CHANGES IN FREQUENCY, DURATION OR INTENSITY OF THE AUDITORY INPUT TRIGGER INVOLUNTARY SWITCHES OF ATTENTION: A BEHAVIORAL AND EVENT-RELATED BRAIN POTENTIAL STUDY

Ma José Corral, Elena Yago, Vanessa Carral and Carles Escera.
Neurodynamics Laboratory, Department of Psychiatry and Clinical Psychobiology, University of Barcelona, P. Vall d'Hebron 171, 08035 Barcelona (Spain). Email: cescera@psi.ub.es

Abstract

The present study aimed at identifying specific brain mechanisms involved in directing attention to auditory changes in duration, frequency and intensity. Behavioral and electrophysiological cerebral responses (ERPs) were obtained in 12 subjects (23-20 years, 2 males) to the occurrence of task-irrelevant auditory changes during the performance of a visual discrimination task. Subjects classified odd/even numbers presented on a computer screen by pressing the corresponding response button. The visual stimuli were preceded (300 ms) by a standard tone (600 Hz, 200 ms, 85 dB; p=0.8) or a deviant tone (p=0.2) which was different from the standard tone either in frequency (700 Hz), duration (50 ms) or intensity (79 dB), in separate blocks. ANOVA revealed that the three types of deviant tones increased similarly reaction time ($F_{1,11}$=10.9, p<0.01) and error rate ($F_{1,11}$=32.6, p<0.001), in comparison to performance after standard tones, therefore causing behavioral distraction. Standard minus deviant ERPs revealed the mismatch negativity (MMN), which was larger for the duration deviant tone than to the frequency and intensity deviant tones ($F_{2,20}$=23.37, p<0.001). Scalp potential maps showed different MMN distributions for the three types of auditory change, suggesting different neural populations underlying the involuntary orienting of attention towards changes in the auditory stimulation.

Detecting changes in the auditory environment allows to orient attention towards potentially relevant events. The mismatch negativity (MMN; Näätänen, et al., 1978; Näätänen, 1992) event-related potential (ERPs) is a negative electric brain response elicited by any discriminable change in some aspect of the auditory stimulation. MMN is generated by a brain mechanisms that compares each new auditory input with a neural trace of the repetitive stimulation held in sensory memory (Näätänen, et al., 1978; Näätänen, 1992).

Previous studies have demonstrated that MMN is originated in the supratemporal plane (Alho et al., 1998; Giard et al., 1990), reflecting the detection of a change in the signal, and in frontal areas (Deouell et al., 1998; Giard et al., 1990; Rinne et al., 2000) reflecting the orienting of attention towards the detected change. In particular Giard et al. (1995) have reported that the generators of the MMN could be differently oriented according to the type of change in the auditory stimulation. These authors found different scalp distributions over the scalp of MMNs elicited by tones deviating in frequency (650 Hz), intensity (55 dB) and duration (30 ms) embedded in a sequence of standard stimulation (600 Hz, 65 dB, 75 ms; p=0.85) delivered in random order to the right ear. The duration MMN presented a stronger mastoid positivity than the frequency and intensity MMNs, and frontal activities that were differently distributed for the 3 types of deviant tones. The topographic analysis showed larger significant differences in the left than in the right hemisphere, probably explained by stronger overlap of the nonspecific activity in the right frontal hemisphere.

The present study aimed at investigating specific brain processes involved in involuntary attention towards auditory changes in duration, frequency and intensity by combining ERP and behavioral measures.

Method

Twelve healthy students (23 to 20 years, 2 males), with normal hearing and normal or corrected-to-normal vision participated in the study. They were presented with 6 blocks of 250 stimulus pairs (trials) delivered at a constant rate of one pair every 1.2 s. Each trial consisted of an irrelevant auditory stimulus followed after 300 ms (onset-to-onset) by a visual imperative stimulus. The subjects were instructed to press a response button to even numbers and another to odd numbers, and to ignore the auditory stimuli. The auditory sequence consisted of a repetitive standard tone (600 Hz, 200 ms and 85 dB; p=0.8) randomly replaced by a slightly higher (700 Hz), shorter (50 ms) or less intense (79 dB) deviant tone (p=0.2), separately in different counterbalanced blocks. While the subjects performed on the task, the electroencephalogram (EEG) (bandpass 0.1-100 Hz) was continuously digitized at a rate of 500 Hz by SynAmps amplifier (Neuroscan, Inc) from 19 scalp electrodes positioned according to the 10-20 system except O1 and O2 (Fp1, Fp2, F7, F3, Fz, F4, F3, F8, T3, C3, Cz, C4, T4, T5, T6, P3, Pz, P4 and OZ), and the 12 additional positions: M1, IM1, TP3, CP1, FT3, FC1, FC2, FT4, CP2, TP4, IM2 and M2 (Figure 2a). Two additional electrodes were placed at the canthus and below the left eye to control ocular movements. The electrode of reference was located on the tip of the nose. ERPs were averaged off-line for each auditory stimulus class, with an epoch of 1300 ms including a preauditory stimulus period of 100 ms. Epochs in which the EEG or EOG exceeded ±100 μV, as well as the first 5 epochs of each block, were automatically excluded from averaging. Individual ERPs were band-pass filtered between 0.01 and 30 Hz.

The difference waves were obtained by subtracting the ERPs to deviant tones from the those to standard tones. The mean amplitude of the MMN was computed in 100 ms time window around its maximum peak in the difference waves (145-245 ms for the duration deviant tone, 107-207 ms for the frequency deviant tone and 140-240 for the intensity deviant tone).

Results and Discussion

The analyses of the performance showed that subjects were slower ($F_{1,11}$=10.9, p<0.01) and made more errors ($F_{1,11}$=32.6, p<0.001) in those trials in which the visual stimulus was preceded by a deviant tone, as compared to those preceded by a standard tone, independently of whether the deviant tone differed in duration, frequency or intensity from the standard tone (see Fig. 1). These results revealed that attention was effectively oriented towards the detected change.

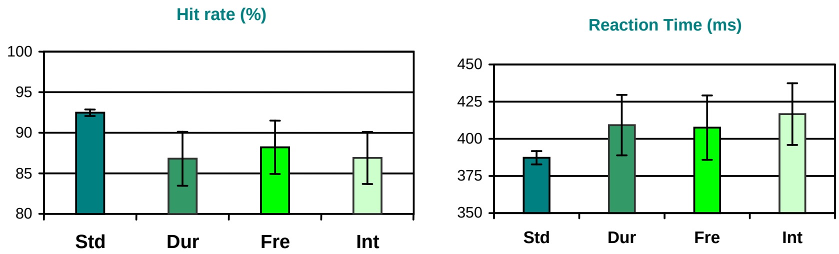

Figure 1. Hit rate and reaction time in trials in which the sound preceding the visual stimulus was a standard tone (Std) or a deviant tone in duration (Dur), in frequency (Fre) or in intensity (Int). The vertical bars show the standard error of mean.

MMN was significantly generated in the three conditions, as indicated by the t-test comparison between the mean amplitude of MMN at Fz and at the M1 (left mastoid) in the duration (t_{11}=5.09, p<0.001), frequency (t_{11}=2.64, p<0.002) and intensity conditions (t_{11}=1.27, p<0.02) (Figure 2b). The polarity reversal at the locations below de Sylvien fissure (i.e. at the mastoids) suggests generators located in the supratemporal plane of the auditory cortex, in agreement with previous studies (Giard et al. 1990, 1995; Alho et al. 1998). MMN was larger for the duration deviant tone than to the frequency and intensity deviant tones ($F_{2,20}$=23.37, p<0.001; at Fz).

Distribution analyses of MMN was performed on normalized values (McCarthy & Wood, 1985) of the mean amplitude of MMN at 100-ms intervals around the maximum peak in each condition. ANOVA with frontality (3 levels: anterior, central or posterior), laterality (5 levels: sweeping from left to right hemispheres) and condition (3 levels: duration, frequency and intensity) as factors showed interactions between the three factors ($F_{16,176}$=2.4, p<0.05) revealing different scalp distributions of MMN depending on the type of the deviant sound (Figure 2c).

The visual inspection of the distribution maps suggests that the MMN for the intensity deviant tone had a more posterior distribution, over temporal areas, as compared to the duration and frequency conditions which had more frontal distributions. These results contrast with those Giard et al. (1995), who found an asymmetric scalp potential distribution predominant over the right frontocentral area in the three types of change.

The present results suggest different neural populations underlying the generation of MMN depending on the type of auditory change as suggested by Giard et al. (1995). However, further studies are needed, with better localization techniques, in order to determinate the localization of the MMN generators to difference types of auditory change.

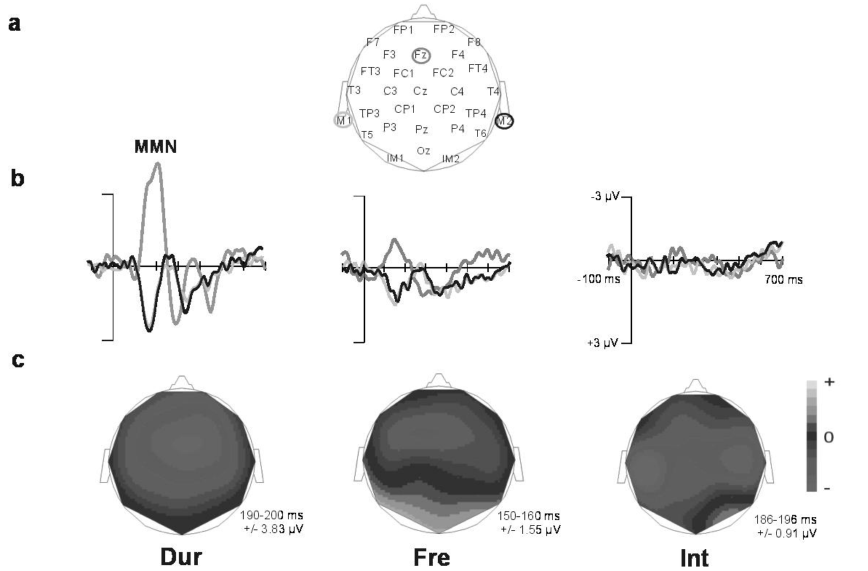

Figure 2. a, Distributions over the scalp of the 30 electrodes used in the recordings. **b,** Difference waves obtained by subtracting the standard ERP from the duration (Dur), frequency (Fre) and intensity (Int) deviant ERP at Fz (dark grey line), M1 (light grey line) and M2 (black line). **c,** Isopotential map of the MMN at a ±10 ms interval around the maximum peak in each condition.

References

Alho, K., Winkler, I., Escera, C., Huotilainen, M., Virtanen, J., Jaaskelainen, I.P., Pekkonen, E. & Ilmoniemi, R.J. (1998). Processing of novel sounds and frequency changes in the human auditory cortex: magnetoencephalographic recordings. *Psychophysiology*, **35**(2), 211-24.

Deouell, L.Y., Bentin, S. & Giard, M.-H. (1998). Mismatch negativity in dichotic listening: evidence for interhemispheric differences and multiple generators. *Psychophysiology*, **35**(4), 355-65.

Giard, M.-H., Perrin, F., Pernier, J. & Bouchet, P. (1990). Brain generators implicated in the processing of auditory stimulus deviance: a topographic event-related potential study. *Psychophysiology*, **27**(6), 627-40.

Giard, M.-H., Lavikainen, J., Reinikainen, K., Perrin, F., Bertrand, O., Pernier, J. & Näätänen, R. (1995). Separate representation of stimulus frequency, intensity and duration in auditory sensory memory: an event-related potential and dipole-model analysis. *Journal of Cognitive Neuroscience*, **7**(2), 133-143.

McCarthy, G. & Wood, C.C. (1985). Scalp distributions of event-related potentials: an ambiguity associated with analysis of variance models. *Electroencephalography and Clinical Neurophysiology*, **62**, 203-208.

Näätänen, R., Gaillard, A.W.K. & Mäntysalo, S. (1978). Early selective-attention effect on evoked potential reinterpreted. *Acta Psychological*, **42**, 313-329.

Näätänen, R. (1992). *Attention and Brain Function*. Hillsdale, NJ: Erlbaum.

Rinne, T., Alho, K., Ilmoniemi, R.J., Virtanen, J., Näätänen, R. (2000). Separate time behaviors of the temporal and frontal mismatch negativity sources. *Neuroimage*, **12**(1), 14-9.

Yago, E., Escera, C., Alho, K. & Giard, M.-H. (2001). Cerebral mechanisms underlying orienting of attention towards auditory frequency changes. Neuroreport, **12**(11), 2583-2587.

Acknowledgements

This study was supported by the grant PM99-0167 of the Spanish Ministry of Science and Tecnology.