configuration of the ERPs show marked similarities. In all three groups, the first part of the response shows a fronto-central positive-negative-positive succession of peaks, all of which show polarity reversal at the mastoid leads. In general, the ERP responses in children appear to have a simpler structure than those in adults. It is interesting to note that the offset of long tones elicited a much more pronounced response in children than in adults. Because our aim was to study the effects of distraction, our analysis will be guided by the deviant-minus-standard difference responses shown in Fig. 3.

The deviant-minus-standard difference waveforms (Fig. 3) showed a similar temporal pattern in all three groups: early negativity or negativities peaking between 100 and 300 ms are followed by a positivity between 250 and 400, and one or more late negativities between 400 and 600 ms. When comparing with the original group averages (Fig. 2) the similarities between the difference waveforms for the three groups are indeed remarkable.

#### 3.2.1. Children

In children, we found two early negative differences peaking at 180 and 240 ms, and a positive difference peaking at 344 ms (Fig. 3, left column). The late negative difference peaked earlier for long tones (at 492 ms) than for short tones (at 560 ms). As all of these components showed some degree of polarity reversal at the mastoids (see Fig. 3, left column), separate ANOVAs were calculated for the fronto-central and the mastoid signals.

**3.2.1.1. N160-200.** For short tones, the stimulus type (standard and deviant)  $\times$  electrode (Fz and Cz) ANOVA showed significant stimulus type and electrode main effects:  $F(1,17) = 5.92$ ,  $p < 0.05$ ,  $\eta^2 = 0.26$ ; and  $F(1,17) = 19.14$ ;  $p < 0.001$ ,  $\eta^2 = 0.53$ , respectively. The similar ANOVA for the mastoids, stimulus type (standard and deviant)  $\times$  electrode (Lm and Rm), did not show any significant effect. For long

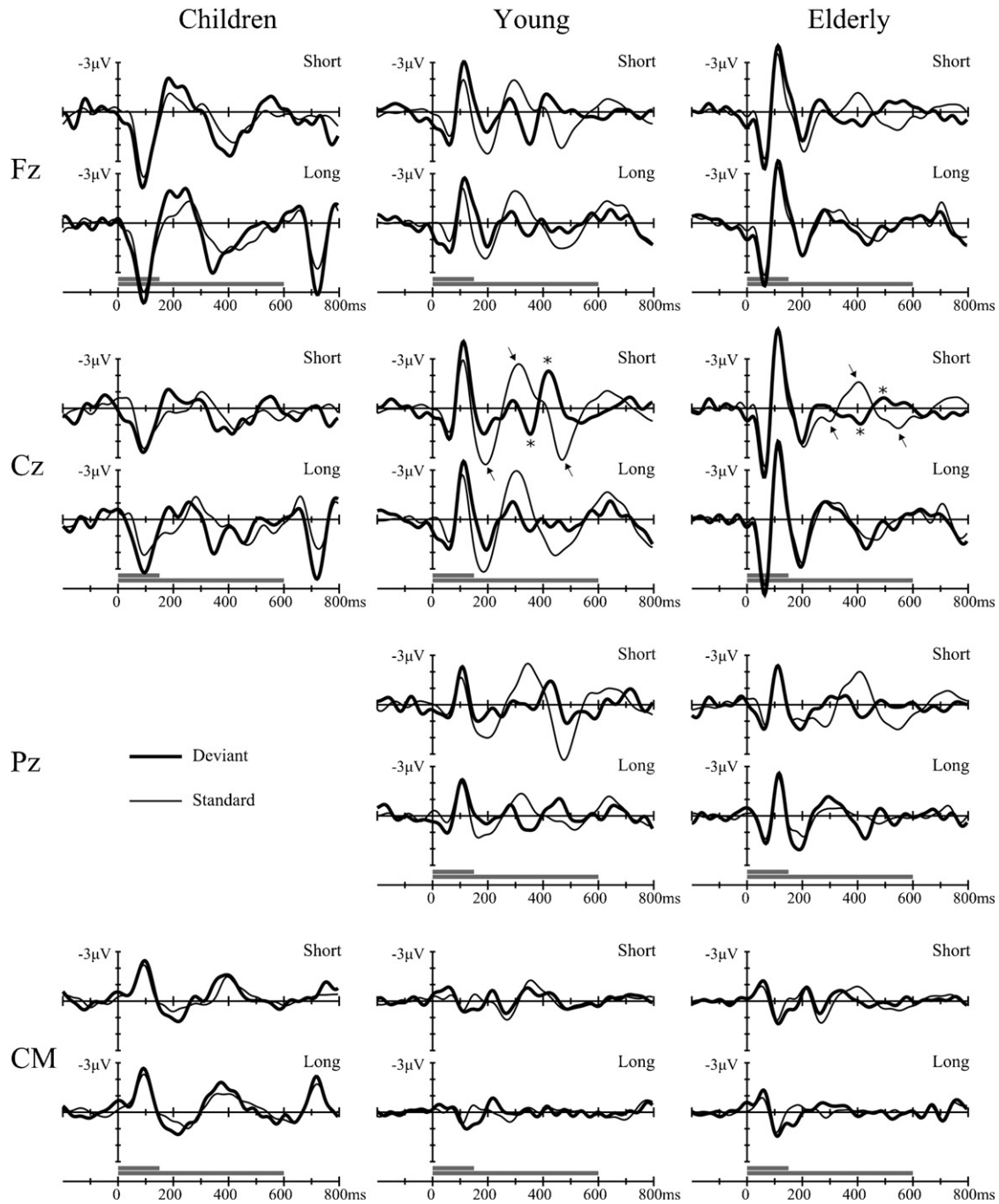


Fig. 2. Group-averaged ERP waveforms for short and long deviants and standards elicited at the Fz, Cz, Pz leads, and the average of the left and right mastoid electrodes (CM) in the three groups. The gray horizontal bars on the rulers denote the timing and duration of the short and long tones. On the Cz leads, arrows indicate the peaks of the ERP waveform elicited by short standards, which is stipulated to be homologous in the two groups, despite an 80 ms delay in the elderly. Similarly, asterisks indicate the homologous ERP waveforms elicited by short deviants in both groups.

tones, the fronto-central ANOVA showed significant stimulus type and electrode main effects:  $F(1,17)=7.34, p<0.05, \eta^2=0.30$ ; and  $F(1,17)=14.74; p<0.01, \eta^2=0.46$ , respectively. The ANOVA for the mastoids showed a main effect of stimulus type:  $F(1,17)=5.19, p<0.05, \eta^2=0.23$ .

The fronto-central and mastoid ANOVAs conducted on the deviant-minus-standard difference measurements, duration (short and long)  $\times$  electrode (Fz and Cz) and duration (short

and long)  $\times$  electrode (Lm and Rm) showed no significant effects.

In summary, in children, a significant fronto-central negative deviant-minus-standard difference was found in the 160–200 ms latency range at both tone durations. The polarity inversion on the mastoids was significant only for long tones. These results may indicate an N1-like increment for infrequent pitch in children as well as the elicitation of the

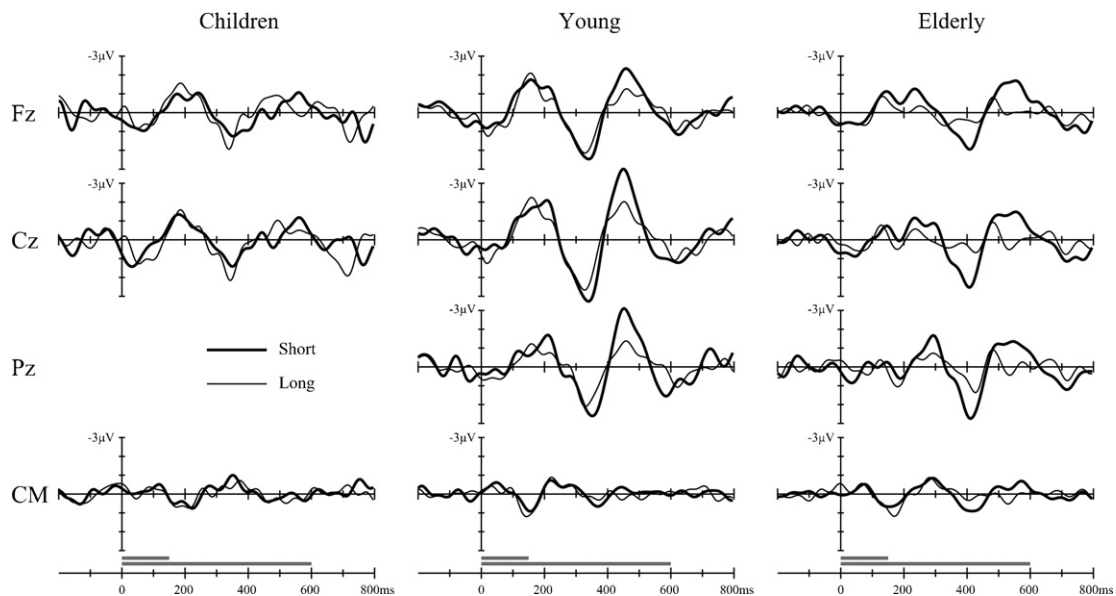


Fig. 3. Group-averaged deviant-minus-standard difference waveforms for short and long tones elicited at the midline, and the average of the left and right mastoid electrodes (CM) in the three groups. The gray horizontal bars on the rulers denote the timing and duration of the short and long tones.

MMN component. Although N1 is not yet fully developed in 6-year old children, the latency of the first negative peak matches that of the observed significant difference. On the other hand MMN has been consistently observed in this age group.

**3.2.1.2. N220-260.** For short tones, the fronto-central ANOVA showed a tendency for the stimulus type main effect  $F(1,17)=3.26$ ,  $p=0.09$ ,  $\eta^2=0.16$ ; and a significant electrode main effect:  $F(1,17)=10.77$ ,  $p<0.01$ ,  $\eta^2=0.39$ . At the mastoids, the ANOVA yielded a significant stimulus type  $\times$  electrode interaction  $F(1,17)=4.68$ ,  $p<0.05$ ,  $\eta^2=0.22$ . Post hoc Tukey-HSD tests revealed that the deviant response at Lm differed from all the other responses ( $p<0.05$  for the two signals on Rm, and  $p<0.01$  for the standard on Lm). For long tones, the fronto-central ANOVA showed a tendency for the stimulus type main effect  $F(1,17)=3.15$ ,  $p=0.09$ ,  $\eta^2=0.16$ ; and a significant electrode main effect:  $F(1,17)=30.43$ ,  $p<0.001$ ,  $\eta^2=0.64$ . The mastoid ANOVA brought no significant effects.

The ANOVAs conducted on the difference waveforms yielded a significant difference between the two mastoid leads  $F(1,17)=6.30$ ,  $p<0.05$ ,  $\eta^2=0.27$ .

In summary, a statistical tendency was found for the elicitation of a second negative difference response with some asymmetry at the mastoid leads.

**3.2.1.3. P324-364.** For short tones, the fronto-central ANOVA showed a main effect of stimulus type:  $F(1,17)=4.66$ ,  $p<0.05$ ,  $\eta^2=0.21$ , and a main effect of electrode:  $F(1,17)=5.05$ ,  $p<0.05$ ,  $\eta^2=0.23$ . At the mastoids, the ANOVA showed a stimulus type main effect:  $F(1,17)=7.98$ ,  $p<0.05$ ,  $\eta^2=0.32$ ; and an interaction between the two factors:  $F(1,17)=5.72$ ,  $p<0.05$ ,  $\eta^2=0.35$ .

For long tones, the fronto-central ANOVA showed a main effect of stimulus type:  $F(1,17)=7.44$ ,  $p<0.05$ ,  $\eta^2=0.30$ , and a main effect of electrode:  $F(1,17)=24.10$ ,  $p<0.001$ ,  $\eta^2=0.59$ , whereas the ANOVA for the mastoid yielded no significant result.

For the deviant-minus-standard difference waveforms, no significant fronto-central effects were found, however, the ANOVA of the mastoid signals showed only a tendency for interaction:  $F(1,17)=3.94$ ,  $p=0.06$ ,  $\eta^2=0.19$ .

In summary, short and long deviants elicited a fronto-central positive component, which can be identified as a P3a. Polarity inversion at the mastoids was significant only for short tones.

**3.2.1.4. N472-512 (long tones) and N 540-580 (short tones).** The deviant-minus-standard difference waveforms for short and long tones exhibited a late negativity with different latencies (see Fig. 3, left column). For short tones the fronto-central ANOVA showed a tendency for a main effect of stimulus type:  $F(1,17)=4.00$ ,  $p=0.06$ ,  $\eta^2=0.19$ , whereas the mastoid ANOVA yielded no significant effect. For long tones the fronto-central ANOVA showed a main effect of stimulus type:  $F(1,17)=4.51$ ,  $p<0.05$ ,  $\eta^2=0.21$ , whereas the ANOVA of the mastoid signals revealed only a tendency for an electrode main effect  $F(1,17)=4.27$ ,  $p=0.05$ ,  $\eta^2=0.20$ .

Due to the different latencies, no ANOVAs were conducted for comparing the late negativities across the different stimulus durations.

In summary, the long deviants elicited a significant fronto-central negativity in the 472–512 ms interval, but only a statistical tendency was found for the similar but later (540–580 ms) negative difference observable in for short stimuli. These negativities are considered as the RON component.



### 3.2.2. Young adults

In young adults, the first negative deviant-minus-standard difference showed a polarity reversal at the mastoids (peak at 156 ms), whereas the second one did not (208 ms). The positive difference following them peaked at 336 ms and the late negativity at 452 ms (Fig. 3, central column).

**3.2.2.1. N136–176.** For short tones, the ANOVA of the fronto-central responses, stimulus type  $\times$  electrode (F3, Fz, F4, C3, Cz and C4) showed a stimulus type main effect:  $F(1,8)=52.01$ ,  $p<0.01$ ,  $\eta^2=0.87$ ; and an electrode main effect:  $F(5,40)=4.99$ ,  $\varepsilon=0.47$ ,  $p<0.05$ ,  $\eta^2=0.38$ . The ANOVA of the mastoid signals, stimulus type  $\times$  electrode (Lm and Rm) ANOVA showed a stimulus type main effect:  $F(1,8)=16.06$ ,  $p<0.01$ ,  $\eta^2=0.67$ ; and a tendency for an interaction between the two factors:  $F(1,8)=4.99$ ,  $p=0.06$ ,  $\eta^2=0.38$ . For long tones, the fronto-central ANOVA showed a stimulus type main effect:  $F(1,8)=36.94$ ,  $p<0.01$ ,  $\eta^2=0.82$ , an electrode main effect:  $F(5,40)=5.13$ ,  $\varepsilon=0.48$ ,  $p<0.05$ ,  $\eta^2=0.39$ , as well as a significant interaction between the two factors:  $F(5,40)=4.56$ ,  $\varepsilon=0.53$ ,  $p<0.05$ ,  $\eta^2=0.36$ . The mastoid ANOVA showed only a stimulus type main effect:  $F(1,8)=56.43$ ,  $p<0.001$ ,  $\eta^2=0.88$ .

The fronto-central ANOVA conducted for the deviant-minus-standard difference waveforms, duration (short and long)  $\times$  electrode (F3, Fz, F4, C3, Cz and C4) yielded a main effect of electrode  $F(5,40)=3.77$ ,  $\varepsilon=0.49$ ,  $p<0.01$ ,  $\eta^2=0.32$ , whereas the similar ANOVA for the mastoid responses showed only a tendency for a main effect of electrode  $F(1,8)=4.03$ ,  $p=0.08$ ,  $\eta^2=0.33$ .

In summary, compared with standards, both deviants elicited significant additional fronto-central negativity in the 136–176 ms interval, which appeared with inverted polarity at the mastoids. This deviant-minus-standard difference probably sums together contributions from the N1 generators and the MMN component.

**3.2.2.2. N188–228.** The negativity observable on the deviant-minus-standard difference waveform at 188–228 ms showed a wide centrally dominant distribution (Fig. 3, central column) without polarity reversal at the mastoids. Therefore, all EEG channels were analyzed together. For short tones, the stimulus type (standard and deviant)  $\times$  electrode ANOVA (F3, Fz, F4, C3, Cz, C4, P3, Pz, P4, Lm and Rm) showed a stimulus type main effect:  $F(1,8)=16.13$ ,  $p<0.01$ ,  $\eta^2=0.67$ ; an electrode main effect:  $F(10,80)=13.73$ ,  $\varepsilon=0.20$ ,  $p<0.001$ ,  $\eta^2=0.63$ ; and a significant interaction  $F(10,80)=5.13$ ,  $\varepsilon=0.23$ ,  $p<0.05$ ,  $\eta^2=0.39$ . For long tones a stimulus type main effect:  $F(1,8)=9.45$ ,  $p<0.05$ ,  $\eta^2=0.54$ ; and an electrode main effect:  $F(10,80)=12.83$ ,  $\varepsilon=0.18$ ,  $p<0.001$ ,  $\eta^2=0.62$  were obtained.

The ANOVA of the deviant-minus-standard difference waveforms, duration (short and long)  $\times$  electrode (F3, Fz, F4, C3, Cz, C4, P3, Pz, P4, Lm and Rm), ANOVA showed a significant main effect of duration  $F(1,8)=8.86$ ,  $p<0.05$ ,  $\eta^2=0.52$  ( $-1.41 \mu\text{V}$  (0.36) for short;  $-0.80 \mu\text{V}$  (0.29) for

long stimuli); a tendency for a main effect of electrode  $F(10,80)=3.06$ ,  $\varepsilon=0.24$ ,  $p=0.06$ ,  $\eta^2=0.28$ ; and a tendency for interaction  $F(10,80)=2.84$ ,  $\varepsilon=0.30$ ,  $p=0.06$ ,  $\eta^2=0.26$ .

In summary, the central negative difference in the 188–228 ms interval was significant for both stimulus durations. The amplitude of the component was significantly higher for short tones than for long ones. Based on its latency and scalp distribution, we identify this component as N2b.

**3.2.2.3. P316–356.** The positivity peaking between 316 and 356 ms in the deviant-minus-standard difference waveform showed a central distribution with almost no signal at the mastoid leads, which were, therefore, removed from the analysis (Fig. 3, central column). For short tones, the stimulus type (standard and deviant)  $\times$  electrode (F3, Fz, F4, C3, Cz, C4, P3, Pz and P4) ANOVA showed a stimulus type main effect:  $F(1,8)=57.99$ ,  $p<0.001$ ,  $\eta^2=0.88$ ; an electrode main effect:  $F(8,64)=6.31$ ,  $\varepsilon=0.25$ ,  $p<0.001$ ,  $\eta^2=0.44$ ; and a significant interaction  $F(8,64)=4.45$ ,  $\varepsilon=0.32$ ,  $p<0.001$ ,  $\eta^2=0.36$ . For long tones, we found a stimulus type main effect:  $F(1,8)=28.48$ ,  $p<0.001$ ,  $\eta^2=0.78$ ; a tendency for an electrode main effect:  $F(8,64)=4.04$ ,  $\varepsilon=0.28$ ,  $p=0.07$ ,  $\eta^2=0.27$ ; and an interaction:  $F(8,64)=3.79$ ,  $\varepsilon=0.30$ ,  $p<0.01$ ,  $\eta^2=0.32$ .

For the deviant-minus-standard difference waveforms, the duration (short and long)  $\times$  electrode (F3, Fz, F4, C3, Cz, C4, P3, Pz and P4) ANOVA showed a main effect of duration  $F(1,8)=7.81$ ,  $p<0.05$ ,  $\eta^2=0.49$ ; and a main effect of electrode  $F(8,64)=6.06$ ,  $\varepsilon=0.34$ ,  $p<0.001$ ,  $\eta^2=0.43$ .

In summary, the positive P3 component was elicited by both deviants with its amplitude higher for short than for long tones.

**3.2.2.4. N432–472.** The negativity peaking between 432 and 472 ms in the deviant-minus-standard difference waveform showed a central distribution with almost no signal at the mastoid leads, which were, therefore, removed from the analysis (Fig. 3, central column). For short tones, the ANOVA showed a stimulus type main effect:  $F(1,8)=78.6$ ,  $p<0.001$ ,  $\eta^2=0.91$ ; and an interaction between the factors  $F(8,64)=6.48$ ,  $\varepsilon=0.28$ ,  $p<0.01$ ,  $\eta^2=0.45$ . For long tones, we found a stimulus type main effect:  $F(1,8)=5.57$ ,  $p<0.05$ ,  $\eta^2=0.41$ ; an electrode main effect:  $F(8,64)=7.11$ ,  $\varepsilon=0.23$ ,  $p<0.05$ ,  $\eta^2=0.47$ ; and an interaction:  $F(8,64)=4.37$ ,  $\varepsilon=0.30$ ,  $p<0.05$ ,  $\eta^2=0.35$ .

For the deviant-minus-standard difference waveforms, the ANOVA yielded a main effect of duration  $F(1,8)=11.39$ ,  $p<0.01$ ,  $\eta^2=0.59$ ; and an electrode main effect:  $F(8,64)=9.38$ ,  $\varepsilon=0.34$ ,  $p<0.001$ ,  $\eta^2=0.54$ .

In summary, significant negativity, the RON component was elicited with higher amplitudes for short than for long tones.

Both P3 and RON was elicited with higher amplitudes for short tones. From Fig. 1, it appears that the higher amplitudes in response to short tones was brought about by the elicitation of a biphasic waveform starting with a positive peak at

about 350 ms and followed by a negative peak at about 420 ms (these are marked by asterisks on the Cz lead in Fig. 2). This biphasic response cannot be seen in the responses to long tones.

### 3.2.3. Elderly adults

In the elderly adults, three early negativities could be observed in the deviant-minus-standard difference. The first peak (136 ms) was frontal and showed a polarity reversal at the mastoids. The second (236 ms) was also frontal, but showed no polarity reversal, and it was more prominent for the short tones. The third (292 ms) peak exhibited a posterior distribution. The following positive difference (420 ms) was parietal, and its amplitude was higher for short tones. In the interval of the late negativity two peaks could be observed. Though the first peak (480 ms) was present for both durations, the second (550 ms) was present only for short tones (Fig. 3, right column).

**3.2.3.1. N 116-156.** For short tones, the ANOVA of the frontal responses, stimulus type  $\times$  electrode (F3, Fz and F4) showed a stimulus type main effect:  $F(1,8) = 6.58, p < 0.05, \eta^2 = 0.45$ . The ANOVA of the mastoid signals, stimulus type  $\times$  electrode (Lm and Rm) showed a stimulus type main effect:  $F(1,8) = 8.85, p < 0.05, \eta^2 = 0.52$ ; and an interaction:  $F(1,8) = 10.03, p < 0.05, \eta^2 = 0.56$ . For long tones, the stimulus type  $\times$  electrode (F3, Fz and F4) ANOVA showed a tendency for a stimulus type main effect:  $F(1,8) = 4.47, p = 0.07, \eta^2 = 0.36$ . The stimulus type  $\times$  electrode (Lm and Rm) ANOVA showed a stimulus type main effect:  $F(1,8) = 34.39, p < 0.001, \eta^2 = 0.81$ .

For the deviant-minus-standard difference waveforms, the duration  $\times$  electrode (F3, Fz, F4, C3, Cz, C4, P3, Pz and P4) ANOVA showed a main effect of electrode  $F(8,64) = 6.67, \epsilon = 0.25, p < 0.01, \eta^2 = 0.45$ . The ANOVA on the mastoids showed a tendency for a main effect of electrode  $F(1,8) = 5.24, p = 0.05, \eta^2 = 0.40$ .

In summary, short deviants elicited a significant additional frontal negativity, which inverted polarity at the mastoids. For long tones, the statistical tendency found for the elicitation of the frontal part of the component and the significant positivity at the mastoids indicated the possibility of MMN emergence. However, MMN elicitation in this age-group was not particularly robust.

**3.2.3.2. N 216-256.** This deviant-minus-standard negativity exhibited a fronto-central distribution (see Fig. 3, right column), without polarity reversal at the mastoids. For short tones, the ANOVA of the fronto-central responses, stimulus type  $\times$  electrode (F3, Fz, F4, C3, Cz and C4) showed a stimulus type main effect:  $F(1,8) = 5.43, p < 0.05, \eta^2 = 0.40$ . For long tones, the stimulus type  $\times$  electrode (F3, Fz, F4, C3, Cz and C4) ANOVA showed no significant effects.

For the deviant-minus-standard difference waveforms, the duration  $\times$  electrode (F3, Fz, F4, C3, Cz and C4) ANOVA showed no significant effects.

In summary, compared to standards, short deviants elicited a negativity in the 216–256 ms interval, whereas long deviants did not.

**3.2.3.3. N 272-312.** This negativity showed a posterior distribution on the group-average deviant-minus-standard difference waveform (see Fig. 3, right column). For short tones, the ANOVA of the posterior responses, stimulus type  $\times$  electrode (P3, Pz, P4, Lm and Rm) showed a stimulus type main effect:  $F(1,8) = 6.78, p < 0.05, \eta^2 = 0.46$ . For long tones, the stimulus type  $\times$  electrode (P3, Pz, P4, Lm and Rm) ANOVA showed a tendency for a stimulus type main effect:  $F(1,8) = 4.55, p < 0.1, \eta^2 = 0.36$ ; and a tendency for an electrode main effect:  $F(4,32) = 3.79, \epsilon = 0.33, p < 0.1, \eta^2 = 0.32$ .

For the deviant-minus-standard difference waveforms, the duration  $\times$  electrode (P3, Pz, P4, Lm and Rm) ANOVA showed a tendency for an interaction  $F(4,32) = 2.64, \epsilon = 0.61, p < 0.1, \eta^2 = 0.25$ .

In summary, short deviants elicited a parietal negativity in the 272–312 ms interval compared to standards, whereas long deviants showed only a tendency for the elicitation of the component.

**3.2.3.4. P 400-440.** This deviant-minus-standard positivity showed a broad central distribution (see Fig. 3, right column). For short tones, the stimulus type  $\times$  electrode ANOVA (F3, Fz, F4, C3, Cz, C4, P3, Pz and P4) showed a significant stimulus type main effect:  $F(1,8) = 14.51, p < 0.01, \eta^2 = 0.64$ , and a tendency for an electrode main effect:  $F(8,64) = 2.72, \epsilon = 0.26, p < 0.1, \eta^2 = 0.25$ . For long tones, the stimulus type  $\times$  electrode ANOVA showed a significant stimulus type main effect:  $F(1,8) = 6.73, p < 0.05, \eta^2 = 0.46$ ; and a tendency for an interaction  $F(8,64) = 3.29, \epsilon = 0.21, p < 0.1, \eta^2 = 0.29$ .

For the deviant-minus-standard difference waveforms, the duration  $\times$  electrode (F3, Fz, F4, C3, Cz, C4, P3, Pz and P4) ANOVA showed a duration main effect:  $F(1,8) = 5.31, p = 0.05, \eta^2 = 0.40$ .

In summary, both short and long deviants elicited a significant positivity (P3) compared to standards, which had higher amplitude for short tones than for long ones.

**3.2.3.5. N 460-500.** This negativity can be seen as a single peak for long tones, and as the first peak of a double-peaked deflection for short tones (see Fig. 3, right column). For short tones, the stimulus type  $\times$  electrode (F3, Fz, F4, C3, Cz, C4, P3, Pz and P4) ANOVA did not show significant effects. For long tones, however, a stimulus type main effect:  $F(1,8) = 5.50, p < 0.05, \eta^2 = 0.41$ ; and an electrode main effect:  $F(8,64) = 3.75, \epsilon = 0.19, p < 0.1, \eta^2 = 0.32$  was found.

For the deviant-minus-standard difference waveforms, the duration  $\times$  electrode (F3, Fz, F4, C3, Cz, C4, P3, Pz and P4) ANOVA did not show significant effects.

In summary, whereas long deviants elicited a significant negativity compared to standards, short deviants did not elicit

a significant negativity in the 460–500 ms interval. This component can be considered as the early part of the RON.

**3.2.3.6. N 532-572.** This negativity in the deviant-minus-standard difference waveform can be observed only for the short tones (see Fig. 3, right column). For short tones, the stimulus type  $\times$  electrode (F3, Fz, F4, C3, Cz, C4, P3, Pz and P4) ANOVA showed a stimulus type main effect:  $F(1,8) = 7.97$ ,  $p < 0.05$ ,  $\eta^2 = 0.50$ . For long tones, the stimulus type  $\times$  electrode (F3, Fz, F4, C3, Cz, C4, P3, Pz and P4) ANOVA showed no significant effects.

For the deviant-minus-standard difference waveforms, the duration  $\times$  electrode (F3, Fz, F4, C3, Cz, C4, P3, Pz and P4) ANOVA showed a duration main effect:  $F(1,8) = 6.45$ ,  $p < 0.05$ ,  $\eta^2 = 0.45$ ; and a tendency for an electrode main effect:  $F(8,64) = 2.30$ ,  $\epsilon = 0.46$ ,  $p < 0.1$ ,  $\eta^2 = 0.22$ .

In summary, short tones elicited a significant negativity (late RON) in the 532–572 ms interval compared to standards, whereas long ones did not.

### 3.2.4. Latency-effects

Two prominent ERP latency effects were observed. The first was a latency difference between ERP components elicited by standard tones. In both groups of adults, long standards elicited a positive component peaking at about 200 ms from stimulus onset, followed by a fronto-central negativity peaking at about 300 ms and by a fronto-central positivity peaking between 400 and 500 ms (Fig. 2, central and right columns). In young adults, this positive–negative–positive wave-complex was elicited by short standards as well, with two differences: (1) the second and third components of the wave-complex exhibited centro-parietally maximal scalp distribution, and (2) they were delayed by about 30 ms compared to the response elicited by long tones (Fig. 2, central column, Cz lead, peaks marked with arrows). In the elderly adults, this wave-complex elicited by short standards featured centro-parietal components similar to those in the young adults. However, the delay from the response to long tones was more substantial in the elderly than in the young adults, approximately 80–100 ms (Fig. 2, right column, Cz lead, peaks marked with arrows). For the latency-analysis, the negative component of the wave-complex was used. The group (young and elderly)  $\times$  stimulus-duration (short and long) ANOVA of the peak latency showed a group main effect:  $F(1,16) = 10.57$ ,  $p < 0.01$ ,  $\eta^2 = 0.40$ ; a duration main effect:  $F(1,16) = 31.70$ ,  $p < 0.001$ ,  $\eta^2 = 0.66$ ; and an interaction:  $F(1,16) = 12.72$ ,  $p < 0.01$ ,  $\eta^2 = 0.44$ . Post hoc Tukey-HSD tests revealed that the wave-complex was significantly delayed in the elderly for short standards ( $p < 0.001$ ; a mean of 420 ms vs. 329 ms [long standard elderly adults], 305 [short standard in young adults], and 325 ms [long standard for young adults]; the standard error was 15 ms for all the four means).

The second group of latency differences was observed in the group-average difference waveforms. The P3 and the following late negativities (RON) showed different temporal patterns in the three groups. In children, the peak

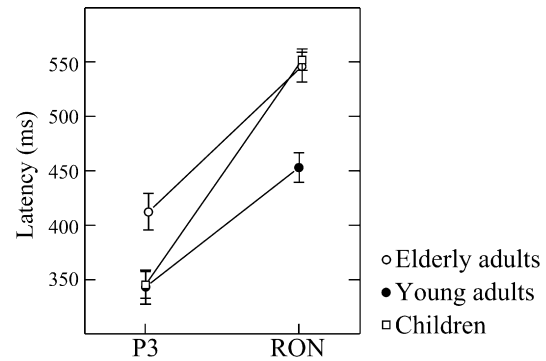


Fig. 4. Group-averaged P3 and RON peak latencies for short tones (standard error of mean marked) in the three groups of participants.

latency of the P3 was similar to that of the young adults, but RON was delayed by about 100 ms. In the elderly participants, both components were uniformly delayed by about 100 ms compared to the young adults. Since the elicitation of both components was more robust for short tones in both groups of subjects, the analysis of the individual latencies was carried out for short tones only. Fig. 4 shows that P3 was elicited later in the elderly compared with the other two groups, whereas RON was elicited earlier for young adults than for the other two groups. The temporal separation between P3 and RON was similar in both adult groups. The group (children, young adults and elderly adults)  $\times$  component (P3 and RON) ANOVA showed a group main effect:  $F(2,33) = 8.76$ ,  $p < 0.001$ ,  $\eta^2 = 0.35$ ; a component main effect:  $F(1,33) = 532.20$ ,  $p < 0.001$ ,  $\eta^2 = 0.94$ ; and an interaction between the two factors:  $F(2,33) = 24.90$ ,  $p < 0.01$ ,  $\eta^2 = 0.60$ . A post hoc Tukey-HSD test revealed that there were significant differences for all comparisons ( $p < 0.05$  at least), except for P3 between the children and the young adults, RON between the children and the elderly adults, between the P3 elicited in the elderly group and the RON elicited in the young adult group (i.e., the elderly P3 latency was close to the young-adult RON latency).

## 4. Discussion

### 4.1. Behavioral results

We found that children's responses were generally slower and they produced more errors in the discrimination than the two adult groups did. Nevertheless, distraction effects as measured by reaction time increase and  $d'$  decrease did not differ across the three groups. It has to be noted, that the child group included only those children from the sample who did not prematurely lose interest in performing the task.

Comparing younger and older adults, our results confirm the results of Mager et al. (2005), who found comparable behavioral distraction effects for young and middle-aged adults in a paradigm similar to the present one. On the other hand, behavioral measures showed increased distractibility

in the elderly in the auditory-visual version of the distraction paradigm (Andrés et al., 2006). In this study, participants performed odd-even categorization of visually presented digits. On standard trials, the digits were preceded by a sinusoid tone, whereas on deviant trials, the digits were preceded by novel environmental sounds. One possibility is that the age-effect found by Andrés et al. was due to the higher saliency of the environmental sounds compared with the deviants used in the Mager et al. (2005) and the present study. It is also possible that the involvement of higher-order-processing (e.g. semantic processing) in the odd–even discrimination of Andrés et al. (2006) contributed to the aging effect on behavioral distraction. Increased sensitivity to distractors has often been found with aging (e.g. Brink and McDowd, 1999; Connelly et al., 1991; Maylor and Lavie, 1998; Phillips and Lesperance, 2003). However Madden and Langley (2003) note that the relationship between age and distractibility is rather complex.

One explanation of the lack of both general and distraction-related RT effects between young and elderly adults is that our task was optimized for 6-year-old children. That is, the difference between the two task-relevant stimulus categories was large and stimulus presentation was slow. In short, this was a very easy task (at least for adults). Thus young adults did not have an advantage over elderly participants, because performance was at a ceiling level in both groups (see Table 2). The advantage of this aspect of the performance data is that ERP differences between the groups are not confounded by differences in the number of errors and error-related compensatory processes. On the other hand, the fact that the task was probably too easy for young adults, may have resulted in larger freedom in this group in terms of the response criteria (i.e., the lack of time pressure allowed a more leisurely attitude of performing the discrimination) and, possibly, lower motivation for some participants. Signs of these effects can be observed on the individual response patterns (see Fig. 1), which shows that two of the young adults responded generally slower than any of the elderly participants. However, it should be noted that the RT effects of distraction did not differ as a function of the overall response speed, including even the group of children, whose responses were significantly slower than that measured in either group of adults. Thus the distraction-related ERP results represent genuine processing differences between the three groups.

With respect to the comparison of children and young adults, the present results are compatible with those of Wetzel et al. (2006), who found a greater distraction-related reaction time increase in children than in young adults with 20% frequency separation between the standard and deviant sounds, but not when the difference was only 5%. The pitch difference was 10% in the present study. Thus, it appears that children are more sensitive to highly salient changes than young adults (for corroborating evidence from newborn babies, see Kushnerenko et al., 2007), possibly similarly to the elderly. The observed magnitude of distraction-related

hit-rate decrease (8%) in children was also similar to the one found by Wetzel et al.

#### 4.2. Distraction-related ERP differences

ERPs elicited in children were morphologically different from those of the adults, as could be expected from previous research (Vaughan and Kurtzberg, 1992). There are also slight changes in the obligatory ERP components with aging (e.g. Czigler et al., 2006; Federmeier and Kutas, 2005), although these are much smaller than those between children and adults. Despite these differences, the deviant-minus-standard difference waveforms exhibited strikingly similar patterns in all three age groups, i.e., negativities between 100 and 300 ms were followed by a positive difference between 300 and 450 ms and one or more late negativities in the 400–600 ms interval.

##### 4.2.1. Negativities between 100 and 300 ms (N1/MMN and N2b)

In all three age groups, the deviant-minus-standard difference waveforms exhibited fronto-central negativities in the 100–300 ms interval. The earliest of these peaks showed polarity inversion at the mastoids for all groups. Since the auditory N1 and MMN usually show similar polarity-reversal at the mastoids (both generators lying in auditory cortex, see Scherg et al., 1989), the observed early negative deviant-minus-standard difference can be identified as summing an N1 difference caused by lower refractoriness for the deviant pitch and the MMN elicited by pitch deviance. In young and elderly adults, the N1/MMN wave was followed by an N2b response. In the elderly, deviant targets also elicited a later (292 ms) parietal negativity.

##### 4.2.2. Positivity between 300 and 450 ms (P3)

P3 was elicited in the 300–450 ms interval in all three groups of participants. In children, the frontal positivity showed a polarity inversion at the mastoids for short tones. This is in line with previous findings of Gumenyuk et al. (2001), and suggests prolonged auditory processing for deviants, which may be also caused by overlapping offset-related activity in the present study. In young adults a slightly larger central positivity was elicited by short tones than by long ones. In the elderly, the component peaked about 80 ms later than in young adults and children, showed a more parietal distribution (see Fig. 1, right column), and its amplitude was substantially higher for short than for long tones. The centro-parietal scalp distribution suggests contribution from P3b generators with more parietal distribution in the elderly bringing up the possibility that the task was more demanding for the elderly participants than for the young adults (Polich and Criado, 2006).

##### 4.2.3. Negativities between 400 and 600 ms (RON)

RON was observed in all three age groups. In young adults, RON was elicited at both stimulus durations, although it was



larger for short (target) than for long (non-target) tones. In children and elderly adults, short (target) and long (non-target) deviants elicited RONS with a latency difference of about 60 ms. The late peak (corresponding to short tones) was observable in both groups approximately 100 ms later than in young adults, but its amplitude was only marginally significant in children, whereas it was significant in the elderly. A number of previous studies observed RON in children using similar distraction paradigms (e.g. [Wetzel et al., 2004, 2006](#); [Gumenyuk et al., 2001](#)). Therefore, it is reasonable to assume that this marginally significant negativity elicited in the RON time range is indeed a RON response. Higher variability (lower signal-to-noise ratio) of the signals measured in children (compared with that in adults) made detection of this relatively small response less reliable.

#### 4.3. *The locus of age-related distraction effects with respect to the three-stage model*

Whereas P3 and RON were shifted by approximately the same amount of time in the elderly compared to young adults (i.e. the temporal separation between P3 and RON was the same in both groups), P3 in children coincided with that in young adults, but RON was delayed by approximately 100 ms (at least for target deviants). This pattern of results supports the notion that P3 and RON reflect different processes. Moreover, this suggests that deviants exert differential effects at different stages in the three groups. Compared to young adults, deviants differently affected the third stage of processing of the distraction model in children, as was revealed by the delayed and less robust RON. That is, restoration of the optimal attention set commenced later in 6-year-old children. One may speculate that maintaining controlled processes for extended periods of time is more difficult for children than for young adults. In contrast, in the elderly, deviants differently affected processes of the second stage of the distraction model compared to young adults, as was shown by the uniform delay of P3 and RON (compared to young adults). Thus it appears that in the elderly, triggering the attention-switching mechanism takes longer. As a possibility, the effect of stimulus features outside the task-set could be weaker in elderly ([Czigler et al., 2006](#)). Another explanation is that older adults compensate for increased distractibility by stronger focusing of their attention, thus making it more difficult for the task-irrelevant stimulus information to break through (cf. the next section).

#### 4.4. *Dissociation between behavioral and ERP results*

Whereas behavioral performance indices are virtually identical between young and elderly adults, after ca. 200 ms from the onset of short standard tones, the ERPs elicited in elderly subjects exhibit a ca. 80 ms latency delay compared to young adults (compare the waves marked with arrows between the central and the right column of [Fig. 1](#)). Despite the fact that these components were elicited 80–100 ms ear-

lier in young adults, reaction times did not differ between the two groups. The same 80–100 ms delay was observed for P3 and RON (at least for target tones; see the previous section and [Fig. 2](#)) between the young and elderly group; in children, RON was elicited by target tones ca. 100 ms later than in young adults.

However, the magnitude of the behavioral distraction-effects did not differ between the three groups. The dissociation between behavioral and ERP results probably stem from the fact that the task left room for performance compensation for elderly participants (see the discussion of task-related issues in [Section 4.1](#)). It is thus possible that some young participants did not react as fast as they could (because the long SOA probably did not pose serious time pressure; see [Section 4.1](#) and [Fig. 1](#)), whereas the elderly did, possibly using additional resources compared with young participants. Note that, whereas P3 showed a central distribution in young adults, it was parietal in the elderly. As the distribution of P3 becomes more parietal in more demanding tasks ([Polich and Criado, 2006](#)), the distribution difference may signal that the elderly needed to invest more effort than young adults in order to achieve the same performance level. Alternatively, it is also possible that (some of) the components and the reaction times are independent of each other. For example, it is possible that reaction times are dependent on the P3, but not on the RON latency, which would suggest that the task-related evaluation of the deviant stimulus proceeds even in a suboptimal (distracted) attention state. However, the present data does not provide sufficient evidence for this point.

#### 4.5. *Duration/target effects*

Tone duration and target status are confounded in the present design, that is, the design does not make it possible to fully separate the effects of these factors. However, at least the onset and offset responses are mainly related to the stimulus effects. Whereas onset-related ERP components appeared in all age groups and all stimuli, offset-related ERPs were observable only for long tones in accordance with previous findings ([Näätänen and Picton, 1987](#)). However, unexpectedly, we observed a much more pronounced offset response in children than in adults. One explanation for the lower-amplitude offset response in adults can be based on the attention-related increase of the onset and offset responses ([Näätänen and Picton, 1987](#)). It is possible that adults were able to selectively focus their attention on the task-critical point in time (i.e. at 150 ms after the onset, when the tone either ended or continued) and disregard the task-irrelevant later offset, whereas children attended the long tones throughout.

The morphology of the ERPs elicited by non-target (long) standards was similar in the two adult groups, which may imply similarity in their processing. On the other hand, target (short) standards elicited a positive–negative–positive wave complex (marked with arrows on the Cz traces on [Fig. 1](#), cen-



tral and right column) which was delayed by approximately 80 ms in the elderly compared to young adults. This delay in the ERP waveform may indicate that, compared to young adults, some steps in the processing of targets are delayed in the elderly. Due to its latency (and its delay for the elderly), it is unlikely that this waveform corresponds to the physical duration of the stimuli. A similar age-related delay of the N2 and P3 components was reported by Amenedo and Diaz (1998a).

#### 4.6. Interaction between distraction and duration/target effects

In children, the P3 amplitude did not differ between target and non-target deviants. RON elicitation was only significant for non-target deviants, for targets only a tendency was found. In young adults, both P3 and RON were smaller for non-target stimuli. In the elderly, P3 was smaller for non-target deviants, which elicited only a small early RON. These (partly) asymmetrical results could have been caused by asymmetries in the experimental design. One possibility is that short tones can be detected faster by their sharp transient ending, whereas establishing the lack of this transient may take longer. Thus attentive focusing can be relaxed earlier for short target than for long non-target tones possibly leaving more capacity for processing the deviant feature for short than for long tones. This would be reflected by higher-amplitude P3a for short than for long tones and, as a consequence, stronger reorientation processes. Children, as was suggested before, may not be able to relax their focusing as easily as adults, which may account for the lack of duration-dependent P3 difference in their responses. On the other hand, target stimuli afford an overt response, non-targets do not. Therefore it is also possible that response-related processes play a role in attention-switching, and further in the restoration of the task-optimal attention-set.

## 5. Conclusions

In summary, the present results are consistent with the notion that the automatic filtering of task-irrelevant stimulation is similar in the three groups. Later processes, however, showed an age-dependent pattern. Whereas violations of the detected sensory regularities led rapidly to an involuntary attention-shift in the children and the young adults, this process was delayed in the elderly. On the other hand, the following restoration of the task-optimal attention set commenced with similar speed in both groups of adults, whereas it was delayed in the children. These results suggest that maturation and aging selectively affects different stages in the processing of distracting stimuli, providing evidence against single factor models of cognitive aging (e.g., general slowing, Salthouse, 1996). Since these age-differences were reflected in the ERPs, but not in the reaction times and  $d'$  scores, it can be assumed that processes not revealed by the ERPs

also contribute to the deterioration of performance caused by distracting stimuli.

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## Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.neurobiolaging.2007.10.003.

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