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Successful measurement of the mismatch negativity despite a concurrent movie soundtrack: Reduced amplitude but normal component morphology

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HIGHLIGHTS

- The mismatch negativity (MMN) is observed but with reduced amplitude when EEG is recorded while listening to a movie soundtrack.
- The movie soundtrack acts as a low-level masking noise.
- MMN amplitude increases as the sound-to-noise ratio of the MMN-critical tones over the soundtrack increases.

ABSTRACT

Objective: To examine the mechanisms responsible for the reduction of the mismatch negativity (MMN) ERP component observed in response to pitch changes when the soundtrack of a movie is presented while recording the MMN.
Methods: In three experiments we measured the MMN to tones that differed in pitch from a repeated standard tone presented with a silent subtitled movie, with the soundtrack played forward or backward, or with soundtracks set at different intensity levels.
Results: MMN amplitude was reduced when the soundtrack was presented either forward or backward compared to the silent subtitled movie. With the soundtrack, MMN amplitude increased proportionally to the increments in the sound-to-noise intensity ratio.
Conclusion: MMN was reduced in amplitude but had normal morphology with a concurrent soundtrack, most likely because of basic acoustical interference from the soundtrack with MMN-critical tones rather than from attentional effects.
Significance: A normal MMN can be recorded with a concurrent movie soundtrack, but signal amplitudes need to be set with caution to ensure a sufficiently high sound-to-noise ratio between MMN stimuli and the soundtrack.

1. Introduction

When a physically deviant sound is presented within a sequence of repetitive acoustic stimuli, diverse event-related potential (ERP) components may be observed in response to the sound deviance. One of these components, the mismatch negativity (MMN), has proven to be a sensitive index of the perceptual detection of change for many acoustic stimulus features (Näätänen and Winkler, 1999; for a critical review, see May and Tiitinen, 2010). In the paradigm classically used to elicit an MMN, sounds are presented to the observer along with a diversion task generally consisting in reading a book or watching a silent subtitled movie (Muller-Gass et al., 2005).

Although the MMN is typically measured by presenting sounds in silence, in some MMN studies, the participants were allowed to listen to the soundtrack of a movie at a low intensity level (40–55 dB SPL) while they were presented with the auditory stimulation designed to produce the MMN (e.g., Bellis et al., 2000; Bradlow et al., 1999; Hayes et al., 2003; Kraus et al., 1999; McGee et al., 2001; Starratt and Nash, 2004; Todd et al., 2008; Tremblay et al., 1997). In a recent study, McArthur et al. (2003) assessed the efficacy of presenting a movie with the soundtrack to elicit an MMN component.

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They presented binaurally through headphones, a 600 Hz deviant tone and a 700 Hz standard sound (duration, 25 ms; ISI, 320 or 200 ms) at an intensity level of 80 dB SPL as the participants watched a movie with the soundtrack presented at 50 dB SPL in one condition, and with the movie soundtrack turned off in the other condition. They observed a reduction in MMN amplitude when the movie soundtrack was on. A similar MMN reduction was also observed in children by Mahajan and McArthur (2011).

These results clearly point to an observable effect of the movie soundtrack on the MMN. However, they do not explain why the MMN is reduced. Presenting the movie soundtrack could facilitate the testing of pre-literate children or the illiterates, or some clinical populations, by alleviating boredom by means of an entertaining distraction. But before using such a paradigm, there is a need to ensure that the movie soundtrack does not alter the generation mechanism of the MMN in such a way that it could confound the interpretation of the results. From a theoretical point of view, it is also worth studying the effect of the soundtrack on the MMN. Indeed, the reduction observed in MMN amplitude in the presence of the soundtrack may reflect an attentional effect. On the other hand, as suggested by Mahajan and McArthur (2011), it could also be that the soundtrack generated a masking noise effect, by which the complex array of voices, sounds, and music of the soundtrack may interfere with the sensory encoding of MMN-critical tones.

The attentional effect hypothesis has not been raised in previous studies evaluating the effect of a concurrent soundtrack on the MMN, and this hypothesis deserves consideration. Before exploring diverse hypotheses regarding the effect of the soundtrack on the MMN, it is first worth examining how the MMN generation mechanism works and how attention is expected to affect MMN. According to Näätänen's model Näätänen (1990), the elicitation of the MMN depends on the formation of a short-lived sensory memory trace of a frequent sound (often called the standard). The standard stimulus memory representation is strengthened as the sound is repeatedly presented. However, if a subsequent deviant stimulus is detected as different from the sensory trace of the standard sound, then the MMN generator mechanism is activated. More recently, the MMN has rather been described as representing a response to a violation of an auditory regularity, such as a rare change in the physical features of a standard repetitive stimulus (Winkler, 2007). That is, the repeating standard sounds generate a regularity representation to which the auditory upcoming events are compared. If a stimulus breaks the regularity, then the MMN is elicited. Furthermore, in the classic oddball paradigm used to elicit an MMN, there is also some evidence of the contribution of the auditory N1 component (Kujala et al., 2007). In fact, as the standard sounds are repeatedly presented, the neurons gradually become increasingly more refractory, which generates a smaller N1 to the standard. Following this adaptation, the neurons dedicated to the frequency of the deviant sounds will show less refractoriness and will generate a larger N1. Thus, when subtracting the waveforms in order to extract the MMN, the contribution of the N1 will remain. However, in this article, we will refer solely to the MMN but the reader should bear in mind that it also likely contains N1 contributions.

Many studies have also focused on the neural generators of the MMN. Näätänen and Alho (1995) have suggested that the MMN-generating mechanism reflects the activation of neural populations in the temporal lobes, responsible for the detection of change, and in the frontal areas involved in the initiation of an attentional switch towards the (previously) unattended stimulus (see Deouell, 2007, for a critical review). When both temporal and frontal neural generators are activated, a resulting MMN can be observed as a fronto-central negative deflection generally peaking at Fz between 100 and 250 ms after the onset of the rare stimulus (Tiitinen et al., 1994). Central to Näätänen's model of the MMN generating system is the claim that the change detection process is automatic and does not require attention, which has generated an ongoing debate on the effects of attention on the MMN (see Sussman, 2007, for a critical review).

In early studies aiming to demonstrate the insensitivity of the MMN to attention, researchers used selective-listening tasks with dichotic auditory stimulation that aimed to focus attention on the stimuli presented in one ear and divert attention from the sounds presented to the other ear. These paradigms have demonstrated that small changes in the auditory stimulation elicited comparable MMNs when the stimuli were either presented to the to-be-attended or to the to-be-unattended ear (Näätänen et al., 1978, 1980). However, these results have been criticized (Woldorff and Hillyard, 1990), and further studies have demonstrated that attention could affect the recording of the MMN (Alain and Woods, 1997; Näätänen et al., 1993; Oades and Dittmann-Balcar, 1995; Woldorff et al., 1991), by showing that MMN amplitude increased when the stimuli were being attended. Yet, these results were also criticized and described as reflecting the effect of an additional task-relevant ERP component named N2b (Näätänen, 1991). The N2b which is a negative deflection that reflects a response to a target stimulus when the task requires detecting deviations, that may overlap with the MMN both temporally and spatially, resulting in a summation of ERP components that could be (mistakenly) interpreted as a larger MMN in the attended condition (Näätänen, 1991).

In order to avoid the problem created by the summation of the N2b with the MMN in the attended condition, further studies manipulated task demands to avoid attention from being actively directed to the MMN-critical tones, and they generally found no effect of concurrent visual task difficulty on the MMN response (Alho et al., 1992; Dittmann-Balcar et al., 1999; Harmony et al., 2000; Kathmann et al., 1999; Muller-Gass et al., 2006; Otten et al., 2000). Only a few studies found an attentional load effect on the MMN with contradictory results (Kramer et al., 1995; Yucel et al., 2005; Zhang et al., 2006). More recently, Sussman (2007) shed new light on the debate on the effects of attention on the MMN by proposing that attention does not influence the MMN generating mechanism as a whole, but can specifically interfere with the formation process of the standard. Attentional effects were observed when focusing on specific aspect of the auditory stimulation, such as actively discriminating sound pitches (Sussman et al., 1998a) or focusing on sequential patterns within the stream of sounds (Sussman et al., 2002). These considerations highlight the potential importance of the acoustic context for the formation of the memory trace of the standard, *per se*, rather than solely on the deviance detection mechanism.

The issues addressed in the debate on the effect of attention on the MMN raise interesting questions regarding the paradigms used to generate the MMN in studies not aiming to evaluate attentional effects. Indeed, in the MMN experiments using a movie soundtrack, the diversion task presented to the participant requires attention in both visual and auditory modalities. However, watching a movie is not a highly demanding task, and when the soundtrack is presented, part of the participant's attention is likely oriented to the auditory modality and probably also to the MMN-critical tones occurring simultaneously. On the other hand, one could also wonder if the semantic content of the soundtrack interferes with the elicitation of the MMN by generating semantic processing of the information. Furthermore, as the soundtrack is presented simultaneously to the auditory stimulation meant to evoke the MMN, the MMN-critical tones become part of a complex auditory scene that will act as masking noise, out of which it may be difficult to extract the standard and deviant sounds needed for the deviance detection generating mechanism of the MMN to occur, which may result in the reduction or the abolition of the MMN. These are all possibilities that need to be addressed before considering presenting a movie soundtrack in a study using the MMN.