Behavioral and neural evidence of music training improving audiovisual matching ability

Mingmin Zhang[a, Ψ], Zitong Lu[b, Ψ], Huihang Su[a] & Zhaoxin Wang[a, *]

[a]Institute of Cognitive Neuroscience, School of Psychology and Cognitive Science, East China Normal University, Shanghai, China
[b]Department of Psychology, The Ohio State University, Columbus, Ohio, USA

[Ψ]Equal contribution
*To whom correspondence may be addressed. Email: zxwang@nbic.ecnu.edu.cn

Abstract

Understanding the neural mechanism of cognitive control has become an extremely popular question in cognitive neuroscience domain. Especially, we process complex surrounding information from different modalities simultaneously in our daily life. Previous studies found that people with music training background were more sensitive to sound and sound-related visual stimuli. In this study, we are focusing on the relationship between audiovisual cross-modality matching and music training. We used both behavioral and event-related potentials (ERPs) to investigate whether music training can improve the audiovisual match ability and how music training influences this cross-modality conflict detection process in an audiovisual matching task. At the behavioral level, we found musician group performed significantly less reaction time than non-musician group. At the neural level, we found musician group had significantly stronger strength of N400 component than non-musician group. These results suggested that people with music training had stronger ability of audiovisual integration than people without music training, and musician group were more sensitive to audiovisual match and mismatch. Our study gave both strong behavioral and neural evidence that music training could effectively improve audiovisual matching ability.

Keywords: music training, audiovisual matching, cognitive control, N400

Introduction

Cognitive control plays an important role in cognition process, which has been studied by various interference task, such as the Stroop task, flanker task, Simon task and matching and/or matching-like task (Botvinick, Braver, Barch, Carter, & Cohen, 2001; Davranche, Hall, & Mcmorris, 2009; Folstein & Petten, 2010; Heinemann, Kunde, & Kiesel, 2009). Using matching and/or matching-like tasks, previous studies (Proctor, 1981) found that not only more reaction time was needed to identify mismatching stimuli, but also it was harder to distinct correctly.

In addition to behavioral indicators, many studies have found that electroencephalogram (EEG) were sensitive to different levels of the conflict (Huayun, Huibin, & Dongchuan, 2018; Li, Jia, Chung-Fat-Yim, Jin, & Yu, 2017). The event-related potential (ERP) N400 component, a prominent negativity at central parietal locations around 400ms, has been generally observed in matching task (S. E. Barrett & MD, 1990; S. E. Barrett & Rugg, 1989; Sarah E Barrett & Rugg, 1990; Khateb et al., 2007; Kramer & Donchin, 1987), which might reflect the stimuli similarity (A. Khateb, A. J. Pegna, T. Landis, M. S. Mouthon, & J. M. Annoni, 2010b) or the mismatch level (Chuderski, Senderecka, Kaamaa, Kroczek, & Ociepka, 2016; B. Liu, Wang, & Li, 2011; Zhou et al., 2010). This component was firstly observed under semantic incongruity condition during sentence reading, and it has been related to the semantic process.(M Kutas & Hillyard, 1980). The incongruent-versus-congruent N400 component was also usually observed in the classic Stroop task(Rebai, Bernard, & Lannou, 1997).However, many other studies (S. E. Barrett & MD, 1990; S. E. Barrett & Rugg, 1989; Sarah E Barrett & Rugg, 1990; Khateb et al., 2007; Khateb et al., 2010b; Kramer & Donchin, 1987) have also found that N400 was evoked in matching or matching-like tasks, including orthographical matching of words, non-words and picture's names, category matching of pictures, faces, letters or numbers. Although the different types of stimuli and representational formats has been used across matching tasks, the N400 components were qualitatively similar in the matching task(Khateb et al., 2010b). Quantitatively, the conflict level of stimuli could effectively influence the amplitude of N400. For instance, compared with a lower conflict level, a more negative deflection would be observed under the higher conflict level (Chuderski et al., 2016; B. Liu et al., 2011).

Importantly, in everyday life, people process complex surrounding information through different sensory modalities simultaneously rather than one single sensory modality. Thus, it's important to match both auditory and visual information from the real-life world. For instance, the human need to match auditory and visual speech in daily communication (Baart, Vroomen, Shaw, & Bortfeld, 2014). Interestingly, the N400 effect could be observed not only in unimodal matching task but also in cross modal matching task. Many previous studies have found that the mismatch audio-visual cross modal information could elicit N400 component (Cornejo et al., 2009; B. Liu et al., 2011; B. Liu, Wu, & Meng, 2012; Baolin Liu, Wu, Wang, & Ji, 2011; Zhang et al., 2017).

People with a musical background are more sensitive to both sound and visual stimuli related to sound. Previous study found that the pitch labeling process evoked an increased N400 component in absolute pitch musicians, indicating absolute pitch musician shows an stronger audiovisual memory associations (Elmer, Sollberger, Meyer, & Jäncke, 2013). However, it remains unclear whether music training can help improve the sensitivity to audio-visual conflict instead of unimodal conflict and the processing difference of visual-auditory matching between people with no musical background and people with music learning experience.

In present study, we explored how music training influences the behavioral performance and neural processing in visual-auditory matching. We recruited two groups of people, non-musician group and musician group, to participate an audiovisual matching task with EEG recording. Participants were asked to judge whether the audio pitch (auditory stimulus) and musical note (visual stimulus) were in the same pitch level during the task. Here, we set three kinds of conflict conditions: congruent, major incongruent and minor incongruent. For behavioral level, we computed and compared the accuracy and reaction time among different conditions between two groups. For neural level, we conducted the ERP comparison, especially N400, to understand the neural mechanism how brain processing of visual-auditory conflict changes with music training. Our work aims to find both behavioral and neural evidence that music training can improve the visual-auditory cross-modal matching ability.

Methods

Participants

Overall, fifty-five healthy, right-handed adults were recruited in this experiment. They were divided into two groups based on their instruments learning experiences. The non-musician group includes 28 participants (13 females and 15 males) aged 18-25 ($M = 23.3$, $SD = 2.0$). All non-musicians had not been formally trained in instruments, and we recruited them in East China Normal University. The musician group includes 27 participants (16 females and 11 males) aged 18-26 (Mean = 22.0, $SD = 2.9$), and we recruited them in Shanghai Conservatory of Music. All musicians received formal instrument training before the age of 10, and they've been trained for at least 9 years so far. Among all musicians, 19 majored in piano, 4 musicians majored in violin, 1 majored in violoncello, 1 majored in bass fiddle, 1 majored in erhu, and 1 majored in pipe organ. Four non-musician participants were excluded before the final analysis because they pressed the wrong buttons or did not fully understand the task. All experimental protocols and informed consents were approved by the Institutional Review Board of East China Normal University.

Materials and procedure

The experiment includes visual and auditory stimuli (Fig. 1a). The auditory stimuli include 4 MATLAB generated pure tones: C4 (261Hz), E4(329Hz), C5(523Hz), and E5(659Hz). Visual stimuli consisted of 4 notation images. Each notation image includes a stave with a whole note, representing a specific musical pitch (C4, E4, C5, and E5). Visual and audio stimuli were simultaneously presented, and were divided into three conditions based on the pitch intervals between visual and audio stimuli. For example, the Congruent condition defined as the visual and auditory stimulus representing the same pitch: (C4-C4, E4-E4, C5-C5, E5-E5). In the minor incongruent conditions, the pitch interval between the visual and auditory stimuli is a major third (C4-E4, E4-C4, C5-E5, E5-C5). In the major incongruent condition, the interval between visual stimulus and the pitch tone of auditory stimulus is a perfect octave (C4-C5, E4-E5, C5-E4, E5-E4).

The participants were seated in a quiet room facing a monitor placed at a distance of 60cm for the eyes. The stimuli spanned approximately at 10 by 10° of the visual angel. And two loudspeakers were located below the monitor (one at the left and the other at the right). All auditory stimuli have a sound level of approximately 76 dB.

Participants were required to conduct three procedures of practice before the main task. First, in the visual notation procedure, participants were informed of the details about the notation images presented in this experiment. They were required to press the button with correct number on the keyboard when the visual stimulus was presented (1 for C4, 3 for E4, 8 for C5 and 0 for E5). Second, in the auditory pitch procedure, participants then were informed of the details about the pure auditory tones that were played in this experiment. They were required to press the buttons with correct number on the keyboard, the same as in the visual notation practical procedure when the auditory stimulus was played. Thirdly, in the main task procedure of practice, participants were informed to distinguish whether the pitch of a visual stimulus and an auditory stimulus are the same. Each of these procedures includes 16 trials, following with immediate feedback after response. Before the main task, participants had to practice each procedure repeatedly until the correct rate was higher than 90%.

In the visual-auditory matching main task, in each trial (Fig. 1b), a fixation cross (+) was first shown for 500ms to 700ms randomly in the center of the screen, followed by a visual note card stimulus and a simultaneously played auditory pure tone stimulus. And, the participants were instructed to judge as rapidly as possible whether two pitch patterns from visual note and pure auditory tone are in the same pitch level. After response, an auditory white noise and a visual mask stimulus were presented simultaneously for 500ms to 800ms randomly. At the end of each trial, a blank screen was presented for 500ms. To increase the homogeneity of the experimental materials, the main task included five blocks, and each block consisted of 80 trials (40 for congruence, 20 for minor incongruence, and 20 for major incongruence). We created a randomized stimuli order for each block before the task. Thus, all participants would see and hear stimuli in a same randomized order.

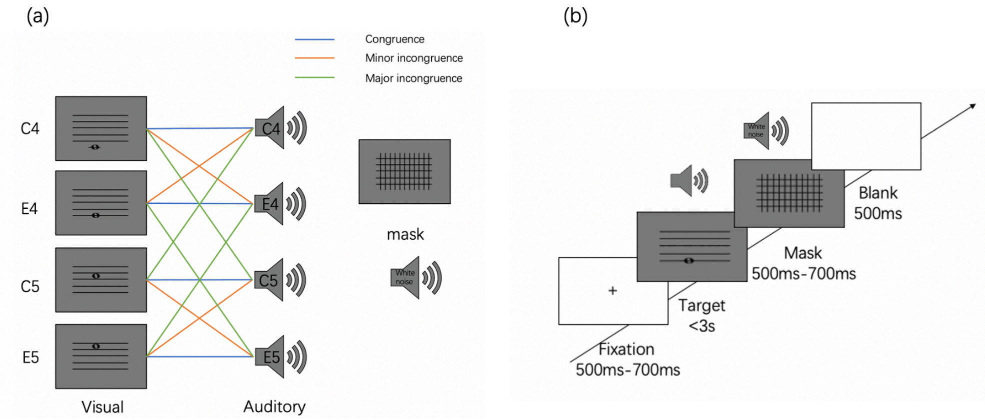

Figure 1 The experimental setup for experiment. (a) The stimuli set consisted of four visual notation images and four

pure auditory tones. (b) An example of a trial in the main task.

Electrophysiological recording and analysis

We recorded brain electrical activity of each subject during the main task from 64 scalp sites using tin electrodes mounted in an elastic cap (Brain Product; Brain Products GmbH, Stockdorfer, Munich, Germany), with the reference on the whole brain average. The vertical electro-oculogram (EOG) was recorded with electrodes placed below the right eye. All interelectrode impedance was maintained below 5 kΩ. The electroencephalogram and EOG were amplified using a 0.05–30 Hz band-pass and sampled continuously at 500 Hz for each channel for off-line analysis. Eye-movement artifacts (blinks and eye movements) were rejected off-line. Trials with EOG artifacts (mean EOG voltage exceeding ± 100 μV) and those contaminated with artifacts because of amplifier clipping, bursts of electromyographic activity, or peak-to-peak deflection exceeding ± 100 μV were excluded from averaging.

Electroencephalogram signals were averaged within an epoch of 1200 ms that started 200 ms before the onset of the stimulus and ended 1000ms after stimulus. Only segments with correct responses were selected and at least 45 trials were available for each condition. Before the mass univariate analyses applied, we reduced the sampling rate of the ERP data from 500Hz to 125Hz by using the function decimateGND provided by Mass Univariate ERP Toolbox.

To detect reliable differences among the ERPs to congruent, minor incongruent, and major congruent conditions in task, the ERPs under these conditions were submitted to a repeated measure, two-tailed cluster-based permutation test based on the cluster mass statistic (Bullmore et al., 1999)using a family-wise alpha level of 0.05. All time points between 100 and 900 ms at all 64 scalp electrodes were included in the test. Repeated measures t-tests were performed for each comparison using the original data and 2500 random within-participant permutations of the data. For each permutation, all t-scores corresponding to uncorrected p-values of 0.05 of less were formed into clusters with any neighboring such t-scores. Electrodes within approximately 5.44 cm of one another were considered spatial neighbors and adjacent time points were considered temporal neighbors. The sum of the t-scores in each cluster is the "mass" of that cluster and the most extreme cluster mass in each of the 2501 sets of tests was recorded and used to estimate the distribution of the null hypothesis. The permutation cluster mass percentile ranking of each cluster from the observed data was used to derive its p-value. The p-value of the cluster was assigned to each member of the cluster and t-scores that were not included in a cluster were given a p-value of 1.

To detect reliable differences between the ERPs to tones from musician and non-musician in the task, these ERPs were submitted to an independent sample, two-tailed permutation test based on the cluster mass statistic (Bullmore et al., 1999) using a family-wise alpha level of 0.05. All time points between 300 and 500 ms at all 64 scalp electrodes were included in the test (i.e., 754 total comparisons). Independent samples t-tests (assuming equal variance in the two groups) were performed for each comparison using the original data and 2500 random between-participant permutations of the data. t-scores corresponding to an uncorrected p-value of 0.05 or less were formed into clusters with any neighboring such t-scores. Electrodes within approximately 5.44 cm of one another were considered spatial neighbors and adjacent time points were considered temporal neighbors.

This permutation test analysis was used in lieu of more conventional mean amplitude ANOVAs because it provides much better spatial and temporal resolution than conventional ANOVAs while maintaining weak control of the family-wise alpha level (i.e., it corrects for the large number of comparisons). Moreover, the cluster mass statistic was chosen for this permutation test because it has been shown to have relatively good power for broadly distributed ERP effects(Groppe, Urbach, & Kutas, 2011; Maris & Oostenveld, 2007). 2500 permutations were used to estimate the distribution of the null hypothesis as it is over twice the number recommend by (Manly, 2018) for a family-wise alpha level of 0.05.

Results

Behavior results

Accuracy

Repeated measure ANOVA reveled a significant main effect of the group (musician vs. non-musician) factor on accuracy (F (1, 49) =14.63, p<0.001, η^2=0.23). Musician group (M = 0.946 , SD =0.011) showed greater accuracy than non-musician group (M =0.884 , SD = 0.012) with t(53)=3.88, p<0.001. And the main effect of condition factor (congruent vs. major congruent vs. minor incongruent) was significant (F(2, 49) =12.603, p<0.001, η^2=0.20). The minor incongruent condition (M=0.082, SD=0.014) showed a less accuracy than major incongruent condition (M=0.938, SD=0.008) and congruent condition (M=0.924, SD=0.009) with t(54)=-4.23, p<0.001 and t(54)=-3.5, p<0.01, respectively. In addition, the interaction effect between the group and condition is significant (F (2, 49) =7.22, p<0.001, η^2=0.13).

Musician group performed a higher accuracy than non-musician group under the congruent (t(53)=3.20, p<0.005) and minor congruent condition (t(53)=4.00, p<0. 001). In non-musician group, the major congruent condition showed a higher accuracy than minor incongruent and congruent condition (t(27)=5.26, p<0.001; t (27)=2.36, p<0.05), and the congruent condition showed a higher accuracy than the minor incongruent condition (t=3.72, p<0.001). All statistical values were Greenhouse-Geisser corrected.

Reaction Time

Repeated measure ANOVA reveled no significant main effect of the group factor on reaction time (F (1, 49) =1.441, p=0.23, η^2=0.03). The main effect of condition factor is significant (F (2, 49) =44.25, p<0.001, η^2=0.48). The congruent condition (M=0.98， SD=0.031) took significant less reaction time than the major incongruent condition (M=1.07， SD=0.034) and minor incongruent condition (M=1.12， SD=0.039) with t(54)=-7.23, p<0.001 and t(59)=-9.0, p<0.001. And the major incongruent condition took less reaction time than the minor incongruent condition (t(54)=-2.72, p<0.01).

In addition, the interaction effect between the group and condition was significant (F (2, 49) =15.99, p<0.001, η^2=0.25). Musician group showed a longer reaction time than non-musician group in the congruent condition (t(53)=2.94, p<0.01). In musician group, the congruent condition showed a less reaction time than the minor incongruent condition (t(26)=-3.14, p<0.01). In non-musician group, the congruent condition showed a less reaction time than in major incongruent condition (t(27)=-8.89, p<0.001) and minor incongruent condition (t(27)=-9.61, p<0.001), and the major incongruent condition showed a less reaction time than minor incongruent condition (t(27)=2.00, p<0.05). All statistical values were Greenhouse-Geisser corrected.

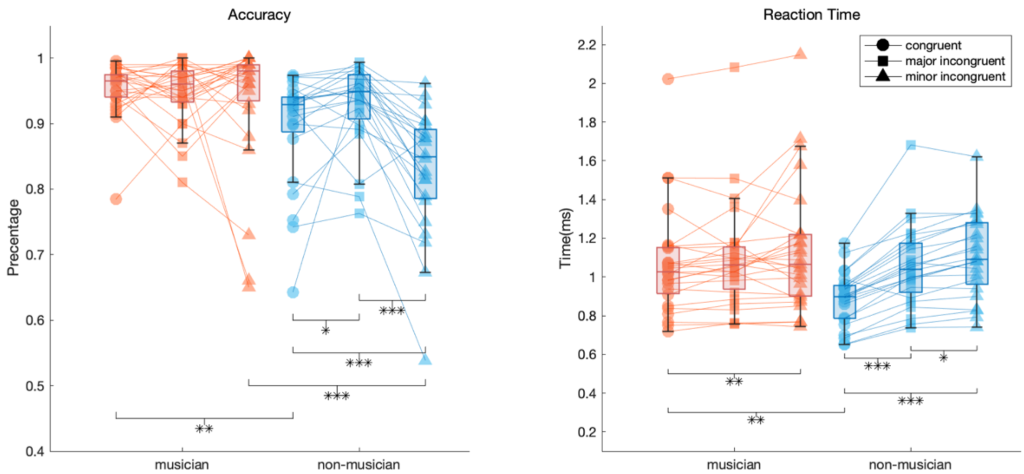

Figure 2 Behavioral results of accuracy (left) and reaction time (right).

ERP results

Condition-dependent congruent/incongruent effects

Here, in order to find neural differences between congruent and incongruent conditions (major congruent vs. incongruent and minor congruent vs. incongruent), we conducted the cluster-based permutation test to do comparisons in two groups (non-musician and musician).

For non-musician group, the ERP comparison between major incongruent and congruent conditions showed no significant difference. But we found some significantly different time-windows between minor incongruent and congruent conditions, we found the amplitude under minor incongruent condition was significantly higher than the amplitude under congruent condition in frontal area at around 500-900ms. But there was significantly lower amplitude under minor incongruent condition in parietal area at around 350-750ms.

For musician group, the ERP comparison between major incongruent and congruent conditions also showed no significant difference. But we also found significant differences between minor incongruent and congruent conditions. The amplitude under minor incongruent condition was significantly higher than the amplitude under congruent condition in frontal area at around 500-800ms. And there was significantly lower amplitude under minor incongruent condition in parietal area at around 400-750ms.

Figure 3a shows ERP results in Cz for three experimental conditions and two groups. However, there was not significant difference among N400 components under three conditions for both non-musician and musician group.

Group effects

For the cross-group comparison, we were focusing on the N400 to test whether this neural marker could be influenced by music learning experience. We found significant cross-group differences under all three conditions. The ANOVA showed a significant group main effect (F (1,51) =15.22, p<0.001, η^2=0.23). Also, under all three conditions, N400 of musician group were significantly lower than N400 of non-musician group (congruent condition: t(53) =-3.82, p<0.001; major incongruent condition: t(53) =-3.91, p<0.001; minor incongruent condition: t(53)=-3.56, p<0.001).

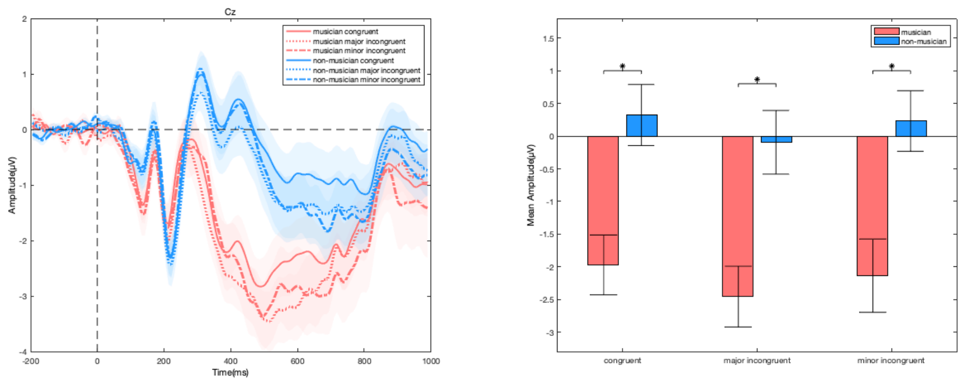

Figure 3 Left: ERPs under three experimental conditions of two groups. Right: N400 amplitudes under three experimental conditions of two groups (using Cz channel from 300-500ms time-window).

Discussion

In our current study, we aimed to explore how music training influences the behavioral performance and neural processing in visual-auditory matching. Here, we set three different experimental condition corresponding to different levels of matching (congruency, minor and major incongruencies) and recruited two groups of participants corresponding to the background of music training (musician group and non-musician group). And we were focusing on both the differences between different experimental conditions and the differences between two groups and conducted comparisons based on both behavioral and neural levels.

Here, the behavioral results showed a significant less reaction time of musicians than non-musicians. Previous studies found that musicians had an stronger audiovisual memory associations (Elmer et al., 2013) and music training can strengthen cognitive functions and auditory perception (Kraus & Chandrasekaran, 2010), especially those functions relate to language and literacy (Strait, Kraus, Parbery-Clark, & Ashley, 2010). Also, compared with non-musicians, musicians utilize more abstract code, transforming the visual input into naming or pitching when they recognize music notation (Sloboda, 1976). Our behavioral results indicated that music training could improve the audiovisual matching ability rather than pure musical or semantic perception and control abilities. The people without music training had more troubles in audiovisual matching task, and they needed more time to compare and judge the cross-modality difference. Meanwhile, we found no significant difference among different mismatch levels in musician group. But we could find significant differences of accuracy and reaction time among three mismatch levels. This indicated that people with music training were able to respond quickly to cross-modality cognitive conflict at the behavioral level. Music training compensated for the deficiency of audivisual matching, which led no difference in behavioral outputs among three experimental conditions.

To explore the neural differences between these two groups, especially to understand how musician group improve the audiovisual matching ability, we mainly applied N400 ERP component as an index. Previous studies have linked N400 to the conflict monitoring (Coderre, Conklin, & Heuven, 2011; Horowitz-Kraus & Breznitz, 2008; West, 2003), and some studies suggested the process of semantics memory (Baggio & Hagoort, 2011) and cross-modal memory association (Marta Kutas & Federmeier, 2011) would evoke N400. In our audiovisual matching task, we observed a negative deflection during 300-500ms in musicians at the Cz electrode, and we think it is N400 component because it consists of both spatial and latency characteristics of N400. (Gunter, Jackson, & Mulder, 1995; A. Khateb, A. J. Pegna, T. Landis, M. S. Mouthon, & J.-M. Annoni, 2010a; Rebai et al., 1997)If N400 amplitude was significantly less in musician group than non-musician group, it suggested that people with music training were more sensitive to the cross-modality conflict detection. If N400 amplitude was significantly less in non-musician group instead of musician group, it might suggest that music training let people become less sensitive to the conflict detection. Our neural results confirmed the former possibility. This indicated that music training could improve the monitoring sensitivity of cross-modality matching. In addition, it was also significantly different between two groups under congruency condition, which suggested that music training improved our sensitivity of matching tasks rather than only the detection of conflict.

Some previous studies indicated the N400 was modulated by the level of mismatch (Chuderski et al., 2016; B. Liu et al., 2011; Zhou et al., 2010). However, our ERP results didn't reflect the differences between different levels of mismatch. On the one hand, it might be caused by the low task difficulty. In our future study, we were considering increasing the task difficulty, such as providing a melody and a string of notes instead of a single syllable and a single note. On the other hand, N400 may not be enough to capture the difference of the level of mismatch in an audivisual cross-modality task. More brain regions may be involved in this complex proess of integrating both sematic and visual information. In the future, we planned to use fMRI technique and multivariable pattern analysis (MVPA) method to delve deeper into the process to further distinguish the neural processes of audiovisual integration, audiovisual conflict detection and conflict level representations.

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