

Music Sound and Picture Perception: Topography of the Human Brain Electrical Activity

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Abstract

The functional properties and topographic distribution of event-related potential (ERP) components elicited by simultaneously music sound and picture discrimination were investigated. Simultaneous audio-visual stimulus in the oddball paradigm was used to re-examine the MMN occurrence in auditory, visual and audiovisual modalities. This study was 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. The grand-average deviant-related components producing deviant-related negativities (DRNs) divided into and early DRN1 around 100-200 ms and late DRN2 around 200-300 ms. Two ERP components were found: MMN associated with DRN1, and N2b associated with DRN2. MMN and N2b were more negative when a stimulus was a target, showing the selection negativity effect. Feature-specific effects on component amplitude or topography varied by component. ANOVA shows that the interaction between electrode site and modality of MMN amplitudes at 100-200 ms was statistically significant. The difference waves with 100-200 ms latency at the anterior sites were markedly different to the posterior sites. In visual modality, there was no MMN elicitation in the posterior sites compared to the auditory and audiovisual modalities. The emergence of posterior negativity (MMN) in the present study is thus not to be attributed to visual discrimination process. These data provide topographic evidence that ERP components in the 100-300 ms time domain can be differentiated on the basis to proceeding of specific stimuli features, and reflect neurophysiologically distinct auditory and visual pathways in the human cortex.

Keywords: *Event-related potentials, Sound, Music, Mismatch negativity, bisensory processing*

1. Introduction

Event-related potential (ERP) recordings have brought new insight to the neuronal events behind auditory change detection in audition of the human brain function. Theoretically, ERPs components 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]. Event-related Potential (ERP) components are here labeled by the polarity (negativity or positive) and temporal order of appearance. The ERP components elicited by visual discrimination stimuli with long inter-stimulus intervals (ISI > 500 ms) include the P1, N1, P2, N2, and P3 components [5]. In visual ERP components elicited during discrimination tasks, the peak latency ranges for the ERP components are typically in the following ranges: P1 (80-145 ms), N1 (100-200 ms), P2 (200-300 ms), N2 (200-300 ms), and P3 (280-600 ms) [5]. Previous studies demonstrated that attention directed toward a specific visual region enhances the P1 and N1 components to stimuli in that region [5]. Importantly, this effect was also largest over posterior electrode sites contralateral to the attended region. The electrical sources of P1 and N1 probably include both striate and lateral occipital cortex [6-15]. In addition to the exogenous N1 and P2 components, the N2 and P3 components increase with the difficulty of discrimination and classification [11,16-22]. The occurrence of both N2 and P3 components reflect operations on a representation of the stimulus [16,23-28].

The auditory system has a remarkable ability to establish memory traces for invariant features of acoustic sounds in the environment such as human speech sound and music, in order to correct the interpretation of these natural acoustic sounds heard [1]. Mismatch negativity (MMN) component of ERP elicited in the auditory cortex when incoming sounds are detected as deviating from a neural representation of acoustic regularities. It is mainly generated in the auditory cortex occurring between 100 to 250 ms [29] and thus long been regarded as specific to the auditory modality [30-31]. 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 [32-33]. 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. Even though Näätänen [34] stated that “no MMN appears to occur in the visual modality”, 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 [35] with possibly a more anterior component [36-37]. Cammann’s study [38] also 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. 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 [39-40]. Moreover, Pazo-Alvarez et al., [41] reviewed several previous reports to provide convincing evidence for the existence of this visual MMN. However, Alho *et al.*, [42] suggested that the effect of target-specific negativity is a considerable contamination factors in which the impact of simultaneous memory traces in different modalities could also be considered.

The present study compared attentional non-musician brain processes during the discrimination of the different synthesized acoustic sounds by using a modified (four acoustic sounds) auditory oddball paradigm to record ERP components in a group of healthy subjects, hoping to find evidence for specific brain signatures of acoustic sound and picture processing in the human brain. The simultaneous audio-visual stimulus in the oddball paradigm was used to re-examine the effects of attention on MMN in auditory, 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 [43] as a function of processing of the other feature. If visual-specific components are evoked by visual deviances, then the present audio-visual 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. This study used a 28 channel electrode montage to characterize the scalp topography of these effects. Advanced reference-independent topographical analysis was used to identify the ERP components. The topographic analysis was used to locate multiple non-dipolar sources particularly involved in the discrimination of these different synthesized acoustic sounds and picture perception as well as characterizing the cortical distribution of the ERP electrical generators.

2. Materials and Methods

2.1 Subjects

Sixteen subjects (9 female and 7 male) between the ages of 22 and 26 were evaluated. All subjects were right-handed (handedness assessed according to Oldfield [45]), with no history of neurological or psychiatric hospitalization, substance or alcohol abuse, or medical illness that might affect visual function. All subjects had normal or 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. Approval of the institutional committee on human research and written consent from each subject were obtained prior to data acquisition. After a complete description of the intended study, written informed consent was obtained. The subjects were paid for their participation.

2.2 Materials

Stimuli were presented on a computer screen (640 x 480 pixel resolutions) placed 100 cm from the subject for simultaneously audiovisual presentation and discrimination tasks. A stimulus system (STIM2, Neurosoft, Inc. Sterling, USA) was employed for controlling the presentation of the stimuli. A set of four synthesized acoustic sounds were distinguished by frequencies (Hz). All acoustic sounds were digitally edited to have an equal maximum energy level in dB SPL with the remaining intensity level within each of the stimuli scaled accordingly. The stimuli were digitally edited using the Cool Edit Pro v. 2.0 (Syntrillium Software Cooperation) with 300 ms duration. All four acoustic sounds were binaurally presented through headphones at a comfortable listening level of ~85 dB, with different pitch contour: Tone 1 with high-level, Tone 2 with high-rising, and Tone 3 with low-dipping (10ms rising/falling time, 200 ms plateau). The sound pressure levels of stimuli were then measured at the output of headphones using a Brüel and Kjaer 2230 sound level meter. ERPs were recorded during a four-tone auditory oddball paradigm. The deviant was ‘X’ with 1,800Hz tone (VTAT; Visual Target

Auditory Target) in 20% probability, and the standard was 'Y' with 800Hz tone (VSAS; Visual Non-target Auditory Non-target) in 60% probability. Additionally, the 'X' with 800Hz tone (VTAS; Visual Target Auditory Non-target) and 'Y' with 1,800Hz tone (VSAT; Visual Non-target Auditory Target) were used in 10% probabilities. To be able to check that subjects were attending the stimuli, the number of target stimuli was reported at the end of the experiment. EEG signal recording was time-locked to the onset of the stimuli. Subjects were instructed to press button when reacting to the target stimuli only. The experiment lasted 1-2 h, including breaks.

2.3 Test Procedures

Subjects were tested in a quiet, dimly lit and electrically shielded room. The subject was seated in an adjustable reclining chair, with his or her forehead 100 cm from the computer screen where the stimuli were presented. At the beginning of each block, the subject was instructed to press a key with his or her right hand when the target stimulus appeared (e.g., VTAT), and to ignore other stimuli. Prior to the experimental session, a practice block was administered to ensure that the subjects understood the task. The subject was also asked to respond as quickly and accurately as possible. The experiment consisted of 3 blocks and each block had 300 trials. Every stimulus was presented with 300ms exposure duration and inter-stimulus interval was 1,800ms in every condition. Stimuli were randomly presented with a block. The accuracy of each trial was recorded, and mean value were compared between conditions. There was a one to two minute interval between blocks. Tasks and blocks were counterbalanced across subjects.

2.4 EEG Recordings

Electroencephalographic (EEG) was recorded from a Quick-Cap equipped with 28 channels according to the international 10-20 system using Scan system (Scan 4.2, Neurosoft, Inc. Sterling, USA). Linked mastoids were used as reference. Horizontal and vertical electro-oculograms (HEOG and VEOG) were also recorded for artifact correction. Impedance was maintained at 5k Ω or less. During the experiment, EEG was amplified with a band pass 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 band pass 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 artifacts rejection was conducted in all channels with threshold of \pm 100 μ V before averaging. Single trial ERPs were saved

and subsequently processed off-line. Off-line processing included baseline correction using the averaged baseline voltage for epoch at each recording channel.

2.5 Data Analysis

Four midline electrodes (Fz, Cz, Pz and Oz) were used to assess anterior-posterior ERP component topography. Two electrodes on each side of the head were chosen from the left (F7, T3, T5, O1) and right (F8, T4, T6, O2) lateral electrode chains. The lateral electrodes were symmetrically placed in the region of largest component amplitude, which allowed testing for lateralized differences in voltage topography. For analysis of processing time, ERP component latency was measured at the electrode site where the mean component amplitude was maximal or near maximal across conditions. Peak amplitude and latency values were used to measure components in this study. These data provide a topographic description of these peak-related components.

To analyze the deviant-related components (DRC), difference potentials were calculated where responses elicited by the VSAS stimuli were subtracted from responses to VTAS and VSAT stimuli referred to visual (Vi) and auditory (Au) modalities, respectively. In the audiovisual (AV) modality, VTAT minus VSAS difference was also calculated. MMNs were statistically assessed by *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 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).

All amplitude measures were taken relative to average baseline voltage in the 100 ms interval prior to stimulus onset. A *p* value criterion of $\leq .05$ was used for significance testing of main effects and interaction. When significant stimulus main effects or stimulus X electrode interactions were detected, interpolated topographic maps were generated from the mean peak voltage values across subjects in a condition to assist in interpretation of the stimulus effect. Stimulus X Electrode interactions were statistically evaluated using *t*-testing between conditions at electrode sites included in the ANOVA, and *t*-tests between electrode sites within a condition. Significance level for all statistical tests was set at $p \leq 0.05$ (two-tailed).

3. Results

Reaction times (RTs) and response accuracy (mean \pm standard deviation: SD) is shown in Table 1. No main effect was observed in behavioral data.

Table 1 Mean reaction time and response accurate rates for the VTAT condition

| | Mean | SD |
|--------------------|-------|-----|
| Reaction time (ms) | 455 | 102 |
| Accurate rate (%) | 98.24 | 2.0 |

The grand-average deviant-related components in the Au, Vi and AV modalities producing deviant-related negativities (DRNs). The deviant-related negativities were divided into an early DRN1 around 100-200 ms and a late DRN2 around 200-300 ms. According to the previous study showing that MMN appears between 100 to 250 ms [30] and the characteristics of DRN2 match with those of N2b component [44], 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.

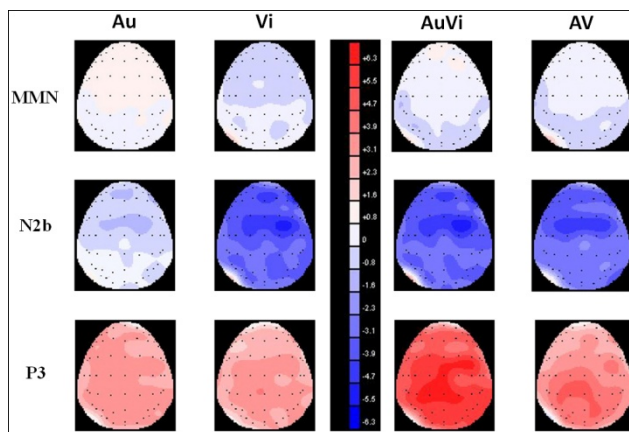


Fig. 1 Topographic maps showing the interpolated voltage distributions of MMN, N2b, and P3 to auditory (Au), visual (Vi), audiovisual (AV) and audiovisual additivity (AuVi) modalities. Voltages at each of the 28 recording sites were obtained using the mean peak voltage across subjects for that component. The maps are oriented so that the posterior of the map is at the base of each map, and viewer right is subject right.

ANOVA shows that the interaction between electrode site and modality of MMN amplitudes at 100-200 ms was 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 [$F(11,429) = 6.50, P < 0.0001$]. 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 [$F(2,78) = 6.50, P < 0.0001$]. The voltage topographies of components sensitive to feature differences of all stimuli (MMN, N2b, and P3) are shown in figure 1.

As shown in Figure 1, the topographies with 100-200 ms latency (MMN component) sensitive to all modalities 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 (Au) and audiovisual (AV) modalities. The voltage topographies of the MMN component to different modalities is shown in figure 2.

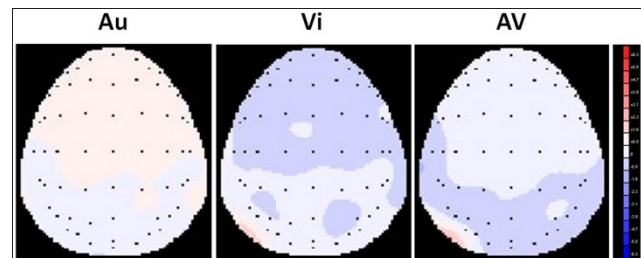


Fig. 2 Voltage distribution maps showing the voltage distribution of the MMN component (blue color) to auditory (Au) and audiovisual (AV) modalities, but not in visual (Vi) modality, markedly different to the posterior sites.

On the other hand, the Vi MMN was significantly larger only in the anterior sites, being maximum at F3 ($t(39) = -68.04, P < 0.0001$). This result consistent with the previous study showing no posterior selection negativity elicitation in the difficulty discrimination task [46]. The emergence of posterior negativity (MMN) in the present study is thus not to be attributed to visual discrimination process. We also compared the mean amplitude values of all Au, Vi and AV difference potentials at anterior locations. ANOVA shows that the interaction between anterior electrode site and modality was significant [$F(17,663) = 52.37, P < 0.0001$] and significant level was also reached in the interactions between posterior electrode site and modality [$F(17,663) = 27.52, P < 0.0001$].

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 voltage topographies of the N2b component elicited by Vi and AV is shown in figure 3.

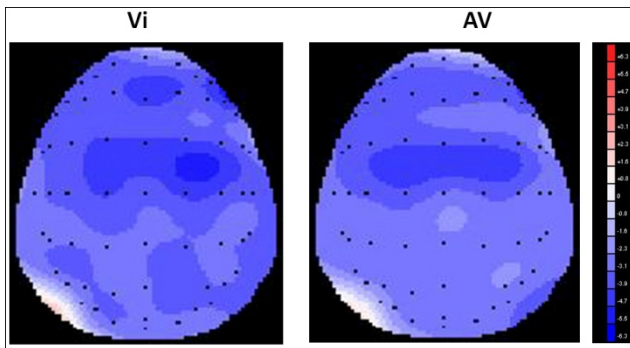


Fig. 3 Voltage distribution maps showing the voltage distribution of the N2b component (blue color) to visual (Vi) and audiovisual (AV) modalities.

Moreover, the N2b to the AV modality peaked earlier than the N2b to the Vi and Au modalities, respectively. The shorter N2b latency to AV modality further suggests that the attention-related components reflect activity following elementary discrimination process. Such activity would have been different upon the different discrimination demand [43,46]. Therefore, the emergence of N2b and MMN in this study supports this view.

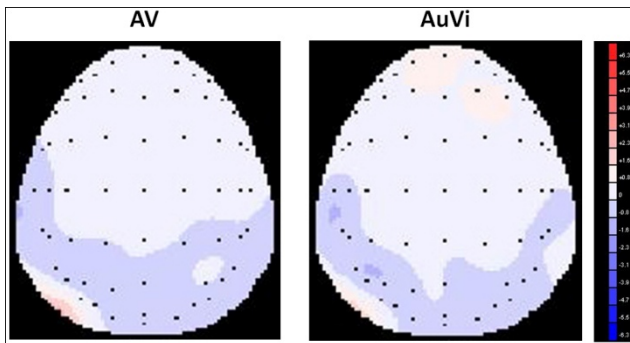


Fig. 4 Voltage distribution maps showing the voltage distribution of the MMN component to audiovisual (AV) and audiovisual additivity (AuVi) modalities.

The additivity of the MMN was also examined by adding together the Au and Vi MMNs and comparing this ‘modeled’ (AuVi) MMN with the AV MMN in order to see the possible attention effects on the additivity of MMN. If the 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. The results will suggest complex interactions between brain processes involved in analyzing several simultaneous deviant features [47]. Additivity of the Au and Vi MMNs produced slightly larger amplitude than did the corresponding AV modality, being maximum at P3 (mean amplitude; AuVi vs. AV: -1.56 (0.02) vs. -1.12 (0.02) μV ,

$t(39) = -230.41, p < 0.0001$). The voltage topographies of the MMN component to audiovisual (AV) and audiovisual additivity (AuVi) is shown in figure 4.

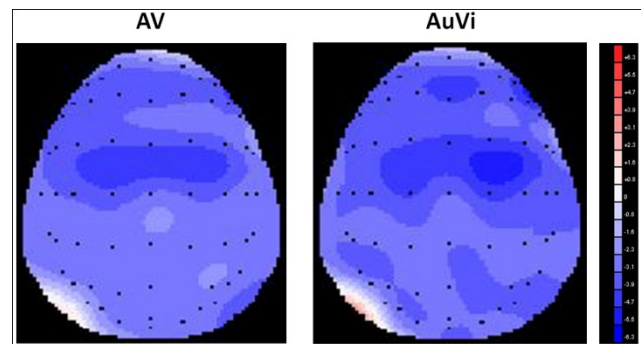


Fig. 5 Voltage distribution maps showing the voltage distribution of the N2b component to audiovisual (AV) and audiovisual additivity (AuVi) modalities.

Figure 5 shows voltage maps for the N2b component to audiovisual (AV) and audiovisual additivity (AuVi) modalities. The N2b component, following MMN was also larger than that of the AV modality, being maximum at Fz (mean amplitude: -4.51 (0.04) vs. -3.97 (0.05) μV , $t(39) = -230.41, P < 0.0001$). N2b was also followed by a positive component identified as P3a [30]. The voltage topographies of the P3 component to auditory (Au), visual (Vi), audiovisual (AV), and audiovisual additivity (AuVi) modalities is shown in figure 6.

As shown in Figure 5, the underadditivity of AV modality in these attention-related components suggests either that common neural populations are involved in the controlled processing of changes in different features [48] or that the populations are separate but strongly interacting [47]. This result was in the line of previous studies showing processing of a feature, hierarchically dependent on another feature [43,46].

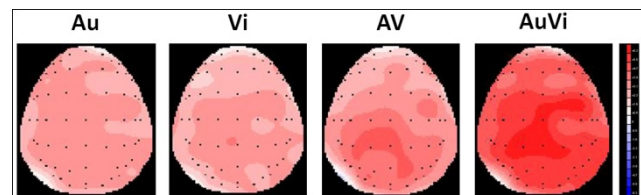


Fig. 6 Voltage distribution maps showing the voltage distribution of the P3 component to auditory (Au), visual (Vi), audiovisual (AV) and audiovisual additivity (AuVi) modalities.

4. Discussion

The main finding of this study indicates that the prominent response to Au, Vi, and Av modalities producing DRNs at 100 to 300 ms from stimulus onset. The deviant-related negativities were divided into an early DRN1 around 100-200 ms associated mainly with the MMN component and a late DRN2 around 200-300 ms associated with the mixed ERP components between the MMN and the N2b. The magnitude of the N2b appearance was followed by a positive component identified as P3. As shown in Figure 1, there was no MMN elicitation for the Vi modality at the posterior electrode sites compared to the Au and Av modalities. These results and those of other researchers suggest that scalp-recorded visual ERP components can tap functionally distinct aspects of visual representation and processing. These data provide further support for previous study [49] that the visual selection negativity encompasses a complex ensemble of information processing operations. An ongoing challenge is to relate these temporally overlapping and transient operations revealed by ERP techniques to local neural generators [50] and to regional patterns of activation observed in rCBF studies [27,51-54].

The identical N2 component was elicited in all modalities. The N2 components measured in this study most closely correspond to the visual N2 component described by O'Donnell et al. [5], Novak et al. [21], Potts et al. [18], Simson et al. [24], and Ritter et al. [22], Luck and Hillyard [55], Harter and Aine [17]. The anterior or posterior N2 component was sensitive to both within and across feature differences in stimulus attributes [5]. Moreover, the sensitivity of N2 to variations in visual feature dimensions, including orientation, color, size, and spatial frequency [5,49,55-56]. The sensitivity of N2 to variations in stimulus features, or task demands requiring responding to different features associated with a stimulus [5]. Therefore, the anterior and posterior N2 components reflect the perceptual representation of task-relevant visual features [5].

Several studies have reported that attended to (rare target) and ignored infrequent (rare non-target) stimuli elicit different P300 components, i.e., P3a and P3b components, reflecting different attentive and integrative processes [57-60]. As shown in the figure 1, the N2b in this study was also followed by a positive component identified as P3a. According to the functional role of the two P300 components, P3a reflects a stimulus-driven attentional shift, while P3b reflects the process of effortful attentional allocation and stimulus evaluation for task relevance [61-67]. The functional significance of the P3

component stress its involvement in global revision of expectancies or context, such as working memory reset [28], context updating [16], and stimulus value or meaning [19,68]. In addition, the voltage distribution of the P3 component is relatively insensitive to modality of stimulation when comparing the auditory and visual modalities [5,69-70]. Some studies indicated that the variation of P3 reflected by a function of stimulus features [49,55-56], suggesting that activity in the P3 amplitude range may include subcomponents which index feature-specific processing [5]. The present findings are in the line with the hypothesis that P3a reflects automatic allocation of attention which generated in fronto-parietal regions, the cerebral network for the orienting of attention (i.e., a shift of attention towards new and/or unexpected stimuli [71-75]. In the mean time, the P3b is largely independent from response selection and mainly reflects stimulus categorization activity [57,76-78]. The finding of a significantly P3 component in this study supports to the views indicating a particularly strong asymmetry between the activated neuronal generators in the two hemispheres. Therefore, the P300 response topography and latency in the present study may reveal cortical distribution and activity dynamics of the memory trace.

4. Conclusions

The present study demonstrates the audio-visual interaction of music sound and picture features following elementary within-modality discrimination processes. MMN and N2b effects suggest the attention-related rechecking of the outcome of within-modality analyses. This findings support the view that the processing of a feature, hierarchically dependent on another feature. The automatic detection of the target music sound and picture may be a useful index of auditory and visual memory traces of music sound and picture attention and cognition in the human cortex.

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