

No Visual Mismatch Negativity (MMN) for Simultaneously Presented Audiovisual Stimuli: Evidence from Human Brain Processing

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ABSTRACT

The present study employed simultaneous audiovisual stimuli in the oddball paradigm to re-examine the effects of attention on audio, visual and audiovisual perception. The study was designed to investigate whether task-related processing of audio and visual features was independent or task-related processing in one modality might influence the processing of the other. Electroencephalogram (EEG) was recorded from 12 normal subjects. ANOVA showed statistically significant of the interaction between electrode site and modality. The difference waves with 100-200 ms latency at the anterior sites were markedly different to the posterior sites. The emergence of posterior negativity in the audio-visual modality might not be attributed to visual discrimination process as it did not appear in the visual modality. The findings reveal the processing of a feature, hierarchically dependent on another feature in the audiovisual perception.

Keywords: Event-related potentials, oddball paradigm, Mismatch negativity, bisensory processing

1. INTRODUCTION

The human central auditory system has a remarkable ability to establish memory traces for invariant features in the acoustic environments such as music and speech sounds in order to correct the interpretation of natural acoustic sound heard. Even when no conscious attention is paid to the surrounding sounds, changes in their regularity can cause the listener to redirect his or her attention toward the sound heard [1]. Event-related potential (ERP) recordings have brought new insight to the neuronal events behind auditory change detection in audition. ERPs components (see Fig. 1) reflect the conscious detection of a physical, semantic, or syntactic deviation from

the expected sounds [1]. The ERP recordings thus allow one to probe the neural processes preceding the involvement of the attentional mechanisms. For instances, ERPs have been recorded that reflect memory traces representing sounds composed of several simultaneous or successive tonal elements [2-4].

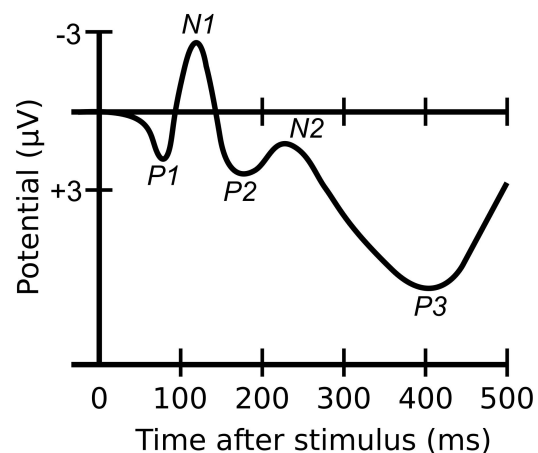


Fig.1: Event-Related Potential (ERP) Components.

Mismatch negativity (MMN) component of ERP is theoretically elicited in the auditory cortex when incoming sounds are detected as deviating from a neural representation of acoustic regularities (see Fig. 2). It is mainly generated in the auditory cortex [5] occurring between 100 to 250 ms and thus long been regarded as specific to the auditory modality [6-7]. The automatic change-detection system in the human brain as reflected by the MMN requires the storage of the previous state of the acoustic environment for detecting an incoming deviating sound [6,8]. MMN implies the existence of an auditory sensory memory that stores a neural representation of a standard against which any incoming auditory input is compared [9]. In the auditory modality, MMN is an automatic process which occurs even when the subject's attention is focused away from the evoking stimuli [6]. Its onset normally begins before the N2b-P3 complex which occurs when attention is directed to the stimuli. The duration of MMN varies with the nature of

Manuscript received September 30, 2009; revised on December 28, 2009.

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the stimulus deviance but it invariably overlaps N2b when the latter is present [10].

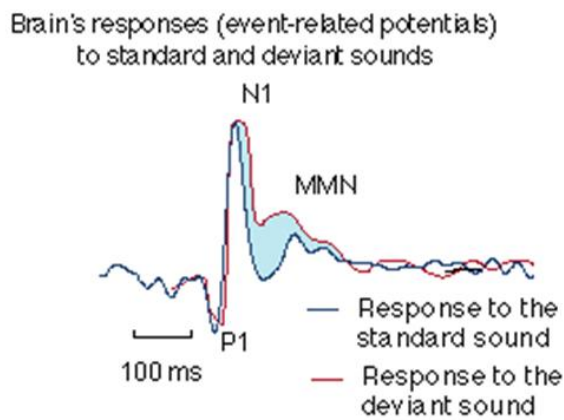


Fig.2: Mismatch Negativity (MMN) Component of ERP.

Previous study [11] has stated that the automatic detection of stimulus change plays a part in directing attention to events of biological importance. If this is the case, one would expect a similar mechanism to operate in the visual modality. Although it is clear that the MMN can be elicited in auditory modality in the absence of attention, it remains somewhat unclear whether there is an analogous automatic deviant-related negativity (DRN) elicited outside the auditory modality. Näätänen [12] has stated that the automatic detection of stimulus change plays a part in directing attention to events of biological importance. If this is the case, one would expect a similar mechanism to operate in the visual modality. Even though MMN had not mentioned to be appeared in the visual modality [12], several studies have shown that visual stimuli deviating from repetitive visual standards can also elicit a visual analogue of the MMN in the same latency range. This visual MMN seems to be mainly generated in occipital areas [12,13] with possibly a more anterior positive component [14,15]. In addition, Cammann's study [16] showed a widely distributed MMN change between 150 and 350 ms, with a parietal maximum suggesting that this MMN may occur in the visual modality. Recently, Pazo-Alvarez et al. [17] reviewed several previous reports to provide convincing evidence for the existence of this visual MMN. Moreover, cross-modal attention studies clearly showed that deviant visual stimuli elicited MMN, largest over the inferior temporal cortex. This visual MMN increased in amplitude with attention, but it was also evident during inattention [18,19].

In the present study, simultaneous audio-visual stimulus in the oddball paradigm was used to re-examine the effects of attention on MMN in audi-

tory, visual and audiovisual dimensions. Attentional ERP components were analyzed in a situation where target stimuli were combinations of both auditory and visual features. Interactive processing of stimulus features would then be indicated by the absence, reduction or early termination of the attention-related components [20] as a function of processing of the other feature. If visual-specific components are evoked by visual deviances, then the present audiovisual paradigm will help to separate them from the effect of visual information on the auditory-specific MMN process by facilitating the focus of attention on auditory and visual MMNs elicited with bimodal features. The audio-visual paradigm was also designed to investigate whether task-related processing of visual and auditory features was independent or task-related processing in one modality might influence the processing of the other.

2. MATERIALS AND METHODS

2.1 Subjects

Twelve right-handed normal subjects (6 males and 6 females) with a mean age of 24.83 (SD= 3.54) participated in the experiment. All participants had normal hearing and had been corrected to normal vision (self reported). None of them had more than three years of formal musical training and none had any musical training within the past five years. All participants had no history of neurological or psychiatric history. After a complete description of the intended study, written informed consent was obtained. The subjects were paid for their participation.

2.2 Stimuli

Stimuli consisted of a set of four audio-visual stimuli that were distinguished by frequencies (Hz) for audio and features for visual appearing on the screen. The duration of the stimuli were 300 ms. The stimulus system (STIM, Neurosoft, Inc. Sterling, USA) was employed for controlling the presentation of the stimuli. An oddball paradigm [1] was chosen for presenting randomized stimulus sequences consisting of all four sets of equiprobable audio-visual stimuli (a simultaneous combination of audio and visual stimuli): the deviant was 'X' with 1800 Hz tone (Visual Target Audio Target; hereafter, VTAT) in 10% probability, and the standard was 'Y' with 800 Hz tone (Visual Non-target Audio Non-target; hereafter, VNAN) in 70% probability were presented as preferred-deviant to be able to check that participants were attending the stimuli. Additionally, the deviant 'X' with 800 Hz tone (Visual Target Audio Non-target; hereafter, VTAN) and the deviant 'Y' with 1800 Hz tone (Visual Non-target Audio Target; hereafter, VNAT) were used in 10% probabilities (see Fig. 3). While visual stimuli were presented on the computer screen, acoustic/audio stimuli were delivered binaurally to

the participants through plastic tubes and earpieces. Sound density was adjusted to be 85 dB above the participant's hearing threshold.

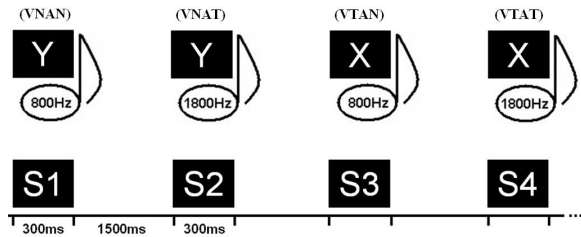


Fig.3: Schematic presentation of the stimuli in bisensory conditions. Stimuli in different modalities are presented simultaneously. The VTAT and VNAN conditions appeared in 10% and 70% probabilities, respectively. Additionally, the VTAN and VNAT conditions were equally presented in 10% probabilities. The stimulus is presented with 300 ms duration, and inter-stimulus interval is 1,800 ms in every condition.

2.3 Procedures

The experiment consisted of 3 blocks and each block had 300 trials. Every stimulus was presented with 300 ms exposure duration and inter-stimulus interval was 1,800 ms (from audio/visual stimuli onset to onset) in every condition. Subjects sat in an electrically shield and soundproofed room with the response buttons under their hands. The subjects had to press the button on the response pad when the deviant (VTAT) was presented and ignored any other types of stimuli. Prior to the experimental session, a practice block was administrated to ensure that the subjects understood the task.

2.4 Electroencephalogram recording

Electroencephalographic (EEG) data were collected in an electrically and acoustically shielded room. EEG was recorded from a Quick-Cap equipped with 128 channels according to the international 10-20 system using Scan system (Scan 4.2, Neurosoft, Inc. Sterling, USA). Linked mastoids were used as reference. Eye movements were monitored with two EOG electrodes. Four electrodes monitored horizontal and vertical eye movements for off-line artifact rejection. Vertical and horizontal electro-oculogram (EOG) was recorded by electrodes situated above and below the left eye, and on the outer canthi of both eyes, respectively. Impedance was maintained at 5k Ω or less. During the experiment, EEG was amplified with a bandpass of 0.05 - 100 Hz, sampled at 1,000 Hz and stored on a hard disk for off-line analysis. ERPs were averaged separately for each types of stimulus. They were digitally filtered with a bandpass of 0.1 -

30 Hz. The averaging epoch was 900 ms, and the 100 ms before the onset of the presenting stimuli served as baseline. The artifact-free epochs were filtered at 0.1-15 Hz, baseline corrected and averaged. The artifacts rejection was conducted in all channels with threshold of $\pm 100 \mu\text{V}$ before averaging. Epochs with EEG or EOG with a large ($>100 \mu\text{V}$) amplitude were also automatically rejected. The limitation restricted EEG recording time to 90 mins, thus minimizing the risk of participants' fatigue (see Fig. 4).

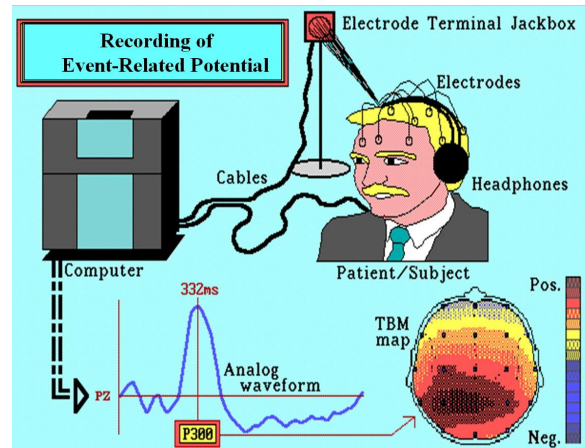


Fig.4: Electroencephalogram (EEG) Recording.

2.5 EEG data analysis

After the data recordings, the EEG was segmented into 1000 ms epochs, including the 100 ms pre-stimulus period. The baseline was corrected according to the mean amplitude of the EEG over the 100 ms period that preceded stimulus onset. The EEG epochs contained amplitudes exceeding $\pm 100 \mu\text{V}$ at any EEG channels were automatically excluded from the averaging. The epoch was separately averaged for the standard and deviant stimulus. The average waveforms obtained from the standard and deviant stimuli were digitally filtered by a 0.1 - 15 Hz band-pass filter and finally baseline-corrected. To analyze the deviant-related components, difference potentials were calculated where responses elicited by the VNAN stimuli were subtracted from responses to VTAN and VNAT stimuli after stimulus onset referred to visual (Vi) modality as in (1) and auditory (Au) modality as in (2), respectively.

$$(VNAN) - (VTAN) = (Vi) \quad (1)$$

and

$$(VNAN) - (VNAT) = (Au) \quad (2)$$

In the audio-visual (AV) modality, VTAT minus VNAN difference was also calculated as in (3).

$$(VNAN) - (VTAT) = (AV) \quad (3)$$

The amplitude of the difference waveform was expressed in microvolt and its latency in milliseconds. MMNs were statistically assessed by two-tailed t-tests comparing the averaged amplitude of the deviant minus standard difference waveform to zero in the 40 ms time-window around the latency of the peak in the grand-average responses. To compare these components, MMN amplitudes were further assessed via two-way analyses of variance (ANOVA) with repeated measurements. The factors were modality (three levels: Vi, Au and AV), and electrode site (two levels: anterior sites at F3, Fz, F4, C3, Cz, C4, and posterior sites at P3, Pz, P4, O1, Oz, O2).

3. RESULTS

Reaction times and response accuracy (mean and standard deviation: SD) are shown in Table 1. Figure 5 presents the grand-average deviant-related components in the Au, Vi and AV modalities producing deviant-related negativities (DRNs). DRNs were divided into an early DRN1 around 100-200 ms and a late DRN2 around 200-300 ms. According to the previous studies showing that MMN appears between 100 to 250 ms [6] and the characteristics of DRN2 match with those of N2b component [23]. The present study thus associated DRN1 mainly with MMN in which we focus in this report, and DRN2 with a mixed wave of MMN and N2b.

way repeated measures ANOVA shows that the interaction between electrode site and modality of MMN amplitudes at 100-200 ms of all modalities was statistically significant [$F(11,429) = 8.27, p < 0.0001$]. At 200-300 ms, significant levels were also reached in the same interaction for N2b component [$F(11,429) = 6.50, p < 0.0001$]. As shown in Fig. 2, the difference waves with 100-200 ms latency at the anterior sites were markedly different to the posterior sites. Additionally, there was no MMN elicitation for the Vi modality at the posterior sites compared to the Au and AV modalities. We thus compared MMN mean amplitudes of all modalities. Two-way repeated measures ANOVA shows that the interaction between posterior electrode site and modality was statistically significant [$F(17,663) = 27.52, p < 0.0001$] and significant level was also reached in the interactions between anterior electrode site and modality [$F(17,663) = 52.37, p < 0.0001$]. We then compared the MMN mean amplitude values of Au, Vi and AV difference potentials at Fz site. The difference was statistically significant [$F(2,78) = 8.75, p < 0.0001$]. Like the MMN, they showed similar significant effect on the N2b amplitude at Oz site [$F(2,78) = 6.50, p < 0.0001$].

The additivity of the MMN was also examined by adding together the Au and Vi MMNs and comparing this 'modelled' (AuVi) MMN with the AV MMN

in order to see the possible attention effects on the additivity of MMN. If processing of Au and Vi is independent of the others, the sum of the MMNs to both modalities should be equal to the MMN elicited by the AV modality. We found that the additivity of Au and Vi MMNs existed in both anterior and posterior locations. However, the additivity of Au and Vi MMNs amplitude was slightly larger than that of the corresponding AV modality, being maximum at P3 (mean amplitude; AuVi vs. AV: $-1.56 (0.02) \mu\text{V}$ vs. $-1.12 (0.02) \mu\text{V}$, $t(39) = -21.89, p < 0.0001$). Moreover, the N2b component, following MMN, was larger than that of the AV modality, being maximum at Fz (mean amplitude: $-4.51 (0.04) \mu\text{V}$ vs. $-3.97 (0.05) \mu\text{V}$, $t(39) = -45.99, p < 0.0001$). The N2b was also followed by a positive component identified as P3a [1] (see Fig. 6).

4. DISCUSSION

The main finding of our study indicates that the prominent response to the Au, Vi and AV modalities produces deviant-related negativities. DRNs were divided into early DRN1 (or MMN), and late DRN2 (or N2b). As shown in Fig. 5, the difference waves with 100-200 ms latency at the anterior sites were markedly different to the posterior sites. There was no MMN elicitation for the visual modality at the posterior electrode sites compared to the auditory and audiovisual modalities. The MMN was significantly larger only in the anterior sites, being maximum at F3 ($t(39) = -68.04, p < 0.0001$). This result was consistent with a previous study showing no posterior negativity elicitation in the difficult discrimination task [22]. Moreover, the present result extends previous findings [23,25] which showed that the deviance related ERP effects in vision could be separated from automatic processing of other stimulus features. We hypothesize that the emergence of posterior negativity (MMN) in the present study is not to be attributed to visual discrimination process. Our result supports the view proposed by Näätänen [12] that "no MMN appears to occur in the visual modality". However, several studies have shown that visual stimuli deviating from repetitive visual standards can also elicit a visual analogue of the MMN in the same latency range [12,24,14,15].

Furthermore, cross-modal attention studies showed that deviant visual stimuli elicited MMN, largest over the occipital and inferior temporal cortex [19]. This visual MMN was not affected by the processing load during attention to the other modality and had restricted, occipito-temporal distribution, consistent with generation in modality-specific sensory cortex. This early MMN-like portion of the visual deviance-related negativity was independent of attention. It increased in amplitude with attention, but it was also evident during inattention [19]. However, Alho et al. [25] has argued that if a visual MMN exists, its elicita-

tion may have a higher threshold than auditory MMN which evoked by any discriminable change. The effect of target-specific negativity is thus a considerable contamination factors in which the impact of simultaneous memory traces in different modalities could also be considered. In addition, the persistence of the visual MMN may reflect the automatic detection of physical change in sequences of visual stimuli [12].

As shown in Fig. 5, the identical N2b components were elicited by Vi and AV modalities, whereas in case of Au modality, latency of this component was longer than that of the Vi and AV modalities. The N2b effect suggests the attention-related rechecking of the outcome of within-modality analyses. Such activity would have been different upon the different discrimination demand [20,22]. Therefore, the process underlying N2b component thus performs independent within-dimension selection [20]. The shorter N2b latency to AV further suggests that this component is a correlate of processes following the elementary discrimination processes, instead of being an on-line correlate of such processes [22].

The additivity of the MMN was also examined by adding together the Au and Vi MMNs and comparing this 'modelled' (AuVi) MMN with the AV MMN in order to see the possible attention effects on the additivity of MMN. Assuming that the MMNs to these features are generated by different, non-interacting neural populations, each deviating feature in the bimodal deviants should elicit its own MMN. The additivity of Au and Vi deviants should thus elicit a larger MMN than the AV deviant. As shown in Fig. 6, our findings show that the additivity of the Au and Vi MMNs was larger than that of the AV modality. This implies that there are complex interactions between brains processes involved in analyzing several simultaneous deviant features in the AV modality. Our results are in the line of previous studies revealing that at least partly different neural populations are involved in processing deviance in different auditory features and being suggest the independent MMN generators for these features [26-29]. Moreover, the underadditivity of AV MMN in the present study suggests either that common neural populations are involved in the controlled processing of changes in different features [27] or that the populations are separate but strongly interacting [29]. However, Paavilainen et al [29] has argued that the additivity hypothesis of MMN does not hold at least in its simplest form which presupposes that the processing of various features is completely independent of each other, the contributions of the different simultaneous MMNs just simply 'piling up' in the ERPs. According to this hypothesis, the AuVi MMN in the present study was slightly larger than did the corresponding AV modality, being maximum at P3 site. Like AuVi MMN, the N2b component was also larger than that of the AV modality, being maximum at Fz site.

, our findings are consistent with the previous study showing that the deviant-related negativities consist of two successive components, the earlier being generated at the auditory cortex and the latter at the frontal areas [30]. In addition, the degree of additivity may be different from those two components. That is, the existence of several partially overlapping and interacting brain processes may complicate the estimation of the additivity of MMN [29]. The negativity associated with deviants in the present study thus resembles auditory mismatch negativity inasmuch as it occurs automatically while the focus of attention is directed away from the evoking stimuli.

Finally, the morphology of ERPs to AuVi modality differed to the AV modality. The N2b was followed by a large positive component identified as P3a [6] in the AuVi modality, but little P3a was evident in the AV modality (see Fig. 6). Like the MMN/N2b, the empirical AuVi P3a tended to be larger than the AV P3a. Its amplitude increased as the number of the deviant features was increased, with the additivity of Au and Vi deviants eliciting a larger P3a than did the corresponding AV deviants. This implies that both Au and Vi modalities were demanding, performance in the inattention remained high, and the occurrence of P3a component depend on another feature. The occurrence of AV P3a also implied the complex interactions between brains processes involved in analyzing several simultaneous deviant features. This component possibly reflects involuntary attention-switching mechanism to deviant stimuli [23,31,32]. Consequently, our results support the view that the processing of a feature, hierarchically depends on another feature [20,22].

5. CONCLUSION

The present study demonstrates the audiovisual interaction following elementary within-modality discrimination processes. MMN and N2b effects suggest the attention-related rechecking of the outcome of within-modality analyses. The task-related processing of audio and visual features was independent and one modality might influence the processing of the other. This findings support the view that the processing of a feature, hierarchically dependent on another feature in the condition of audio-visual perception.

6. ACKNOWLEDGMENT

This research was conducted in cooperation with Clinical Cognitive Neuroscience Center (CCNC) in the Seoul National University, College of Medicine, Seoul, Korea. The author gratefully thank Prof. Dr. Jun Soo Kwon, Dr. Do-Hyung Kang, Dr. Kyung Whun Kang and Dr. Bo Reom Lee for their guidance and providing the equipment and data sources during this work. In addition, this research was supported by

the following organizations; the Brain Research Center of the 21st Century Frontier Research Program (Ministry of Science and Technology of Republic of Korea), and the International Scholar Exchange Fellowship (ISEF) Program, 2006-2007 (Korea Foundation for Advanced Studies).

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