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Parameter-specific modulation of the mismatch negativity to duration decrement and increment: Evidence for asymmetric processes

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Abstract

Objective: The mismatch negativity (MMN) component of event-related potentials (ERPs) reflects a change-detection process in the brain. The present study investigated whether stimulus parameters (sound type and duration) exert a differential influence on the MMN for a duration decrement and increment of an equal magnitude. Some asymmetries were reported in the previous studies; yet no systematical study has been conducted.

Methods: ERPs were recorded from 16 healthy adults presented with repetitive standard sounds interspersed with duration changes (deviant sounds). In separate sequences, stimuli were vowels, music chord, sinusoid, or band-pass filtered white noise. The stimulus durations (standard/deviant) were either 200/120 ms or 400/240 ms for decrements, and vice versa for increments.

Results: The MMN for the increments was abolished in the 400/240 ms condition, whereas the MMN for decrements was significant irrespective of the sound duration. The amplitude of the increment MMN paralleled with the spectral complexity of the stimulus sound, whereas that of the decrement MMN was larger for natural sounds than artificial sounds.

Conclusions: The observed interactions demonstrated asymmetries in the MMN for duration increment and decrement.

Significance: The present findings suggest that the effects of stimulus parameters should be taken into account when comparing different studies, especially where clinical populations are involved, with one another.

Keywords: Mismatch negativity; Sound duration; Temporal processing; Preattentive change detection; Event-related potential

1. Introduction

The mismatch negativity (MMN) (Näätänen et al., 1978) is an event-related potential (ERP) component that is elicited by changes in a regular sound flow even when the stimulus sounds are task irrelevant and ignored. The MMN amplitude generally varies as a function of the magnitude of change and correlates with the accuracy of sound discrimination in behavioural performance (Amenedo and Escera, 2000; Jaramillo et al., 2000; Tiitinen et al., 1994). The MMN has attracted considerable interest in clinical research for it does not rely on the patient's active response and thus provides an objective index of central auditory processing (see e.g., Kujala et al., 2007 for a review).

The MMN elicited by duration changes (the duration MMN) is one of the most frequently used responses in clinical studies. It is typically recorded in an "oddball" paradigm, in which repetitive "standard" sounds are interspersed with occasional "deviant" sounds that differ from the standard only in duration. By comparing the duration MMN with that elicited by changes in other attributes, it can provide a clue to determine whether the problem is specific to temporal processing or not. For example, in persons with schizophrenia, duration MMNs are more deficient than frequency MMNs (for reviews, see Michie,

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2001; Umbricht and Krljes, 2005). Also, quite a similar pattern was found in children with autism (Lepistö et al., 2005).

One distinctive trend in the MMN studies on schizophrenia is that they mostly use duration increment, whereas basic studies mainly use duration decrement. This trend is based on two early studies (Catts et al., 1995; Shelley et al., 1991) that compared between schizophrenic patients and controls the MMNs to duration increment and decrement of an equivalent magnitude and found a significant group difference only for the increment. In line with these results, two more recent studies (Kasai et al., 1999, 2002) using duration decrement alone reported little difference between patients and controls. The results of these studies, taken together, may reflect some disparity between the neural process underlying the MMN responses to duration decrement and increment. Such disparity, however, has not been studied systematically yet. Hence, the present study examined whether stimulus factors (sound duration and sound type) exert differential effects on the MMN for duration increment and decrement of an equal magnitude. Since the amplitude of duration MMN usually varies as a function of the magnitude of deviance (Jaramillo et al., 2000; Näätänen et al., 2004), any disproportional effect on the increment and decrement MMNs elicited by an equal magnitude of deviance would indicate the existence of an asymmetrical process.

One important stimulus factor determining duration MMN is the duration of deviant-stimulus. Previous studies, using duration decrement, reported absence or a significant amplitude reduction for deviant-stimulus durations beyond 400 ms (400 ms in Grimm et al., 2006; 600 ms Grimm and Schröger, 2005; 400 ms in Näätänen et al., 2004). On the other hand, no significant amplitude difference was found for deviant-stimulus below 200 ms (25-200 ms in Näätänen et al., 1989; 100 and 200 ms in Näätänen et al., 2004). This susceptibility of duration MMN to the deviant-stimulus duration of 400 ms can be used for testing the asymmetry between increment and decrement MMN: for a given set of two sounds differing only in duration, presenting the longer sound more frequently than the shorter one form a decrement deviant, and vice versa an increment deviant of an equal magnitude. If the longer sound alone exceeds the "threshold" duration of 400 ms (above-threshold condition), the increment MMN should be significantly smaller than the decrement MMN even though the magnitude of deviance is equal between the increment and decrement deviants. On the other hand, if both two sounds are shorter than the threshold (below-threshold condition), the amplitudes of the decrement and increment MMNs should be similar to each other.

Technically, decrement and increment MMNs can reflect different neuronal activities. For a decrement deviant, the magnitude of deviance is already physically present at the onset of deviance. In contrast, for an increment deviant, a delay necessarily exists between the onset of deviance and the moment when the magnitude of deviance is physically present at the offset of deviant sound. Thus, if each of these two cues (deviance onset and the magnitude of deviance) contributes to the MMN generation process, a topographical difference between an increment and decrement MMN is expected since the temporal overlap of the neural activities associated with the two cues is larger for decrement than increment MMN.

While most clinical studies on duration MMN used sinusoids as stimuli, recent studies reported that the duration MMN generation process may partly differ depending on sound type in which duration changes are embedded. One recent study on schizophrenia reported a significant correlation between verbal memory and the amplitude of duration MMN for phoneme but not for sinusoid (Kawakubo et al., 2006). Also, an fMRI study by Tervaniemi et al. (2006b) reported that duration decrement embedded in speech and music sound differently activated the temporal and frontal lobes and thalamic structures. In addition, sound type can influence the increment and decrement differently too; Jaramillo et al. (1999), comparing the amplitude of the increment and decrement MMNs with each other for speech-like and noise-like synthesized sounds, observed a significant interaction between sound type and change direction, that is, a larger increment than decrement MMN for the noise stimuli and the opposite pattern for the vowel stimuli. Hence by using various sound types and stimulus durations that are similar to and longer than those in Jaramillo et al. (1999), we examined whether the interaction of change direction and sound type is specific to the contrast of speech and non-speech sound and/or certain stimulus duration. We employed both spectrally matched speech and non-speech sounds (semi-synthesized vowel and music chord) and spectrally distinct non-speech sounds (sinusoid and band-pass filtered white noise) (see Fig. 1) for the afore-mentioned two duration conditions.

2. Methods

2.1. Subjects

Sixteen adults participated in the study (eight males and eight females, mean age 22.6 years, range 19–27 years). All the subjects were right-handed native speakers of Finnish. They had reportedly normal hearing and no history of neurological disease. They gave written informed consent after the nature of the study was explained to them. They received monetary compensation or course credit for participation. The study was approved by the Ethical Committee of the Department of Psychology, the University of Helsinki.

2.2. Stimuli

The vowel sound /e/ was created using Semisynthetic Speech Generation (SSG) method (Alku et al., 1999), which allows the quantification of the acoustical features of speech sounds while preserving the naturalness. The fundamental frequency of the vowel stimuli was 104 Hz and the lowest