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Sensory memory during physiological aging indexed by mismatch negativity (MMN)

Manuela Ruzzoli[a], Cornelia Pirulli[a], Debora Brignani[a], Claudio Maioli[b], Carlo Miniussi[a,b,*]

[a] Cognitive Neuroscience Section, IRCCS San Giovanni di Dio Fatebenefratelli, Brescia, Italy

[b] Department of Biomedical Sciences and Biotechnology, National Institute of Neuroscience, University of Brescia, Italy

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Abstract

Physiological aging affects early sensory-perceptual processes. The aim of this experiment was to evaluate changes in auditory sensory memory in physiological aging using the Mismatch Negativity (MMN) paradigm as index. The MMN is a marker recorded through the electroencephalogram and is used to evaluate the integrity of the memory system. We adopted a new, faster paradigm to look for differences between 3 groups of subjects of different ages (young, middle age and older adults) as a function of short or long intervals between stimuli. We found that older adults did not show MMN at long interval condition and that the duration of MMN varied according to the participants' age. The current study provides electrophysiological evidence supporting the theory that the encoding of stimuli is preserved during normal aging, whereas the maintenance of sensory memory is impaired. Considering the advantage offered by the MMN paradigm used here, these data might be a useful reference point for the assessment of auditory sensory memory in pathological aging (e.g., in neurodegenerative diseases).

Keywords: MMN; Auditory memory; ERP; Normal aging

1. Introduction

Physiological aging is commonly associated with a general decline of cognitive skills, including executive functions, memory, visuo-spatial abilities and the speed of information processing. These reductions in cognitive performance probably reflect age-related changes in the brain, which involve several structural and functional modifications during aging (Creasey and Rapoport, 1985). These changes also affect early sensory-perceptual processes (De Sanctis et al., 2008; Fitzgibbons and Gordon-Salant, 1995; Schneider and Hamstra, 1999; Snell et al., 2002) and play an important role in many cognitive processes by functioning as an interface between attention, memory and action (Baddeley, 1996). Mismatch negativity (MMN) is a neurophysiological marker of auditory sensory memory (Näätänen and Winkler, 1999) that is used to evaluate the integrity of echoic memory (Näätänen et al., 2005), learning and the accuracy of the auditory system (Garrido et al., 2009). MMN is elicited when a detectable auditory change or a regularity violation (Winkler et al., 2001) occurs (e.g., an infrequent deviant tone) in a sequence of frequent standard stimuli (Näätänen et al., 1978). MMN arises from an automatic comparison between the current sensory input and the memory trace of the previous tone; this comparison can be accounted for short-term plasticity mechanisms. In healthy subjects, the sensory memory decays after several seconds because MMN is no longer elicited if the stimulus-onset asynchrony (SOA) is longer than 10 seconds (Sams et al., 1993). During that interval, the SOA reflects the ability of the memory system to maintain information.

In comparison with other indexes, the MMN provides several advantages for the study of memory trace decay in aging because it occurs in the absence of attention engagement or task demands. For these reasons, the MMN is particularly suitable for use in a broad range of clinical populations, including patients with pathological aging (e.g., Alzheimer's and Parkinson's diseases), psychiatric disorders and coma (Bronnick et al., 2010; Näätänen, 2003;

* Corresponding author. Tel.: +39 0303717441; fax: +39 0303717443.
E-mail address: miniussi@med.unibs.it (C. Miniussi).

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Pekkonen, 2000). Despite the large number of studies on MMN, there is little consensus on whether and how the MMN is modulated during normal aging. An understanding of the natural changes affecting auditory sensory memory during normal aging should be the starting point for all investigations on MMN in pathological aging.

Some studies on MMN in older adults have provided evidence for a reduction of MMN compared with younger groups during short SOAs, which supports a specific deficit in the encoding process of sensory information (Alain and Woods, 1999; Cooper et al., 2006; Czigler et al., 1992; Karayanidis et al., 1995; Woods, 1992). However, this result has not been confirmed by other studies (Amenedo and Diaz, 1998; Gaeta et al., 2001; Gunter et al., 1996; Kazmerski et al., 1997; Pekkonen et al., 1993). Few investigations have explored MMN modulation during long SOAs; these experiments state a general decrease of MMN amplitude (Cooper et al., 2006; Czigler et al., 1992; Pekkonen et al., 1993, 1996). When this reduction was concomitant with a normal MMN during short SOAs, only impairment of information maintenance was suggested (Pekkonen et al., 1993, 1996).

The divergence among previous findings might be attributed to several factors, including differences in experimental design (e.g., SOAs, the probability of deviants), in MMN recording and analysis (e.g., reference electrode) and in the age of the groups. Another relevant confounding variable is generated by the characteristics of the deviant stimulus, which may differ from the standard tone in frequency or duration (Cooper et al., 2006; Pekkonen et al., 1996; Schroeder et al., 1995).

Here, we used a new and faster paradigm, proposed and validated by Grau et al. (1998), that reduces the recording time compared to the classical paradigm by about one-third, which is not a trivial aspect in the testing of patients. By delivering trains of 3 stimuli instead of single tones, Grau et al. (1998) reduced the temporal length of the entire presentation, yet preserving the correct proportion between standard and deviant stimuli. The advantage of the short duration suggests that its potential application in pathological aging is greater than that of the standard paradigm. Thus, we intended to identify normative data about changes in auditory sensory memory during normal aging using this paradigm. In addition, to better characterize any alterations in auditory sensory memory across aging, we studied 3 groups of subjects: young, middle-aged and older adults. Finally, we investigated both the frontal and temporal components of MMN, which have been linked to different cerebral sources and functional roles (Alho et al., 1994; Giard et al., 1990; Opitz et al., 2002; Rinne et al., 2000).

The aim of the present study was to evaluate the presence of any significant alterations in auditory sensory memory during physiological aging by studying the MMN elicited by a duration-deviant stimulus across 3 groups of subjects. To determine whether older adults have difficulty in encoding acoustic stimuli or in maintaining the representation of such stimuli over time (Cowan, 1984), we compared the MMN elicited at short vs long intertrain intervals (ITI) (400 vs 4000 ms).

2. Methods

2.1. Participants

Fifty-four voluntary participants took part in the experiment. They were divided into 3 groups according to age with each group composed of 18 subjects: young (age range from 21 to 40 yr), middle-aged (ranging from 41 to 60 yr) and older adults (ranging from 61 to 80 yr).

Participants underwent a neuropsychological evaluation in order to test their cognitive status. The tests battery assessed language comprehension (Token Test), memory (Digit Span; Spatial Span; Auditory-Verbal Learning Test, immediate and delayed recall; Rey-Osterrieth Complex Figure, Recall; Wechsler Memory Scale), constructional and visuo-spatial abilities (Rey-Osterrieth Complex Figure, Copy) attention and executive functions (Trial-Making Test A and B). All tests were administered and scored according to standard procedures (Lezak et al., 2004). In addition, a brief hearing test was performed on all participants to exclude those who presented sensory deficit. Nine subjects who presented one or more pathological test scores were excluded from the study. Moreover, 3 additional subjects were excluded from the analyses for excessive artefacts during EEG recording. The final composition of the groups was as follows: 15 young subjects (6 males, mean age 33.60 $\pm$ 4.42 yr), 12 middle-aged subjects (8 males, mean age 50.83 $\pm$ 6.60 yr) and 15 older adult subjects (9 males, mean age 68.13 $\pm$ 5.76 yr). Written informed consent was obtained from all participants. The protocol was carried out in accordance with the ethical standards of the Declaration of Helsinki and was approved by the local ethics committee for research in human subjects of the IRCCS San Giovanni di Dio Fatebenefratelli, Brescia, Italy.

2.2. Stimuli and procedure

The stimuli and procedure were the same as those used in Grau et al. (1998) (Fig. 1). Sequences of 3 tones were presented binaurally with earphones. The sequences differed only in the first tone, which could be standard (50%) or deviant (50%). All of the remaining tones were always standard. The overall probabilities of the standard and the deviant tone were 0.83 and 0.17, respectively. The standard tone was a pure sine wave tone of 700 Hz with an intensity of 85 dB SPL (sound pressure level) and a duration of 75 ms. The deviant tone had the same frequency and intensity as the standard tone but a different duration (25 ms). The SOA between tones within the same train was 300 ms.

Every participant completed 2 separate experimental blocks in the same day, separated by five minutes of break. Each block had a short (400 ms) and a long (4000 ms) ITI. The order of presentation of the blocks was balanced be-