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Involuntary Processing of Timbre: A Mismatch Negativity Study

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Abstract. Timbre is a key and complex attribute of sound that might be pre-attentively coded in sensory memory, and the mismatch negativity (MMN) component of event-related potential (ERP) might be adopted to detect this process. The present study investigated the timbre MMN in an oddball paradigm, with piano tone as standard, and sine wave or trumpet tone as deviant separately. Both deviants evoked a MMN component in a streaming of piano tones. Statistical analysis indicated that MMN for pure tone was significantly larger in magnitude than that for trumpet tone. The results evinced that the involuntary processing of timbre variations was relate to not to the spectral complexity but to the discrepancy between the standard and deviant tone.

Keywords: Timbre; Mismatch negativity (MMN); Event-Related Potential (ERP); Oddball; Spectral Complexity;

1. Introduction

Timbre is interpreted as an attribute of sensation to discriminate two sounds with the same loudness and pitch. Unlike other attributes of sound, such as pitch, loudness and duration, which can be described by one physical parameter, timbre is a multidimensional attribute, associated with not only temporal waveform (e.g. attack time) but also the spectral shape (e. g. spectral flux, spectral centroid of sounds [Meyer et al, 2006]. The neural underpinnings of timbre is of obvious interest as the identification of the neural network mediating timber information may allow researchers to learn more about the subtle functional architecture of the auditory system in the human brain [Meyer et al, 2006].

The mismatch negativity (MMN) of the auditory event-related potential (ERP), elicited by discriminable or even undiscriminable changes in any aspect of auditory stimulation [Näätänen et al, 2007], is a useful tool to investigate the early processing of sound features in the auditory sensory memory. MMN is a fronto-central (relative to a mastoid or nose reference electrode) negative potential, with a peak usually around 200 ms after change onset , and sources mainly in the bilateral supratemporal cortices and frontal lobes [Näätänen et al, 2007]. An important feature of MMN is that it is elicited irrespective of whether the subject performs a task with the stimulation. So it is generally assumed that the early, attention independent stages of auditory processing is reflected by MMN [Näätänen et al, 2007]. A number of studies utilizing MMNs to investigate the timbre perception demonstrated that timbre and its dimensions are pre-attentively encoded in the sensory memory [Tervaniemi et al, 1997; Goydke et al, 2004]. Additionally, a MMN study revealed the separate neural representations of the timbre dimensions (attack time, spectral centroid, and spectrum fine structure) in the auditory system [Caclin, 2006]. However, due to the complex nature of timbre, its psychoacoustic underpinnings are not yet sufficiently stipulated.

The present study was aimed to investigate the timbre processing by an ERP experiment in traditional oddball paradigm. As an important index of involuntary auditory processing [Näätänen et al, 2007], the mismatch negativity (MMN) was thus used here to probe the automatic processing of timbre variations in an auditory flow. Two tones (sine wave, trumpet) were used as deviant stimuli in separate blocks to test whether neural representations stored in the auditory cortex is relate to the spectral complexity. As the spectral information of sine wave and trumpet tones are very different, We hypothesis that the MMNs for both tones are significantly different.

2. Material and Methods

2.1. Stimuli

The computer-generated sound stimuli included three kinds of tones (sine wave, piano, trumpet) at B4 pitch. Tones of 400ms in duration were binaurally presented via headphones and the Inter-Stimulus-Interval (ISI) was constant at 400ms. The experiment consisted of two blocks, each with 960 tones presented in pseudorandom order. Two oddball blocks were subsequently presented with piano tone (B4) as the standard stimuli (P=0.875). The deviant stimuli were sine wave tone (B4) and trumpet tone (B4) separately, with a probability of P=0.125. The order of two oddball blocks was counterbalanced across participants. Subjects were seated in a comfortable chair and instructed to ignore the auditory stimuli while watching a self-selected soundless movie on a computer monitor 80cm away from them.

2.2. Subjects

Fifteen subjects (mean age: 24.9 yrs; all males) participated in the experiment. All were right-handed college students with normal hearing and normal or corrected-to-normal vision. None of them reported any history of neurological or psychiatric problems. Each participant signed a written informed consent before the experiment and was paid for their participation.

2.2. EEG Recording

The EEG was measured (bandpass 0.1-40Hz, sampling rate 500Hz) with a 129-channel Geodesic Sensor Net (GSN) (EGI System 200) attached on the subject's scalp according to the 10/20 system. The impedance of recording electrodes was kept below 40 kΩ during the data collection and all electrodes were referred to the vertex. Eye blinks were monitored with electrodes placed below both eyes.

2.2. Data Analysis

After digital bandpass filtering between 1 to 35Hz, the EEG data were divided into 1000ms epochs including a 200 ms pre-stimulus baseline. Artifact rejection was performed to discard epochs contaminated by eye blinks, eye movements, and muscle potentials. The rejection criterion was ±70μV. Data from three participants were excluded from further analysis because of excessive artifacts. Epochs were averaged and baseline corrected for each condition. Then all averaged waveforms were re-referenced with the reference electrode standardization technique (REST) [Yao, 2001].

MMNs were obtained by subtracting the responses to standards from those to deviants. Usually, the classic MMN peaks at 150-250 ms [Näätänen et al, 2007). Thus, MMN latency was defined as the peak latency of the most negative peak between 150 and 250 ms of the subtracted waveform for separate deviant, and MMN amplitude was determined as the mean of the 20ms window centered at the latency.

ERPs at medial frontal site (Fz) were used for statistical analyses. Paired t-test was conducted firstly to detect whether the ERP amplitudes to deviants were significantly more negative than that to standards in the 150-250 ms window. Then the amplitude and latency of MMNs elicited by sine wave and trumpet tones separately were contrasted also by paired t-test.

3. Results

The grand-averaged ERP waveforms for deviant (sine wave tone, trumpet tone) and standard (piano tone) in two separate oddball blocks were illustrated Fig.1, respectively. Difference waveforms were derived by subtracting the standard ERP of piano tone from the deviant ERP of sine wave or trumpet tone, separately, as shown in Fig.2.

The difference between deviant and standard was maximally negative at frontal electrodes and maximally positive at mastoid sites, implicating the elicitation of an MMN response [Tervaniemi et al, 2000]. A paired t-test was then carried out to determine statistical significance between the differences of N1 for standard (piano tone) and deviant (pure tone or trumpet tone) in two separate oddball blocks, which had a normal distribution. Each deviant (pure tone: $t=5.0160$, $p<0.001$; trumpet tone: $t= 7.2753$, $p<0.001$) evoked a more negative N1 than the standard. This evinced that both deviants elicited a significant MMN component. The amplitude and latency for each difference waveform were listed in Table 1.

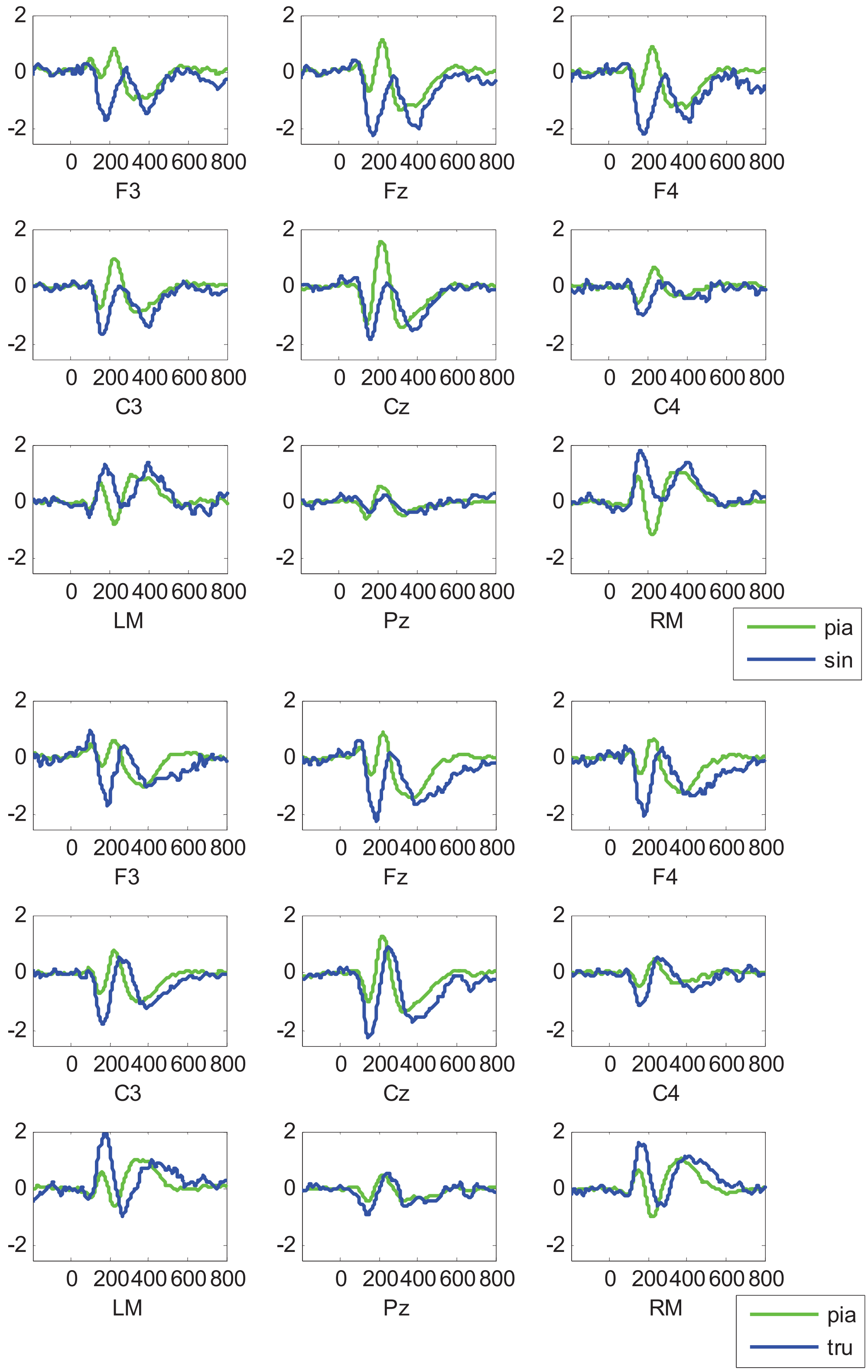

Figure 1. *Grand-averaged ERP waveforms evoked by standard and deviant in two separate oddball blocks (top: piano(standard), pure(deviant); bottom: piano(standard), trumpet(deviant)).*

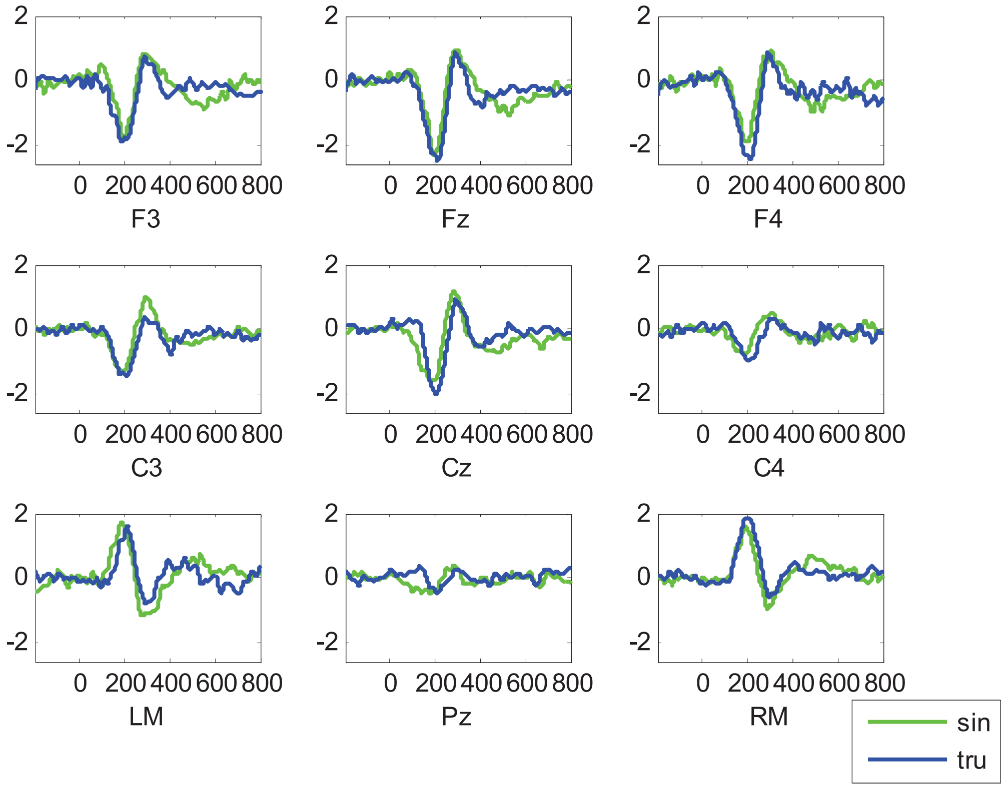

Figure 2. *Difference waveforms for deviant in two separate oddball blocks (trumpet tone (Tru), sine wave tone (Sin)), respectively.*

Table 1. *Magnitude and Latency of MMNs for sine wave and trumpet tones at Fz.*

MMN for pure tone		MMN for instrumental tone	
magnitude(μV)	latency(ms)	magnitude(μV)	latency(ms)
-2.54±0.58	198±28	-2.14±0.86	201±23

A paired t-test was carried out to determine statistical significance between the differences of MMN for sine wave and trumpet tones, which had a normal distribution. The magnitude of MMN for sine wave tone was significantly larger than that for trumpet tone ($t= -2.2770$, $p<0.05$). But no significant difference was found between the latency of MMNs for these two deviant tones.

4. Discussion

The present study was aimed to detect whether the timbre variations have an effect on the corresponding MMNs when the standard stimulus was a piano tone. Statistical analysis showed that the MMN for sine wave tone was significantly larger in amplitude than that for trumpet tone.

Previous research proposed that a larger discrepancy between the deviant and standard might be reflected in larger MMN amplitude [Sams et al, 1985]. Kisley et al [2004] also indicated that the MMN waveform amplitude was sensitive to small temporal change and would increase significantly with the degree of temporal variation, corresponding to the pre-attentive neural activity that subsequently allowed the conscious perception of time during a temporal discrimination task. Further investigations showed that MMN could reflect behavioral discrimination accuracy, i.e. sounds which could be reliably discriminated in behavioral tests would elicit MMN with larger amplitudes and shorter latencies than sounds which were more difficult to be discriminated [Kujala et al, 2001; Tervaniem, 1999]. As the MMN for sine wave tone was larger than that for trumpet tone, it suggested that the deviance between the sine wave and piano tone might be greater than that between the trumpet and piano tone.

According to Meyer et al [2006], significantly increased N1 and P2 amplitudes were found for all types of instrumental tones as compared only to sine wave tones, whereas no difference was between instrumental tones themselves. Then it is most perspicuous to assume the spectro-temporal complexity is similar between instrumental tones, but is significantly different between instrumental and pure tones. That's why the discrepancy between pure and piano tones was relatively larger than that between trumpet and piano tones. The result implicated that the automatic processing of timbre variations was mainly relate to the deviance between the standard and deviant.

5. Conclusions

The present study investigated the processing of timbre variation (sine wave or trumpet tone) in a streaming of piano tone. Statistical analysis indicated that both deviants evoked a MMN component. Furthermore, the MMN for pure tone was larger in magnitude than that for trumpet tone. The results evinced that the involuntary processing of timbre variations was relate to not to the spectral complexity of deviant but to the discrepancy between the standard and deviant tone.

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