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Automatic and effortful processes in auditory memory reflected by event-related potentials. Age-related findings

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Abstract

Mismatch negativity (MMN) and N2b were elicited during a selective dichotic-listening task in 16 young (Y), 16 middle-aged (M) and 19 elderly (E) subjects to evaluate automatic and effortful memory comparison of auditory stimuli. Sequences of standard (80%) and deviant (20%) tones were dichotically presented to subjects in two runs. In each run, subjects were instructed to give a button-press response to the deviant (target) tones in the ear designated as attended and to ignore the input to the other ear.

Peak latencies, peak amplitudes and mean amplitudes were calculated for MMN and N2b components in each subject. MMN latency and amplitude were quite stable regardless of age, while N2b latency was significantly longer in M and E subjects than in Y subjects. These results are interpreted as reflecting that automatic processes of comparison in auditory memory of stimuli presented at short interstimulus intervals remain quite stable from 23 to 77 years of age; however, those requiring attentional effort decline with age.

Keywords: Ageing; Dichotic-listening; mismatch negativity (MMN); N2b

1. Introduction

In accordance with the division of psychological processes into automatic and controlled (Posner and Snyder, 1975; Shiffrin and Snyder, 1977), Hasher and Zacks (1979) proposed the existence of two processes in memory performance depending on the attentional requirements involved: automatic and effortful. According to their assumption, automatic processes do not require either awareness or intention, and they use minimal amounts of energy from the limited attentional capacity. In contrast, effortful processes require awareness and intention, and they use a portion of attentional capacity. The authors also proposed that attentional capacity varies both within and among subjects, and old age is among the variables they consider as reducing attentional capacity. Considering the two assumptions, they predicted that the elderly will show deficits in performance only in memory tasks requiring effortful processing.

Two components of event-related potentials (ERPs) constitute cerebral indexes of such processes in auditory memory: mismatch negativity (MMN) and N2b. MMN is typically elicited when infrequent, physically-deviant sounds occur in a series of unattended standard auditory stimuli (Näätänen et al., 1978; Näätänen, 1988, 1990, 1992). MMN is considered to be generated by an automatic neuronal process which registers the difference between physical features of a deviant stimulus and a neuronal sensory-memory trace produced by repetitive standard stimuli (Näätänen, 1990). MMN is optimally elicited in conditions requiring no attention to the stimulation, because in attention conditions it is partly overlapped by the component N2b (Alho, 1995; Näätänen, 1988, 1990). MMN offers an objective tool to study the detection of automatic stimulus-change in the human auditory system.

Among the proposed different kinds of N2 component that can be distinguished (see Näätänen, 1986), N2b is a sharp negative component with a central modality-non-specific topography, often preceding P3 (Näätänen, 1986; Novak et al., 1990). N2b is elicited by attended infrequent (target) stimuli when they have to be actively selected by the subject to further processing. N2b is considered an index of controlled orienting to and detection of deviant stimuli occurring in the attended auditory input (Näätänen, 1988, 1990; Novak et al., 1990).

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Following Hasher and Zacks' model and prediction, ageing should affect the N2b component, causing no effects on MMN. The effects of ageing on N2b and MMN obtained in their typical conditions have been evaluated in separate studies. Verleger et al. (1991), employing an attended auditory 'oddball' task, found that N2a (referred to as MMN by the authors) and N2b latencies were significantly longer in elderly subjects than in younger subjects. They interpreted these results as reflecting the existence of an age-related slowing in memory comparison processes. On the other hand, the few studies that have investigated possible age-related effects on MMN obtained in non-attended conditions have found divergent results. Czigler et al. (1992) found that MMN to frequency-change elicited with interstimulus intervals (ISIs) of 0.8, 2.4 and 7.2 s was larger in their young group than in their elderly group, and hence suggested that the ability of the auditory system to detect stimulus changes attenuates with ageing. Woods (1992), using random stimulus onset asynchronies (SOAs) between 0.2 and 0.4 s, found that MMN to a change in stimulus duration was smaller for the elderly than for the middle-aged group. However, Gunter et al. (1996), with SOAs of 0.5 s, reported no age-related differences in MMN to a frequency change. Similarly, Pekkonen et al. (Pekkonen et al., 1993, 1996) found that with 0.5 s, 1 s or 1.5 s ISIs, ageing did not affect either frequency or duration MMN, while with 3 s or 4.5 s ISIs MMN are attenuated significantly more in older than in younger subject groups. The authors interpreted these results as indicating that automatic stimulus discrimination per se is not impaired with normal ageing, but that the stimulus trace decays faster in echoic memory with ageing.

There are no studies in which age-related changes in these two components were checked during the execution of the same task under attended and unattended conditions. In the present study, the main objective was to investigate the ageing effects on MMN and N2b components elicited during a dichotic-listening task. We decided to use this task because it allows the two components to be obtained in the same subject under intramodal attention conditions in which the only variant is the attention paid to the stimulation.

2. Methods

2.1. Subjects

Sixteen young (Y, 7 females, age 31 ± 6, range 23–39 years), 16 middle-aged (M, 6 females, age 49 ± 7, range 41–59 years) and 19 elderly subjects (E, 12 females, age 70 ± 5, range 63–77 years) were tested. Subjects were selected from volunteers recruited from retirement homes, clubs for retired persons living on their own, educational centres, faculties of the University of Santiago de Compostela and employment agencies. Subjects were equated in years of formal education (Y, mean 10 ± 5, range 5–17; M, mean 9 ± 4, range 5–15; E, mean 9 ± 5, range 5–17). None had experience with psychophysiological testing. The general exclusion criteria were diseases of the central and peripheral nervous system, cardiovascular diseases and/or hypertension, alcohol abuse, pulmonary problems, cranioencephalic trauma, audiological problems and MEC scores lower than 28 (MEC, Mini Examen Cognoscitivo, the Spanish version of the Mini Mental State Examination.

2.2. Stimuli and procedure

Pure sine-wave tones of 50 ms (10 ms of rise and fall) were generated by the Stim module of a Neuro Scan system and presented dichotically at an intensity of 90 dB SPL through TDH-39 headphones, with a constant ISI (offset-to-onset) of 600 ms. Standard tones had a frequency of 1000 Hz and were randomly replaced by deviant tones of 1500 Hz (probability of 0.2) with the restriction that there was at least one standard tone between two deviant tones. Two blocks of 400 tones (200 in each ear) were presented in two consecutive runs. In each run, subjects were instructed to pay attention to tones in the right or left ear and to press a button with the preferred thumb when they detected deviant tones in the attended ear, while ignoring the stimulation in the other ear. The assignation of each ear as attended was counterbalanced across subjects. Two practice blocks of 60 tones (30 in each ear, 6 deviants) were given to the subjects to ensure a good level of performance. During the recordings, subjects fixated on a spot 2 cm in diameter fixed on the wall, 150 cm from their eyes and were instructed to avoid movement and blinking.

Reaction times and errors (omissions and false alarms) were recorded on-line by the Stim module and stored for further off-line processing.

The EEG (bandpass 0.1–30 Hz) was continuously amplified and digitised with the Scan module connected to a Grass Model 12 Neurodata Acquisition System at a rate of 256 Hz/channel, from 7 tin scalp electrodes inserted in a cap (Electrocap International) according to the 10–20 international system: F3, Fz, F4, C3, Cz, C4 and Pz. The active electrodes were referred to linked earlobes and grounded with an electrode placed between Fz and Fpz locations. Vertical and horizontal EOG activities were recorded bipolarly from above and below the left eye and from the outer canthi of both eyes.

For each electrode, EEG epochs consisting of 500 ms poststimulus and 100 ms prestimulus were obtained off-line and averaged separately for the standard and deviant tones in each ear when attended and when non-attended, yielding a total of 8 averages, two for each stimulus and attended/unattended ear. Trials exceeding ±80 μV were automatically excluded from the averages, as well as trials containing excessive eye movements or blinking. Moreover, only epochs associated with correct responses were included in the average. For the targets, a correct response was a response within 200–600 ms after targets offset. For the unattended deviants, epochs in which subjects gave a button-press were excluded from the average. The first 5 epochs of each block were also rejected, to exclude possible N1-amplitude variation. With these control procedures, a minimum of 30 trials associated with non-attended deviants and with targets could be averaged in each ear when attended and when unattended (non-attended deviants, right ear: mean 34 ± 3, left ear: mean 37 ± 3; targets, right ear: mean 35 ± 4, left ear: mean 36 ± 5).

2.3. Data analysis

To obtain the MMN, difference waves were computed in each subject at each electrode separately by subtracting the ERPs for the non-attended standards from the ERPs for the non-attended deviants in each ear. In these difference waves, peak latencies, peak amplitudes and mean amplitudes of MMN were automatically measured using a latency window of 100–250 ms. Amplitudes were measured relative to the 100 ms prestimulus baseline.

To obtain the N2b, difference waves were computed in each subject at each electrode separately by subtracting the ERPs for the attended standards from the ERPs for the targets in each ear. In these difference waves, peak latencies, peak amplitudes and mean amplitudes of N2b were automatically measured using a latency window of 200–380 ms. Amplitudes were measured relative to the 100 ms prestimulus baseline.

Since the replicability of the difference waves obtained in the two ears was high in all subjects (mean intra-class correlation; MMN in right and left ear: Y, 0.97; M, 0.96; E, 0.98; N2b in right and left ear: Y, 0.95; M, 0.97; E, 0.96), the

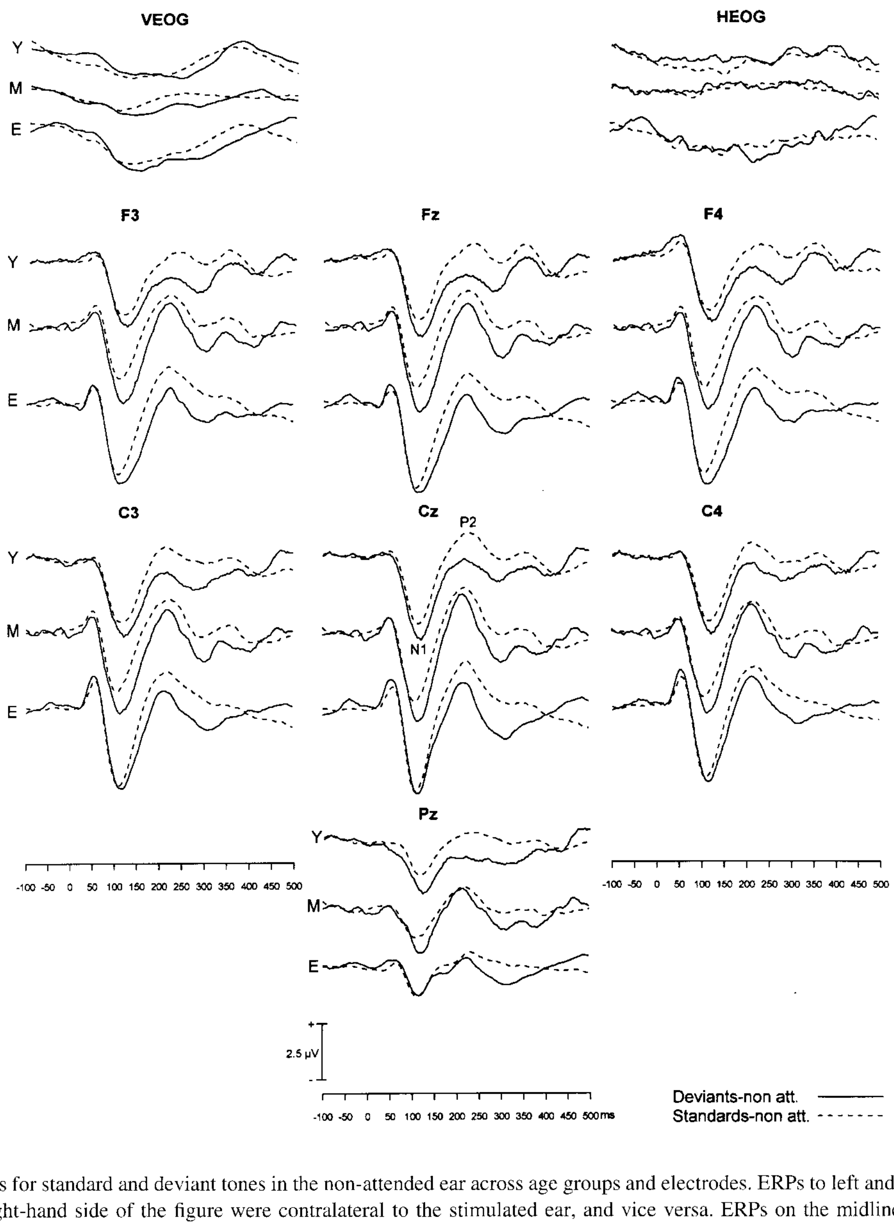

Fig. 1. Grand mean ERPs for standard and deviant tones in the non-attended ear across age groups and electrodes. ERPs to left and right ears are combined, so that the ERPs on the right-hand side of the figure were contralateral to the stimulated ear, and vice versa. ERPs on the midline represent the grand mean waveforms to the two ears.

two difference waves were averaged for the two ears, and statistical analyses were performed on these averages.

Only reaction times associated with correct responses that occurred within 200–600 ms following targets were employed for further analysis.

Data were subjected to mixed-model ANOVAs with age and sex as between-subjects factors and electrode position (ERP data) or attended ear (behavioural data) as within-subject factors. Degrees of freedom were corrected by the conservative Greehouse–Geisser estimate when appropriate.

3. Results

3.1. MMN

Fig. 1 shows the grand mean ERPs for the standard and deviant tones in the non-attended ear for each age group and electrode. In this ear, both tones elicited N1 and P2 responses.

Fig. 2 shows grand mean difference waves (deviant ERP minus standard ERP, non-attended ear) for each age group and electrode. There were no significant differences either among age groups or between sexes in MMN peak latency (age, $F(2,45) = 2.32, P \leq 0.1$; sex, $F(1,45) = 1.2, P \leq 0.28$), peak amplitude (age, $F(2,45) = 1.17$, $P \leq 0.32$; sex, $F(1,45) = 3.42$, $P \leq 0.07$) or mean amplitude (age, $F(2,45) = 1.2$, $P \leq 0.309$; sex, $F(1,45) = 3.45$, $p \leq 0.07$). Table 1 lists peak latencies, peak amplitudes and mean amplitudes of MMN in each age group at all electrodes, which were similar among the 3 age groups.

The electrode position had significant effects on MMN peak amplitude ($F(6,270) = 9.61$, $P \leq 0.0001$, $\epsilon = 0.68$) and mean amplitude ($F(6,270) = 5.83$, $P \leq 0.0001$, $\epsilon = 0.71$). This was because MMN was maximum at the frontal electrodes, as may be seen in Fig. 2 and Table 1.

3.2. N2b

Fig. 3 shows grand mean ERPs for standard and target stimuli (attended ear) for each age group and electrode. In this ear, standard tones elicited N1 and P2 responses, and target tones also elicited N2 and P3 responses.

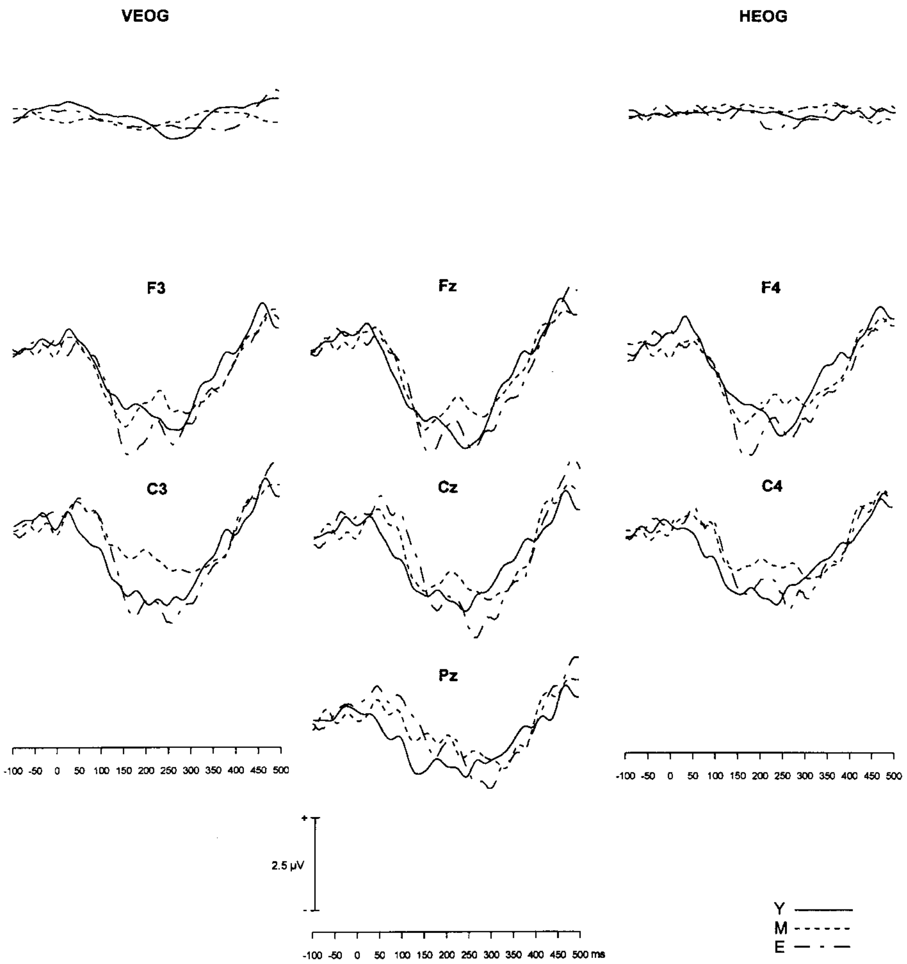

Fig. 2. Grand mean difference waves (deviant ERP minus standard ERP) in the non-attended ear for each age group and electrode. All ERPs represent the grand mean waveforms to the two ears.

Table 1

Peak latencies, peak amplitudes and mean amplitudes of MMN at all electrodes in each age group

Age group (years)	Peak latency (ms)			Peak amplitude (μV)			Mean amplitude (μV)		
23–39	F3 203 (57)[a]	Fz 208 (48)	F4 204 (53)	F3 −2.4 (1.5)	Fz **−2.7 (1.2)**[b]	F4 −2.4 (1.4)	F3 −1.4 (1.1)	Fz −1.8 (1.0)	F4 −1.4 (0.9)
	C3 211 (61)	Cz 191 (47)	C4 197 (56)	C3 −2.0 (1.3)	Cz −2.1 (1.4)	C4 −1.9 (1.2)	C3 −1.4 (1.2)	Cz −1.4 (1.2)	C4 −1.3 (1.0)
		Pz 177 (63)			Pz −1.5 (1.3)			Pz −1.1 (1.2)	
41–59	F3 178 (52)	Fz 181 (54)	F4 177 (56)	F3 −2.3 (1.2)	Fz **−2.4 (1.1)**	F4 −1.4 (1.6)	F3 −1.4 (1.4)	Fz **−1.5 (1.0)**	F4 −1.3 (1.5)
	C3 165 (50)	Cz 179 (54)	C4 163 (52)	C3 −1.3 (1.6)	Cz −1.9 (1.6)	C4 −1.3 (1.8)	C3 −0.8 (1.2)	Cz −1.2 (0.9)	C4 −0.8 (1.5)
		Pz 173 (51)			Pz −1.1 (1.3)			Pz −0.7 (1.0)	
63–77	F3 200 (50)	Fz 207 (54)	F4 198 (54)	F3 −3.1 (1.5)	Fz **−3.1 (1.8)**	F4 −3.1 (1.7)	F3 −1.7 (1.7)	Fz **−1.9 (1.3)**	F4 −1.7 (1.6)
	C3 210 (50)	Cz 210 (53)	C4 221 (59)	C3 −2.5 (1.7)	Cz −2.7 (1.9)	C4 −1.9 (1.6)	C3 −1.5 (1.5)	Cz −1.5 (1.6)	C4 −1.1 (1.3)
		Pz 223 (63)			Pz −1.2 (1.4)			Pz −0.8 (1.2)	

[a]Standard deviations are in parentheses.
[b]Values at electrodes with maximum amplitudes are shown in bold.

Grand mean difference waves (target ERP minus standard ERP, attended ear) for each age group and electrode are shown in Fig. 4. Age had significant effects on N2b peak latency ($F(2,45) = 6.58$, $P \leq 0.003$), but not on peak amplitude ($F(2,45) = 0.37$, $P \leq 0.69$) or mean amplitude ($F(2,45) = 0.55$, $P \leq 0.58$). Sex had no effect on either N2b peak latency ($F(1,45) = 2.85$, $P \leq 0.10$), peak amplitude ($F(1,45) = 2.8$, $P \leq 0.10$) or mean amplitude ($F(1,45) = 0.1$, $P \leq 0.75$). Table 2 lists N2b peak latencies, peak amplitudes and mean amplitudes in each age group at all electrodes. In this table it may be seen that the effects of age on N2b latency were due to longer latencies in M and E subjects than in Y subjects.

The electrode position showed significant effects on N2b peak amplitude ($F(6,270) = 16.22$, $P \leq 0.0001$, $\epsilon = 0.46$) and mean amplitude ($F(6,270) = 5.58$, $P \leq 0.001$, $\epsilon = 0.49$) that were due to the existence of maximum N2b components at the central electrodes (see Fig. 4 and Table 2).

3.3. Behavioural data

The number of errors was not significantly different depending either on age ($F(2,45) = 1.66$, $P \leq 0.20$), sex ($F(1,45) = 0.71$, $P \leq 0.40$) or the attended ear ($F(1,45) = 0.001$, $P \leq 0.96$), and accuracy was high in all subjects (Y: 91.1%, M: 92.6%, E: 90.5%). Reaction times (RT) were not affected either by age ($F(2,45) = 2.56$, $P \leq 0.09$), sex ($F(1,45) = 0.33$, $P \leq 0.57$) or the attended ear ($F(1,45) = 0.17$, $P \leq 0.68$). The averaged RTs were 375 ± 55 ms for Y subjects, 350 ± 40 ms for M subjects and 390 ± 60 ms for E subjects.

4. Discussion

4.1. MMN

In this study, no effects of age on MMN latency for frequency change with ISIs of 0.6 s were observed. Verleger et al. (1991), in the difference wave obtained by subtracting the ERPs to standard tones from the ERPs to target tones in an attended auditory oddball task, reported that the negativity preceding N2b (N2a), which they called MMN, presented significantly longer latencies in 20 elderly subjects than in 18 young subjects. They interpreted this result as reflecting an early onset of delay in memory comparison processes in elderly subjects. In the present study, however, no effects of ageing were found on the latency of MMN measured in the difference waves obtained in the ignored ear. The reasons for this discrepancy can be attributed to the different conditions used to measure MMN. In Verleger et al.'s study, MMN was measured in an attended condition, while in this study MMN was measured in an ignore condition. The MMN in Verleger et al.'s study could be partially overlapped by N2b (Alho, 1995) and so could share some of N2b functional characteristics. Moreover, when employing an attended condition it is difficult to separate ERP components related to automatic processing from those related to controlled processing. At this point it is necessary to consider the possibility that the MMN studied by Verleger and co-workers and the MMN in the present study may be due to different MMN components.

MMN is considered an index of automatic change detection in auditory sensory memory (Näätänen, 1995; Schröger, 1996). MMN latency can be interpreted as the time that the memory comparison process needs to detect the change. The present results, in accordance with those of Pekkonen et al. (Pekkonen et al., 1993; Pekkonen et al., 1996), suggest that the time needed to detect physical changes of sounds in auditory sensory memory remains stable regardless of age.

MMN amplitude for frequency change showed no effects of age in the present study. These results are comparable with Pekkonen et al.'s (Pekkonen et al., 1993) results with 1 s ISIs, with Pekkonen et al.'s (Pekkonen et al., 1996) results with 0.5 s and 1.5 s ISIs, and with Gunter et al.'s (Gunter et al., 1996) results with 0.5 s SOAs. However, they are in contrast with those of Czigler et al. (1992) and Woods

(1992), who found lower MMN amplitudes in the elderly group than in the younger group with ISIs of 0.8 s, 2.4 s. and 7.2 s, and with SOAs of 0.2 s and 0.4 s, respectively. Pekkonen et al. (1996) attributed the discrepancy between the results to two possible causes: first, while Czigler et al. (1992) used constant stimulus loudness irrespective of the subject's age, Pekkonen et al. adjusted stimulus loudness according to the subjective hearing threshold. However, this explanation appears insufficient because, for instance, in Woods' study, stimulus loudness was also adjusted to the individual perceptual threshold. Second, Woods employed a dichotic-listening task, while in Pekkonen et al.'s studies the tones were monoaurally presented in the subject's left (Pekkonen et al., 1996) or right (Pekkonen et al., 1993) ear. Pekkonen and co-workers concluded that the different paradigm employed by Woods might cause differences in the MMN results. However, in the present study constant stimulus loudness and a dichotic-listening task were used, and the results are similar to Pekkonen et al.'s findings with short ISIs, so these cannot be the reasons for the discrepancy. The main reason for the discrepancies between the present study and those of Czigler et al. (1992) and Woods (1992) may lie in the relatively small size of the samples employed by those authors, combined with the low homogeneity in the age distribution within the samples. They only tested 8 young and 8 elderly (Czigler et al., 1992), and 9 middle-aged and 9 elderly subjects (Woods, 1992). Moreover, Woods included in his middle-aged group subjects

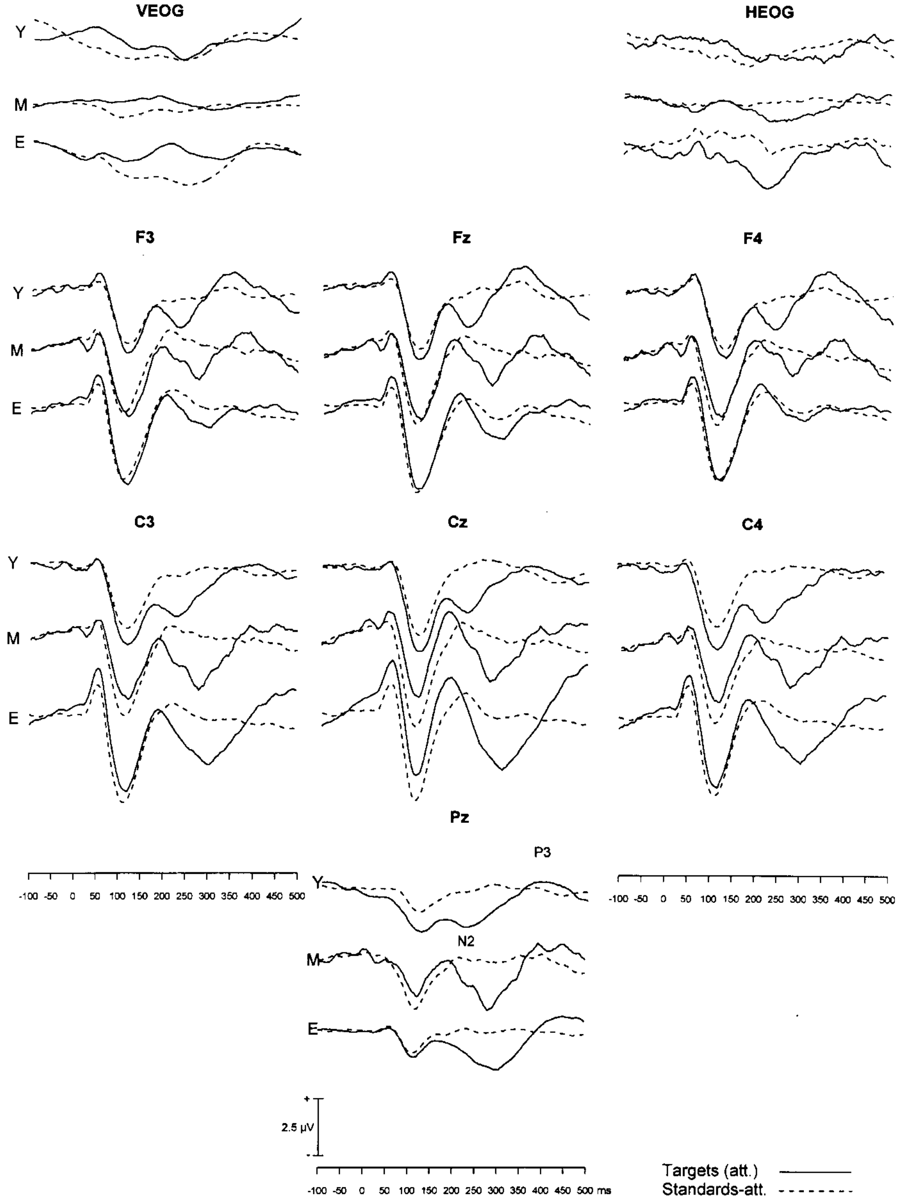

Fig. 3. Grand mean ERPs for standard and target tones in the attended ear across age groups and electrodes. ERPs to left and right ears are combined, so that the ERPs on the right side of the figure were contralateral to the stimulated ear, and vice versa. ERPs on the midline represent the grand mean waveforms to the two ears.

from 26–53 years of age, and this group represents a wide age range. Elderly subjects normally present higher variability in psychophysiological measures and so large and homogeneous samples are recommended (John et al., 1987).

The absence of age-related differences in MMN amplitude in the present study might be due to noise because of the relatively small number of trials associated with deviant stimuli. Although MMN replicability has been found to be similar to that of the N1 component to the deviant stimuli, a large number of trials is recommended in order to improve the clinical usefulness of this component (Pekkonen et al., 1995; Escera and Grau, 1996). Czigler et al. (1992) and Woods (1992) had more trials and they found age-related differences. However, the high correlation values between the MMNs obtained in the left and right ears in the present study give support to the results. Moreover, other studies employing larger numbers of trials have reported no age-related differences in MMN (Pekkonen et al., 1993, 1996; Gunter et al., 1996).

MMN amplitude can be considered an index of the automatic discrimination accuracy in the auditory system, as its sensitivity to small stimulus changes has been found to correlate with behavioural discrimination thresholds (Lang et al., 1990; Näätänen and Alho, 1997). In line with the above interpretation, the present results on MMN amplitude, according to Pekkonen et al.'s (Pekkonen et al., 1993, 1996) results and to Gunter et al.'s (Gunter et al., 1996) results, suggest that the accuracy of the automatic comparison of stimulus physical features in auditory memory is resistant to ageing, at least when stimuli are presented with short ISIs.

In the present study, MMN was at its maximum over frontal electrodes in all subjects, as the significant effect of the electrode position indicated. This is the normal scalp distribution reported for MMN (for reviews see

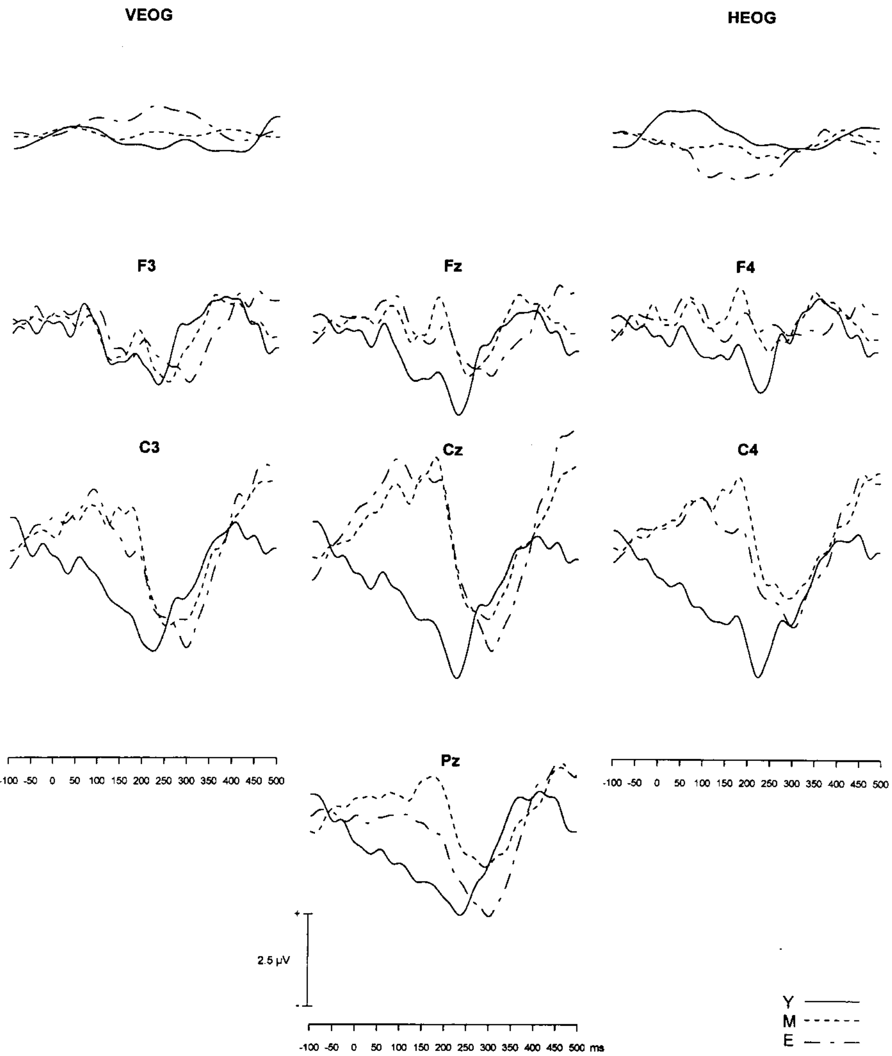

Fig. 4. Grand mean difference waves (target ERP minus standard ERP) in the attended ear for each age group and electrode. All ERPs represent the grand mean waveforms to the two ears.

Table 2

Peak latencies, peak amplitudes and mean amplitudes of N2b at all electrodes in each age group

Age group (years)	Peak latency (ms)			Peak amplitude (μV)			Mean amplitude (μV)		
23–39	F3 228 (62)[a]	Fz 227 (40)	F4 232 (46)	F3 −1.7 (1.0)	Fz −2.5 (1.6)	F4 −1.8 (1.9)	F3 −0.7 (1.5)	Fz −0.6 (1.7)	F4 −0.6 (1.5)
	C3 223 (68)	Cz 226 (50)	C4 223 (51)	C3 −3.6 (2.0)	Cz **−4.0 (2.1)**[b]	C4 −3.7 (1.9)	C3 −1.4 (1.4)	Cz **−1.7 (1.3)**	C4 −1.5 (1.7)
		Pz 235 (53)			Pz −3.5 (1.8)			Pz −1.2 (1.5)	
41–59	F3 253 (56)	Fz 248 (54)	F4 252 (72)	F3 −1.7 (1.8)	Fz −1.3 (1.1)	F4 −0.2 (0.6)	F3 −0.8 (1.6)	Fz −0.8 (1.0)	F4 −0.1 (1.7)
	C3 257 (46)	Cz 294 (60)	C4 289 (51)	C3 **−3.1 (2.4)**	Cz −2.5 (1.2)	C4 −1.9 (0.7)	C3 **−1.2 (1.9)**	Cz −0.9 (1.6)	C4 −0.8 (1.6)
		Pz 291 (58)			Pz −1.7 (1.4)			Pz −1.0 (1.4)	
63–77	F3 297 (79)	Fz 300 (79)	F4 297 (75)	F3 −1.7 (1.5)	Fz −1.5 (0.9)	F4 −0.1 (0.6)	F3 −0.7 (2.0)	Fz −0.8 (2.3)	F4 −0.1 (2.5)
	C3 298 (56)	Cz 303 (69)	C4 302 (71)	C3 **−3.5 (2.0)**	Cz −3.4 (1.2)	C4 −2.6 (2.0)	C3 **−1.2 (2.2)**	Cz −1.0 (2.8)	C4 −0.9 (1.7)
		Pz 298 (52)			Pz −3.1 (1.7)			Pz −0.9 (2.1)	

[a]Standard deviations are in parentheses.

[b]Values at electrodes with maximum amplitudes are shown in bold.

Näätänen, 1990, 1992; Alho, 1995; Näätänen and Alho, 1995).

No differences in the scalp distribution of MMN were observed among age groups in this study. Pekkonen et al.'s (Pekkonen et al., 1993, 1996) results are similar, since they reported the same scalp distribution of MMN for their young, middle-aged and elderly subjects. However, Czigler et al. (1992) found larger MMNs at Fz in their younger group than in their elderly group, and Woods (1992) found larger MMNs over the right hemisphere for the middle-aged group but larger over the left for the elderly group.

4.2. N2b

Significant differences in N2b latency among age groups were observed, indicating that in M and E subjects this component presented longer latencies than in Y subjects. This result is in line with other results (Verleger et al., 1991).

The N2b component is considered an index of attentive change detection and it is held to be related to the identification of a stimulus as deviant (Ritter et al., 1992). Its latency can be interpreted as indexing the time needed to make the conscious identification of the stimulus as deviant. Following this functional interpretation of N2b latency, the present results may reflect that when comparison of physical features of stimulation in auditory memory requires attentional effort to consciously identify the deviants, the effects of ageing become apparent, resulting in a slowing down of this process.

N2b amplitude was not affected by age, and this result agrees with Verleger et al.'s results (Verleger et al., 1991). N2b amplitude may be cautiously related to the accuracy of conscious discriminability which depends on available processing capacity when attended stimuli must be compared (Schröger, 1996). The present results on N2b amplitude may then suggest that the capacity of consciously discriminating between two different stimuli is unaffected by age, although the time needed to make such discrimination slows with age, as the latency findings indicate.

The N2b component was maximum at central electrodes in all subjects. This result is in agreement with the typical distribution of this component, which, in contrast to MMN, is centrally maximum (Näätänen, 1990, 1992; Novak et al., 1990).

Taken together, the present results for MMN and N2b are in agreement with the prediction of Hasher and Zacks' model of automatic and effortful processes, since they show that while electrophysiological activity related to automatic comparison in memory of stimulus changes remains stable with age, that which is related to effortful comparison of the same stimuli slows with age (Hasher and Zacks, 1979).

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