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Auditory sensory memory and the aging brain: A mismatch negativity study

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Abstract

The mismatch negativity (MMN) component of the auditory event-related potential has been used in the past to study between group differences in the accuracy and retention of information in auditory sensory memory (ASM). The MMN is elicited by infrequent 'deviant' tones that differ from a repeating 'standard' tone. In the present study, the type of deviant and the time interval between tones (stimulus-onset asynchrony: SOA) were manipulated in a study of normal aging. MMN responses of an elderly (mean age = 69) and a young group (mean age = 21) to both a duration and a frequency deviant tone were measured at a short (450 ms) and long (3 s) SOA. A smaller and later MMN (recorded at Fz) was observed in the elderly relative to the young group across SOA and Deviant conditions. The results are consistent with an age-related deficit in the encoding of sound properties in ASM. However, analysis of the MMN reversal at the mastoids provides some support for the proposal that the elderly have an additional deficit related to the retention of information in ASM.
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1. Introduction

A review of current mismatch negativity (MMN) literature indicates that there is little consensus on whether elderly persons have difficulty encoding sound stimulus properties in the first phase of auditory sensory memory or in maintaining these representations over time (phase two of auditory sensory memory, see below [6]). The acquisition of quality normative data identifying auditory sensory memory changes characteristic of the natural aging process is needed to aid our understanding of clinical data. For instance, although the MMN has previously been used to evaluate auditory sensory memory functioning in Alzheimer's disease [11,33–35,40,54], results from such studies have been difficult to interpret in terms of whether they constitute an exacerbation of normal aging or a unique pattern of change. Therefore, the primary aim of the present study was to compare MMN in an elderly relative to a young group and investigate whether the elderly have difficulty encoding or maintaining sound properties in auditory sensory memory.

1.1. The mismatch negativity

The MMN is a component of the auditory event-related potential (ERP) that is automatically elicited approximately 100–200 ms following a detectable change in a repetitive sequence of auditory stimulation [27]. The MMN is elicited to infrequent 'deviant' tones that differ from a repeating 'standard' tone [39]. For example, a 'frequency deviant' would differ from the standard only in frequency and be perceived as a change in pitch. The elicitation of a MMN reflects a process in which the brain continually updates an internal model of regularities in the auditory environment. In response to repetitive acoustic stimulation, the brain models incoming stimuli to predict what sound is likely to be heard next. In effect, the MMN not only signals that a deviation (from the model's prediction) has been detected, but also that the model of the acoustic environment is being updated to incorporate characteristics of the deviant event [55].

MMN amplitude is largest when recorded from fronto-central electrode sites [26]. When attention is directed towards sound, it is difficult to observe a pure MMN as attention elicits another ERP component at a similar latency,

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the N2b wave [27]. Therefore, most MMN studies require that participants ignore auditory stimuli by performing a distracting task such as watching a video. One way of distinguishing the MMN from other ERP components is by measuring activity from electrodes placed over the mastoid bones and observing the reversal in polarity of the waveform relative to fronto-central sites. This occurs because the major source of scalp-recorded MMN activity is located in the supratemporal auditory cortex [15,45], which lies between fronto-central and mastoid sites. MMN amplitude measures derived from the mastoids have been argued to primarily reflect activation of the supratemporal generator in the auditory cortex whereas electrodes located fronto-centrally are believed to be additionally sensitive to activation of a proposed frontal generator [15,29]. Specifically, the dorsolateral prefrontal cortex and dorsolateral prefrontal cortex projections have been implicated in MMN generation [3] as has the right fronto-opercular cortex [32].

1.2. The MMN and phase one of auditory sensory memory

According to Cowan [6], two phases of auditory sensory memory can be identified. In phase one, lasting 200–300 ms after stimulus-onset, sound features are analyzed whilst the listener experiences a lingering sense of the previous sound. It is during this period that the representation of sound stimulus properties underpinning our discrimination ability is encoded, and thus, it is in this early stage of processing that the precision of the memory trace is determined. There is evidence indicating that the size (amplitude) and timing (latency) of the MMN are linked to one's capacity for accurate sound discrimination. For example, an easily discriminable change in auditory stimulation elicits a larger MMN than a less discriminable one [47]. In addition, an earlier peak MMN amplitude is predictive of a faster behavioural response to stimulus change [52]. A review of the MMN concluded that increases in the physical difference between standard and deviant stimuli are associated with increases in the peak amplitude of the MMN, decreases in the latency of this peak and improvements in behavioural discrimination [28]. Importantly, MMN and behavioural studies testing sound discrimination ability have typically used a short stimulus-onset asynchrony (SOA: the time between the onset of successive sounds) such as half a second to ensure that MMN reflects primarily the processes relating to the encoding of sound properties. In contrast, lengthening the SOA to several seconds is one way of measuring the integrity with which the memory trace is maintained, or the rate of decay (e.g. [37]).

1.3. The MMN and phase two of auditory sensory memory

The second phase of auditory sensory memory or 'long auditory storage' is defined as a period in which the memory of an encoded sound is retained [6]. The long store maintains a sound stimulus representation for at least several seconds, although Cowan's review indicates that this information could be held for between 10 and 20 s. It has been established that the integrity of the memory trace declines over this period as it is more difficult to make judgments about sound attributes when the time between sounds increases. For example, at SOAs of 0.75, 1.5, 3 and 9 s, participants correctly identified whether successive sounds were the same or different significantly better than chance level [44]. However, when the interval between sounds was stretched to 12 s, the mean performance on this task did not exceed chance. In accordance with the behavioural data, the same study demonstrated a significant decrease in magnetic MMN amplitude at the 9 and 12 s SOA in comparison to the shorter SOAs.

In sum, behavioural and MMN evidence indicates that the duration of auditory sensory memory extends to approximately 10 s. However, estimating the absolute duration of auditory sensory memory in different groups is complex as experimental variables besides SOA, such as the interdeviant interval and the contextual relevance of sounds, have an impact on such estimates [18,42,57]. Therefore, the current study follows the practice of past research (e.g. [37]) in not seeking to obtain an absolute estimate of auditory sensory memory duration in the elderly. Instead, the proposed link between the integrity of the auditory sensory memory trace and MMN recorded at different SOAs is used to explore the precision of encoding and integrity of maintenance of sound stimulus properties in elderly compared to young persons.

1.4. The MMN and aging

Three recent studies provide evidence of changes in central auditory processing in the elderly, demonstrating reduced MMN amplitude in the elderly relative to the young [1,5,14]. The following review (see Table 1 for a summary of stimulus parameters), however, demonstrates that there is little consensus on whether the elderly MMN is attenuated at a short or only a long SOA (here, we refer to an SOA less than 2 s as short and greater than 2 s as long). For example, to date the MMN to a duration deviant sound has only been tested at a short SOA, with four reports [21,37,46,58] of a significantly reduced MMN in an elderly relative to a young group, and one report of no significant MMN attenuation in the elderly at a short SOA of 500 ms [37]. Similarly, whilst five groups of researchers have observed reduced MMN amplitude in elderly relative to younger individuals at a short SOA in response to a frequency deviant tone [2,8,10,12,16], five studies have reported no significant attenuation of frequency MMN in the elderly [4,23,36,37,46].

In three of the aforementioned frequency MMN studies, the MMN was also assessed at a long SOA. Although no difference between a young and elderly group was observed using a short SOA, two studies reported attenuation of the elderly MMN at a long SOA (3 and 4.5 s, respectively [36,37]). An additional study also observed smaller peak MMN amplitude in an elderly relative to a young group

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