Pre-attentive detection of motion direction changes in normal aging

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Effects of normal aging on pre-attentive detection of changes in motion direction were evaluated. Young, middle-aged, and older subjects performed a visual central task while standard and deviant gratings varying in motion direction were presented outside the focus of attention. A greater negativity in the event-related potentials (ERPs) to deviants was observed in all groups at posterior sites within the N2 latency range. Visual mismatch negativity (vMMN) reached its peak between 145 and 165 ms irrespective of age. However, significant age-related changes observed in vMMN mean amplitude may suggest that the pre-attentive visual detection become less efficient in older subjects. This could lead to age-related deficits in switching attention to potentially salient visual changes. *NeuroReport* 15:2633–2636 © 2004 Lippincott Williams & Wilkins.

Key words: Change detection; Event-related potentials; Motion; Pre-attentive processing; Visual mismatch negativity

INTRODUCTION

The automatic detection of sudden changes occurring outside the focus of attention is a fundamental capacity of human brain involved in awareness of significant stimuli that may require an attentional switch. Such a pre-attentive mechanism has been widely studied in the auditory system by recording the mismatch negativity (MMN) event-related potential (ERP) [1]. Recently a comparable response has been described in the visual modality for colour [2], spatial frequency [3] and motion direction [4] changes, suggesting that the visual system is also able to automatically register unattended changes.

The effects of aging on pre-attentive deviance detection have been widely studied by recording the auditory MMN, but the results have been mixed. Some studies have reported an age-related reduction in the auditory MMN amplitude [5,6]. However, this reduction was observed in other studies only when the stimuli were presented at long interstimulus intervals (ISIs; >3 s) [7,8], while similar amplitudes were found regardless of age at relatively short ISIs [7–10]. Moreover, auditory MMN to duration and frequency changes have shown different sensitivities to normal aging in the literature.

To our knowledge, only two studies have recorded visual deviance-related negativities in healthy older subjects [11,12]. However, limitations and inconsistent results make it difficult to conclude whether a true visual MMN was obtained. In one intermodal study, Iijima *et al.* [11] observed two negativities associated to visual deviants that were identified as a vMMN (earlier negativity), and as N2b (later negativity). The latency and the amplitude of the earlier negativity showed no significant differences between young and older subjects. However, the latency of the later negativity was significantly delayed in the older group. The authors concluded that age effects on the processing of visual inputs might occur during controlled processing (N2b), and not during automatic processing (MMN). However, these results should be interpreted with caution due to the following limitations. Firstly, the occurrence of N2b, a component related to active attention mechanisms, indicated that the distracting task was not effective for subjects to ignore visual stimuli in this experiment. Since an essential property of a mechanism for detecting changes that are not the current focus of attention is that it must operate automatically, it was not possible to conclude whether a true visual MMN was recorded in this experiment. Secondly, only midline electrodes (Fz, Cz, Pz) were employed. In this sense, recordings from posterior sites are necessary to evaluate visual information processing.

In the second study, Tales *et al.* [12] observed a late negativity in the period following N2 (250–400 ms) that was associated with unattended changes in the shape of peripheral visual deviant stimuli and that was distributed over occipital and posterior temporal areas. The authors identified this response as a visual analogue of the auditory MMN. This negativity was significantly reduced in amplitude in the older group indicating, according to the authors, age-related deficits in automatic visual processing. However, taking into account the long latency of the negative deflection related to change-detection described in this study, it seems unlikely that it reflects an early, automatic, visual detection mechanism and so a visual MMN response.

In a recent study from our laboratory, Pazo-Alvarez *et al.* [4] suggested the existence of a genuine automatic change-detection mechanism in motion direction in young subjects.

The aim of the current study was to extend our previous results by assessing whether this mechanism was affected by advancing age. So, we applied a paradigm similar to that used previously [4] with some restrictions. In the original experiment, unattended sinusoidal gratings varying in

motion-direction were presented in the peripheral visual field while subjects performed a visual central task. In order to discard the possibility that the effects on the deviance-related response could be due to the direction of motion (exogenous effects), the stimuli that acted as deviant and standard were interchanged in separate experimental blocks (i.e. normal and reverse conditions). Furthermore, to test possible influences of attentional load on the detection of peripheral motion changes, the level of difficulty of the central task was increased in different experimental blocks (i.e. easy and difficult conditions). Since the influence of exogenous effects and attentional load was discarded in that study, we used only the normal condition and the easy central task in the present experiment.

MATERIALS AND METHODS

Subjects: Seven young (four females, 32 ± 6 years, range 24–38), 5 middle-aged (two females, 49 ± 4 years, range 45–54), and 9 older subjects (five females, 62 ± 3 years, range 58–67) were tested. All were healthy, functioning subjects without a history of neurological or psychiatric disease and had normal or corrected-to-normal visual acuity. Older subjects performed the Mini-Mental State exam and had normal scores (>28). Informed consent was obtained from all subjects.

Stimuli and procedure: Subjects sat in a comfortable armchair in an electrically shielded and sound attenuated room at 61 cm viewing distance from a computer monitor. Horizontal sinusoidal gratings differing in motion direction (4.13° visual angle, 20% contrast, speed 1.95 deg/s, spatial frequency 0.7 cycles/deg) were presented bilaterally at 10.7° to the left and to the right from a fixation cross in the centre of the monitor for 133 ms. Stimuli were presented in sequences of repetitive upward-drifting gratings (standard motion, p=0.8), which were occasionally replaced by downward drifting gratings (deviant motion, p=0.2). Stimuli were randomly sequenced with the restriction that at least one standard motion would occur before each deviant motion and were followed by a blank screen ISI of 665 ms. Over the central cross one of nine possible digits (1, 2, 3, 4, 5, 6, 7, 8 or 9), $1.035 \times 0.659°$ visual angle, was equiprobably presented in three different colours (red, green or blue) for 40 ms. Subjects were instructed to fix their gaze on the central cross and to ignore the gratings. They were required to pay attention to the digits and to press a button as quickly as possible in response to numbers lower than 5 of any colour. Subjects were presented with a block of 770 trials, from which 500 corresponded to unattended gratings and 270 to attended digits. All stimuli were presented with a stimulus onset asynchrony (SOA) of 798 ms.

ERPs (bandpass 0.05–100 Hz, 500 Hz/channel) were recorded from 20 active electrodes (Fp1, Fp2, F3, Fz, F4, F7, F8, C3, Cz, C4, P3, Pz, P4, T3, T4, T5, T6, O1, O2, Oz), referred to the nose tip and grounded with an electrode at nasion. Vertical and horizontal eye movements were recorded bipolarly from above and below the left eye and from the outer canthi of both eyes. Data were collected over epochs of 800 ms (100 ms pre-stimulus and 700 ms post-stimulus). Epochs exceeding $\pm 100\,\mu V$ and those containing horizontal or vertical eye movements were excluded from averaging. ERPs elicited to standards and deviants were averaged (digital bandpass of 0.1–30 Hz) separately across subjects and electrodes.

Data analysis: Reaction times were on-line recorded, and hit rates were calculated as the percentage of correct responses with reaction times no longer than 798 ms. Hit rates and mean reaction times were compared across groups using one-way ANOVA with age (young, middle-aged, older) as between-subjects factor.

For electrophysiological analyses, in the ERPs to both standard and deviant gratings, peak latency and amplitude of N2 were measured and subjected to mixed model ANOVAs with age (young, middle-aged, older) as the between-subjects factor and electrode (18 channels) as the within-subject factor. Difference waves (vMMN) were calculated by subtracting the ERPs to standards from those to deviants employing an epoch from 50 ms pre-stimulus to 500 ms post-stimulus. In the resulting waves, mean amplitudes over consecutive $\sim$20 ms latency windows from 100 to 405 ms post-stimulus were measured, and their statistical significance was tested with one-sample t-tests comparing them against a hypothetical zero-level in each group separately.

In order to test the effects of age on vMMN mean amplitude, data were subjected to mixed model ANOVAs with age (young, middle-aged, older) as the between-subjects factor and electrode (18 channels) as the within-subject factor. An alpha level of .05 was used for all statistical tests. Degrees of freedom were corrected by the conservative Greenhouse–Geisser estimate when appropriate.

RESULTS

Behavioral data: There were no significant effects of age on mean reaction times ($F(2,18)=3.24$, p=0.06; young 450 ± 44 ms; middle-aged 491 ± 65 ms; older 524 ± 63 ms) or hit rates ($F(2,18)=2.51$, p=0.11; young 98 ± 2%; middle-aged 98 ± 2%; older 92 ± 9%) in the central visual task.

ERP data: The ERPs elicited to standard and deviant gratings at posterior sites are shown in Fig. 1. The response was dominated by a small positivity (P1) and a prominent negative deflection (N2) in the three groups. A later positivity (P2), maximal at the vertex, was also present in all groups.

There was a significant effect of age on N2 latency ($F(2,18)=10.45$, $p \leq 0.001$), revealing longer latencies in the two oldest groups (young 154.2 ms; middle-aged 171.8 ms; older 172.9 ms). However, there were no effects of age on N2 peak amplitude ($F(2,18)=0.29$, p=0.75).

Difference waves (vMMN) reached its peak between 145 and 165 ms irrespective of age (Fig. 2). t-tests showed that, at the above-referred latency range, vMMN was significantly different from zero at all posterior sites in young and middle-aged subjects. However, a significantly different from zero vMMN was observed only at O2, T6, P4 and Pz in older subjects (Table 1).

ANOVA tests revealed a significant and progressive age-related reduction in vMMN mean amplitude over the 165–205 latency range ($F(2,18)=4.56$, $p \leq 0.025$; young $-2.26\,\mu V$; middle-aged $-1.06\,\mu V$; older $-0.005\,\mu V$; Fig. 2). Analyses also showed a significant effect of electrode ($F(17,306)=7.12$, $p \leq 0.001$, ϵ=0.190) at these latency ranges,

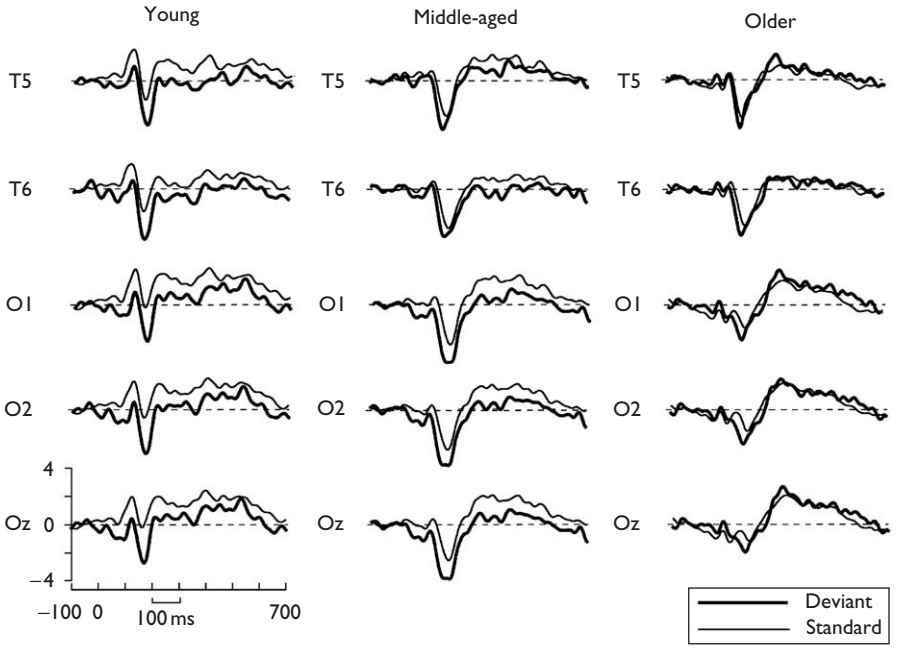

Fig. 1. ERPs to deviant and standard gratings for each group at posterior locations.

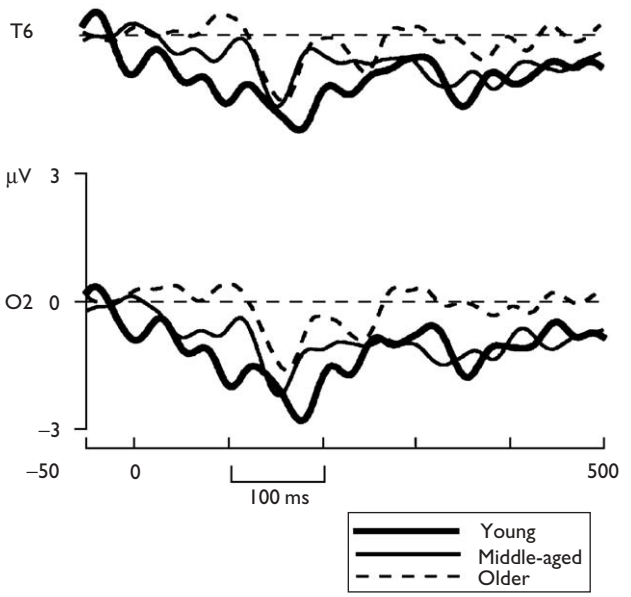

Fig. 2. Difference waves for young, middle-aged and older subjects at the electrodes where they were significantly different from zero in all groups.

reflecting that vMMN amplitudes were maximal at occipital and temporal sites regardless of age.

DISCUSSION

The ERPs to both standard and deviant gratings were characterized by a P1-N2 complex at posterior sites irrespective of age that parallels the major components described in the motion-onset visual evoked potentials (MOP VEPs) research [13]. However, an overlap of pattern and MOP responses was probably observed in the present study, since the gratings were presented at the same time that they began to move. P1 component has been attributed to pattern processing, whereas N2 has been considered as a motion-specific component by its contrast and velocity dependence [14,15] and by its susceptibility to motion adaptation [16].

The present study revealed significantly longer N2 latencies in the two oldest groups. A similar result was obtained by Chlubnová *et al.* [17], who interpreted this latency prolongation as the existence of earlier age-related functional changes in the magnocellular stream of the human visual cortex that is evident already in 50-year-old healthy subjects. This is in good agreement with the hypothesis that the magnocellular system is more sensitive to aging and begins to decline relatively early in life [18]. In this respect, our results must be interpreted with caution, because the paradigm used is unlikely to activate solely the magnocellular stream.

A greater negativity in response to deviant gratings was observed compared to standards within the latency range of N2 at posterior sites irrespective of age. As stated previously, Pazo-Alvarez *et al.* [4] identified a deviance-related negativity associated with unattended motion direction changes that, at occipital (Oz, O2) and temporal (T6) sites, and between 145 and 165 ms, was a possible genuine deviance-related response. In the present study, a similar response was also observed in young and middle-aged subjects. However, in older subjects this response failed to reach significance at Oz. This result might suggest the existence of changes in the neural sources related to the pre-attentive detection process. As it is known from the literature, substantial structural, morphological and functional changes occurring during normal aging in visual cortex may contribute to these changes (see [19] for a review). However, future research employing techniques with more spatial resolution, like MEG, is required to explore the neural generators of this deviance-related response and their possible changes with age.

Table 1. Results of *t*-tests showing the electrodes at which deviance-related negativities were significantly different from zero in each group of subjects at the 145–165 ms latency range.

	Young		Middle-aged		Older	
Electrode	*t*-value	*p*-value	*t*-value	*p*-value	*t*-value	*p*-value
O1	3.035	0.023	13.742	0.0001	n.s.	n.s.
O2	3.040	0.023	17.412	0.0001	2.711	0.027
Oz	3.017	0.023	12.043	0.0001	n.s.	n.s.
T5	2.674	0.037	4.846	0.008	n.s.	n.s.
T6	4.086	0.006	10.199	0.001	2.450	0.040
P3	4.733	0.003	8.561	0.001	n.s.	n.s.
P4	2.932	0.026	4.311	0.013	2.818	0.023
Pz	5.761	0.001	5.933	0.004	2.787	0.024

n.s.=not significant.

In the present study, the scalp distribution of vMMN was maximal at posterior sites regardless of age, as the significant effect of electrode site indicated. This finding is in line with the results of Tales *et al*. [12] since they recorded a deviance related response maximal over visual cortex areas, and might suggest that the deviance detection relies on automatic visual sensory processing.

Moreover, a significant and progressive age-related reduction in vMMN mean amplitude was observed between 165 and 205 ms. This attenuation of the vMMN might indicate a progressive decrease in the duration of the electrophysiological response to unattended motion changes, and so in the neural representation of the detection process. As stated in the introduction, a previous study [12] has also reported a deviance response attenuation with normal aging. However, the difference in the latency range in which the vMMN was identified in both studies make it difficult compare the results. Taking into account that, as explained in the introduction, the relation between age-related attenuation of auditory MMN and ISI duration is under discussion, the present results may suggest that older subjects have difficulty in automatically detecting changes in motion direction at short ISIs as applied in this study. Such difficulty may lead to an inefficient interpretation of the visual environment. In this regard, the decreased ability to pre-attentively detect an unattended moving object in the peripheral visual field might contribute to difficulties in daily life activities, such as driving.

CONCLUSION

Sudden motion direction changes can be considered salient features to be detected, so it is not surprising that an automatic mechanism exists in the visual system that detects such unexpected changes. Our results indicate that this pre-attentive detection process undergoes changes with aging that may suggest a shortening of the deviance representation, and possible changes in the neural sources related to it.

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