The relationship between mismatch negativity and neuronal coding in auditory rhythm changes

Seiji TAMAKOSHI* and Akihiro YAGI*

*Department of Psychological Science, Kwansei Gakuin University

Abstract: The purpose of this study was to investigate human attention and auditory processing as indexed by event-related potential (ERP) mismatch negativity (MMN). MMN was recorded during gaps in rhythmic, repetitive sound. A hemispheric asymmetry was observed for the early negativity but not MMN amplitude. LORETA analysis findings support the assumption that the change detection signal generated in the auditory cortex triggers frontal mechanisms. We conclude that the right hemispheric response to rhythm change triggers attention-switching processes mediated via the ACC.

Keywords: Rhythm change, event-related potential, mismatch negativity LORETA.

1. Introduction

The human auditory system processes sensory information in the form of environmental sound. Related attention and temporal processing enable us to understand speech, as well as rhythm and melody in music. Temporal processes for understanding speech are typically left-hemisphere dominant, whereas those for understanding music are right-hemisphere dominant. Recent functional neuroimaging studies have produced new evidence for auditory hemispheric asymmetry. It has shown that responses to temporal features are weighted in the left hemisphere, while responses to spectral features are weighted in the right hemisphere [1].

The event related potential (ERP) has high time-resolution, and can therefore be used as an index of human auditory cortical activity. Mismatch negativity (MMN) is a front-centrally negative component of the ERP that usually peaks at 100-250 ms after a deviant-stimulus onset, and has a polarity reversal at mastoid. The MMN reflects change detection when a repetitive auditory sound stream changes its intensity, frequency or duration, and also occurs in response to a stimulus omission or gap [2]. The MMN is automatically elicited even if the participant is not directly attending to stimulus sound or some tasks. MMN is thus indicative of subconscious auditory processing.

The purpose of this study was to investigate whether the MMN reflects hemispheric differences pertaining to temporal features of the stimulus, and the question of the dominant hemisphere with respect to MMN generation was examined. Shtyrov, Kujala, and Lyytinen et al. (2000) showed a hemispheric asymmetry of speech and complex nonspeech sounds by measuring the magnetic equivalent of the MMN (MMNm). Perception of speech stimuli was predominant in the left hemisphere, while nonspeech sounds with similarly rapid acoustic transitions (duration 25 ms) were not associated with significant functional asymmetry. In contrast, the right hemisphere is dominant in perception of slow acoustic transitions (duration 90 ms) [3]. However, the findings were not discussed in relation to temporal and spectral features. The present study examined the MMN component as related to rhythmic changes (gaps) in a rapid presentation sequence. Some previous studies examined temporal feature changes [4]. However, potential hemispheric asymmetry and source localization of temporal changes were not examined.
2. Method

Participants were twelve healthy right-handed people with normal hearing and no neurological disease (age range = 21-23 years, 9 males). They gave their informed consent before participating in the experiment.

The stimulus used in the study was a tone with a 25 ms burst (rise and fall time of 5 ms), consisting of a pure tone of 500 Hz. Auditory stimuli were binaurally presented through headphones at an intensity of 70 dB SL, and with a stimulus onset asynchrony (SOA) of 50 ms. The deviant event was an SOA change to 75 ms that randomly occurred once in 1025 ms (probability of 4.8%).

Participants were instructed to watch a silent movie and to not pay explicit attention to the experimental stimuli during the experiment. The experiment was conducted in an electrically shielded and sound-attenuated room. Such a setting is typical for MMN recording and ethically suitable. The electro-encephalogram (EEG) was recorded from 22 tin electrodes according to the international 10-20 system, as well as the left (M1) and right mastoids (M2). All electrodes were referenced to the nose tip. An electro-oculogram (EOG) was recorded for off-line artifact rejection. The EEG and EOG signals were continuously recorded using SynAmps amplifiers and Scan 2.0 software with band-pass filter (0.05-100 Hz). The analysis period was 712 ms long (sampling rate 1000 Hz), including a 300 ms pre-stimulus baseline. Rejection criteria involved exclusion of epochs with EEG or EOG activity exceeding ±50 µV.

EEGs time-locked to gap timing (the moment at which sound should have been presented) were averaged to obtain ERPs. Statistical analysis was carried out using Huyndt-Feldt corrected repeated measures analysis of variance (ANOVA) and Bonferroni multiple comparison tests.

After averaging, low-resolution electromagnetic tomography (LORETA) and LORETA-KEY software were used to localize the measured activities. The LORETA images represented the measured activity in each of the total of 2349 voxels, computed with a 7 mm spatial resolution and applied to the Talairach human brain atlas. LORETA reflects synchronized neighboring neuronal activity [5].

3. Results

The ERP waveforms elicited by deviant stimuli were subtracted from responses to the standard stimuli. The grand-averaged subtracted waveforms showed front-central maximum negativity and the polarity reversal in mastoid recordings at 100-200 ms after the gap (Fig. 1). Negative peaks showed different waveforms at each channel of the grand-averaged waveform. Negative peak latency was around 125 ms at the frontal site (Fz) and right side (T8) after the gap. The negativity at Fz returned to baseline more slowly than it did elsewhere. The negative deflection could therefore be divided into two time windows: An early window at 85-125 ms and a late window at 125-165 ms. Mean amplitudes were thus calculated separately from these two 40 ms time windows. Original values with no amplitudes subtracted out were used for statistical analyses, as required for subsequent analyses for source localizations.

The mean amplitudes were submitted to a two-way repeated measures ANOVA, with time window (early, late) and electrode sites (Fz, T7, T8, M1, M2) as within-participants factors. There was a significant main effect of site, $F(4, 44) = 4.25, p < .05$, and a significant interaction between the factors, $F(4, 44) = 3.93, p < .05$. Post-hoc analyses was performed on mean amplitudes from each electrode site, as well as each time window.

3.1 Electrode site analyses

The results of Bonferroni multiple comparison tests between early and late time windows showed significant differences at T8 ($p < .01$) and M2 ($p < .01$). These results indicate that the right hemispheric negativity was larger only at early latencies.

3.2 Analyses of Early and Late negativity

For the early time window of 85-125 ms, the results of a simple-main effect test indicated no significant differences as a function of site. These results indicated that early negativity was not identified as a MMN component, because the polarity reversal between Fz and mastoid was not significant. Conversely, for the late time window of 125-165 ms, the results of a simple-main effect test indicated a significant difference as a function of site, $F(4, 44) = 5.82, p < .05$. A post-hoc test showed significant site differences between Fz and M1 ($p < .005$), as well as Fz and M2 ($p < .005$). These results confirm the appearance of MMN at Fz during the late time window. The
negative deflection can be divided into two subcomponents according to the time window: The early subcomponent had right hemispheric negativity that did not show inverse polarity at mastoid, whereas the later subcomponent featured mismatch negativity with maximum amplitude at Fz and inverted polarity at mastoid.

3.3 LORETA analysis

LORETA analysis was applied to ERP data at each time window. Fig. 2 shows mean activity at each time window. In the early time window, right superior temporal gyrus (STG) \((x = 60, y = -32, z = 15)\) activity was observed, whereas in the late time window, the anterior cingulated cortex (ACC) \((x = -3, y = 45, z = -6)\) was active.

4. Discussion

Our results demonstrate hemispheric asymmetry of an early negativity ERP component. However, this early negativity does not correspond to the MMN, but instead seems to represent the N1 auditory evoked potential; it reflects the physical feature of sound inputs. The late negativity seems to represent the MMN; it reflects the auditory neural representation.

The early right side negativity observed here suggests a relationship between gap detection as a temporal change and the analysis of spectral features. There are several possible explanations for this right hemisphere bias. First, this experiment used a pure tone burst. It is possible that the early component was elicited to the succeeding tone stimulus, and that this component reflects analysis of spectral features. Second, the participants were not required to perform a specific task during the auditory presentations. In the previous studies of hemispheric asymmetry, participants explicitly paid attention to the stimuli or something to task. This suggests the possibility that the processing done during this experiment was quite different than that previous assessed in the attentive level. Finally, stimuli were rapidly presented, which could have produced some perception of lower pitch.

Lu et al. (2001) have identified two populations of neurons in the primary auditory cortex of marmosets in the waking state. One set of neurons produces stimulus-synchronized discharges with temporal coding at less than 40 Hz (synchronized neurons). The other set produces non-stimulus synchronized discharges and stimulus rate coding at a stimulus rate frequency greater than 40 Hz (non-synchronized neurons) [6]. Primates appear to have two independent neuronal systems in the auditory cortex. These studies suggest that there might be a hemispheric asymmetry in the human auditory cortex, with different substrates underlying temporal and spectral processing. The right hemisphere plays a dominant role in processing spectral resolution, which engages the non-synchronized neurons. It has been suggested that the non-synchronized neurons code not only spectral features but also temporal gap information.

The MMN appears to reflect late negativity localized at the ACC. These results support the assumption that the change detection signal generated by the auditory cortex triggers the frontal attention switch [2, 7]. We conclude that the right hemispheric response to rhythm.
change triggers attention switching localized in the ACC. The temporal resolution of ERP measurement makes this approach useful for the study of temporal processing in the neural system.

5. Conclusion

The negative deflection elicited by rhythm change can be divided into different components according to latency. The early component can be identified as N1, weighted to the right STG. The late component is the MMN, activated in the ACC. The response to gaps (as a form of rhythmic change) is weighted to the right hemisphere rather than the left.

References