Musical expertise attenuates cross-modal fast-"same" effect of pitches: an ERP study

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Abstract

The same-different judgment (SDJ) is a fundamental cognitive ability and previous studies often found that a "same" response usually takes less time than does a "different" response if visual stimuli were presented, i.e., the fast-“same” effect. Yet, it is unknown whether the fast-“same” effect exists in cross-modal SDJ. In this event-related potential (ERP) study, we investigated this issue and the underlying neural processes with a cross-modal SDJ task with visual notations and auditory pitches, and further investigated the effects of musical expertise on the fast-“same” effect. Twenty-eight nonmusicians and 27 musicians without absolute pitch participated in this study. In nonmusicians, an obvious fast-“same” effect and a difference between “same” and “different” judgment in the N400 were found. Moreover, the N400 was downregulated by music expertise, while a difference in N400 between “same” and “different” judgment was also found in musicians, together with a weaker fast-“same” effect behaviorally. Furthermore, the RTs were positively correlated with the N400 in musicians. We concluded that the present study provided evidence of the existence of fast-“same” effect of cross-modal SDJ of pitches as well as its underlying ERP neural correlates, i.e., N400, and further showed the N400 can be modulated by musical expertise, which led to a weakened fast-“same” effect in musicians.

Background

‘‘Sameness and difference are fundamental cognitive relations that enter, at least implicitly, into most forms of adaptive perceptual behavior’’[1]. To our knowledge, studies on same-different discriminations are mostly focused on the visual modality. For a standard version of the visual same–different judgment (SDJ) experiment, every trial contains two independent observation intervals, separated either in time or space [1]. Interestingly, though it seems that processing demands appear to be maximal in the “same” condition and minimal in the “different” condition [2], researchers found that a "same" response usually takes less time than does a "different" response if visual stimuli were presented, i.e., the fast-“same” effect [3-5], which is less inconsistent with auditory stimuli [6-8] when the stimuli are readily codable [6].

Fast-“same” judgments are deemed to be a defining feature of holistic processing [4, 9, 10] and Bamber et al. proposed a two-process model, in which there is an identify reporter (a quick related with “same”, and holistic process) and a serial processor and the “different” was determined by a serial, self-terminating manner [10]. Eviatar et al. [11] suggested a confluence model [12], which posits that objects are compared automatically with respect to the task-relevant and task-irrelevant dimensions via separate neural systems before the outputs converge to a point of confluence where they affect the final judgment. Indeed, at a given moment, the brain represents visual stimuli at multiple levels of granularity. For example, when one retrieves memory for a known concept such as a carrot, its perceptual features, such as its shape and color information are represented in the lateral occipital complex and V4, respectively, while its object-level representation is elsewhere [12]. These early differences may lead to the differences in SDJ, and variables that may lead to differences in brain activations of early processing in these brain regions, such as symmetry, familiarity, difficulty [6, 13, 14], etc, could lead to difference of SDJ [3, 14, 15]. Consistently, ERP studies revealed that differences in early processing occurred between same and different visual stimuli. For example, Chang et al. found a more negative N2 component in different colors and different shapes as compared to SAME between 280 and 320 ms post-stimulus [16], Zhang et al. also reported a main effect of color congruency in the time window 190–260 ms post-stimulus presentation and a main effect of shape congruency in the time window 220–280 ms post-stimulus presentation in both color and shape tasks [1]. Davelaar et al. also reported that the temporal window around the M170 was related that the same identification processes [13]. These studies/theories provided invaluable insights into how our visual cognitive works. However, issues remains, for example, whether the fast-"same" effect exists if the differences in brain activations of early automatic visual processing cannot be used directly for comparisons.

One approach to address these issues is through a cross-modal comparison. Our perception and interactions with the external world consist not of isolated sensory events, but rather, a rich combination of multisensory experiences. Indeed, individual sensory systems such as audition regularly integrate and interact with the other modalities (e.g., vision) in service of enhancing perceptual processing [17], and the same-different judgments are constantly made between modalities, for example, whether a heard name is a certain person. When participants are requested to judge whether two stimuli from two modalities are the same, the effects of early perceptual representations are unlikely to be used for early comparison as they are processed in different sensory cortices with different process speeds. Previous studies reported that information from the acoustic code of visual stimuli can affect the behavioral latency of SDJ, but in a later phase [18]. For example, Posner and Mitchell reported that subjects took longer to classify letters on the basis of nominal identity (such as Aa) than on that of physical identity (such as AA) [19]. Hence, the fast-“same” effect may also exist in cross-modal SDJ and can be used to investigate the role of later mental representation. In a simultaneous SDJ task, information from both stimuli should be processed and compared at the same time, so there should be no selective loss of information and the congruency of the task-irrelevant dimension should interfere with judgments about the task-relevant dimension [1]. Surprisingly, to our best knowledge, no prior cross-modal SDJ study has been carried out.

Pitch is a ubiquitous parameter of human communication which carries important information in both music and language (Plack, Oxenham, Fay, & Popper, 2005), especially in tone language. Brain mechanisms governing music and language processing interact and might share an important link with respect to their underlying neurophysiological processing. Moreover, pitch information can be obtained in visual modality, such as by notations, making it a good candidate for cross-modal SDJ. Moreover, people with a musical background are more sensitive to both sound and visual stimuli related to sound [20]. Tone sequences with conflicting fundamental pitch and timbre changes are heard differently by musicians and nonmusicians [21], and musicians detect pitch violation in a foreign language better than nonmusicians [22] and have significantly smaller Just Noticeable Difference threshold [23].

EEG studies revealed that early processing of pitches is shaped by music training. For example, enhanced brainstem encoding predicts musicians' perceptual advantages with pitch, and training leads to changes in pitch processing at the early collicular level and are preserved and further enhanced in the right auditory cortex [24], although a negative finding was also reported in which musicians and tone-language speakers share enhanced brainstem encoding but not perceptual benefits for musical pitch [25]. Several studies have shown that the auditory cortex responds differently to sound in musicians than in non-musicians. For example, event-related potentials (ERPs) have shown musicians have enhanced N1 responses at about 140 msec after sound onset and enhanced P2 responses at about 180 msec that located at the secondary auditory cortex and superior temporal gyrus [26, 27]. Differences in later pitch processing by musicians are also reported. For example, the pitch labeling process evoked an increased N400 component in absolute pitch musicians, indicating musician shows an stronger audiovisual memory associations [28]. Enduring musician advantage among former musicians in prosodic pitch perception has also been reported [29], and brain structures differ between musicians and non-musicians [30-32]. Given these differences between musicians and musicians in pitch processing, the performance of cross-modal SDJ of pitches could be affected by music training. Hence in the present study, a cross-modal SDJ was carried out with pitches and notations with both nonmusicians and musicians. By comparing the similarities and dissimilarities between them, the neural correlate of the possible fast-“same” effect and whether and how it is shaped by musical expertise can be studied.

A further consideration is that there are two kinds of musicians, musicians with absolute pitch and musicians without absolute pitch. Opposite hemispheric asymmetries for pitch identification in absolute pitch and non-absolute pitch musicians were reported [33]. In comparison, the subjects with absolute pitch displayed the shortest mean P3 latencies, and had smaller P3 amplitudes relative to both musicians without absolute pitch and nonmusicians [34]. In our recent submitted study, we found that there are differences in the judgment of pitches between musicians with absolute pitch and without absolute pitches [35]. Hence, in this study only musicians without absolute pitch were recruited for data uniformity.

In the present ERP study, we aimed to address three questions: 1) whether the fast-"same" effect exists in a cross-modal SDJ of pitches/notations in nonmusicians; 2) And if yes, what is the underlying neural correlates; and furthermore, 3) Whether and how the fast-"same" effect and its underlying neural correlates was shaped by music training.

Methods

Participants

Fifty-five healthy, right-handed adults were recruited in this experiment, including 28 nonmusicians (13 females, aged 18-25, M = 23.3, SD =2.0) and 27 musicians without absolute pitch (16 females, aged 18-26, Mean = 22.0, SD =2.9). All non-musicians had not been formally trained in instruments, and were recruited in East China Normal University. The musicians were recruited in Shanghai Conservatory of Music and none had absolute pitch. All musicians received formal instrument training before the age of 10, and they've been trained for at least 9 years. 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 participants (1 musicians) were excluded from the final analysis because they pressed the wrong buttons or did not fully understand the task. All experimental protocols were approved by the Institutional Review Board of East China Normal University and written informed consents were obtained from all participants.

Materials and procedure

Visual and auditory stimuli were used (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 notations. Each notation image includes a stave with a whole natation, representing a specific musical pitch (C4, E4, C5, and E5).

There were three conditions. For the Congruent condition, the visual and auditory stimuli representing the same pitch were presented, i.e., 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). Visual and audio stimuli were simultaneously presented in each trial. A sample trial was illustrated in Figure 1.

The participants were seated in a quiet room facing a monitor placed at a distance of 60cm for the eyes. The visual stimuli were presented with an LCD monitor, with visual angle about 10 by 10°. The auditory stimuli were presented with two loudspeakers, which 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 practice procedures. First, in the visual notation procedure, participants were informed of the details about the notations presented in this experiment. They were required to press buttons on the keyboard when the visual stimuli were 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, an immediate-feedback was followed after response. The accuracy of 90% was required to enter the next experimental stage.

Participants then were asked to perform a visual-auditory SDJ 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 notation, a simultaneously played auditory pure tone stimulus. The participants were instructed to judge as quickly as possible whether the visual notation and pure auditory tone are the same. The visual and auditory stimuli will disappear upon the participant's keypress and will be presented for a maximum of 3 seconds. 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.

The SDJ task included five blocks, and each block consisted of 80 trials (40 congruent trials, 20 minor incongruent trials and 20 major incongruent trials). The order of trials was presented pseudorandomly.

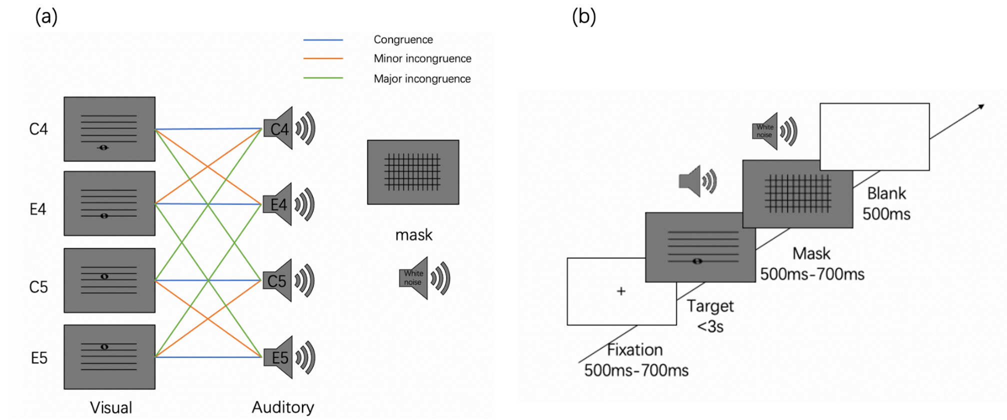

Figure 1. The experimental setup. (a) The stimulus sets consisted of four visual notations and four pure auditory tones. (b) A sample trial.

Electrophysiological recording and analysis

We recorded brain electrical activity of each subject during the SDJ task from 64 scalp sites using tin electrodes mounted in an elastic cap (Brain Product; 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 decimate GND 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 [36] 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. Paired 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 differences between the ERPs to tones from musician and non-musician in the task, these ERPs were further submitted to an independent sample, two-tailed permutation test based on the cluster mass statistic [36] 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[37, 38]. 2500 permutations were used to estimate the distribution of the null hypothesis as it is over twice the number recommend by [39] for a family-wise alpha level of 0.05.

We also implemented the conventional mean amplitude repeated measure ANOVA. The mean amplitude during 300ms-500ms in Cz electrode has been selected in this analysis. This analysis examined the effect of group (musician and non-musician) on N400 across conditions (congruent, major incongruent, and minor incongruent) repeated measurements.

Results

Behavioral results

Between-group results

For the accuracy, a repeated measures ANOVA reveled a significant main effect of the group (musicians vs. non-musicians) on accuracy (F (1, 49) =14.63, p<0.001, η^2=0.23). Musician group (M = 0.946, SD =0.011) showed higher accuracy than non-musician group (M =0.884 , SD = 0.012) with t(53)=3.88, p<0.001. The main effect of conditions (congruent vs. major congruent vs. minor incongruent) was significant (F(2, 49) =12.603, p<0.001, η^2=0.20). The *post hoc* analysis revealed that minor incongruent condition (M=0.082, SD=0.014) showed a lower 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. The group by condition interaction was significant (F (2, 49) =7.22, p<0.001, η^2=0.13). *Post hoc* simple effect analyses revealed that musicians had a higher accuracy than non-musician group under the congruent (t(49)=-3.17, p=0.008) and minor congruent condition (t(49)=-3.93, p<0. 001), but not in the major condition (t(49)=-1.21, p=0.699). Results and following results were Bonferroni corrected.

For the RT, a repeated measures ANOVA revealed no significant main effect of the group factor on reaction time (F (1, 49) =1.44, p=0.24, η^2=0.03). The main effect of condition factor is significant (F (2, 98) =44.3, p<0.001, η^2=0.48). The *post hoc* analysis revealed that 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 $p<0.001$, Bonferroni corrected. And the major incongruent condition took less reaction time than the minor incongruent condition ($p=0.02$, Bonferroni corrected). The group by condition interaction was significant (F (2, 98) =16.0, $p<0.001$, $\eta^2=0.25$). The *post hoc* analysis revealed that Musician group showed a longer RT than non-musician group in the congruent condition ($t(49)=2.94$, $p=0.015$), but not in the major and minor congruent comparisons (t(49)<-.35, $p>0.5$).

Within-group comparisons

For the Nonmusicians, a repeated measures ANOVA revealed a main effect of conditions in the accuracy, F(2,46) = 17.58, $p<0.001$, $\eta^2=0.43$. The *post hoc* analysis revealed that the differences between the minor incongruent condition and major incongruent condition ($p=0.005$), and between the minor incongruent condition and congruent condition ($p<0.001$), but not between the major incongruent condition and congruent condition($p=.186$). For the musicians, no significant main effect of conditions was found, F(2,52) = .586, $p=0.560$, $\eta^2=0.022$.

For RT, a repeated measures ANOVA revealed a main effect of conditions in the Nonmusicians, F(2,46) = 80.6, $p<0.001$, $\eta^2=0.78$. The post hoc analysis revealed that the differences between each pair of the three conditions were significant ($p<0.001$, Bonferroni corrected). In the Musicians, a repeated measure ANOVA revealed a main effect of conditions, F(2,52) = 3.90, $p=0.026$, $\eta^2=0.13$. The *post hoc* analysis revealed that the musicians responded significant faster in the congruent condition than in the minor incongruent condition (*p*=0.027).

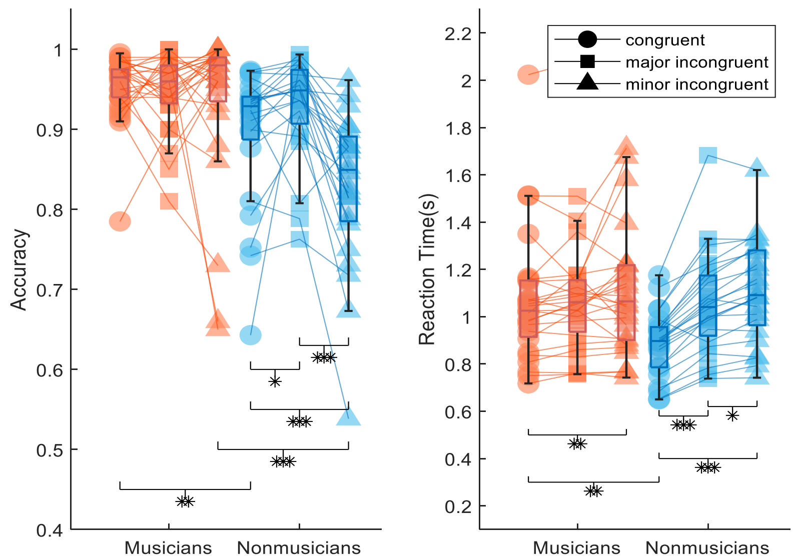

Figure 2. Behavioral results of accuracy (left) and reaction time (right). The median and the 25th and 75th percentiles were displayed. Results are Bonferroni corrected. Center line indicates the median; box outlines show 25^{th} and 75^{th} percentiles. Each colored-point represents an participants' performance.

Table 1. Behvioral results

	Musicians		NonMusicians	
	Accuracy	Reaction Time(ms)	Accuracy	Reaction Time(ms)
Congruent	.954(.042)	1071(276)	.895(.085)	888(138)
Major-incongruent	.947(.047)	1090(271)	.928(.063)	1057(211)
Minor-incongruent	.936(.042)	1137(276)	.829(.096)	1109(216)

Data format: mean(SD).

ERP results

We found there were significant differences between groups/conditions in the N400 component. Yet we did not find significant group difference in early components, such as the N150.

Group differences

For the cross-group comparison, we found significant cross-group differences under all three conditions in the N400. The ANOVA showed a significant group main effect (F (1,51) =15.22, p<0.001, η^2=0.23). Also, the amplitudes of the 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, Bonferroni corrected) in all three conditions. A further cluster-based permutation test was used to confirm these results. In the Cz channel, we found that musicians (vs non-musicians) displayed greater negative amplitudes between 294 to 542 milliseconds in the congruent conditions, between 294 to 606 milliseconds in the major incongruent conditions, and between 294 to 534 milliseconds in the minor incongruent conditions.

Effects of conditions

We conducted the cluster-based permutation test to compare possible difference between the three conditions in all participants, and further compared the possible difference in musicians and nonmusicians.

For all participants, compared to the congruent condition, the major incongruent condition elicited more negative amplitudes in the C2 channel between 374 to 666 milliseconds, in the Cz channel between 374 to 708 milliseconds, and in the C1 channel between 480 to 704 milliseconds, while the minor incongruent condition elicited more negative amplitudes in the Cz channel between 552 to 804 milliseconds, and in the C1 channel between 612 to 804 milliseconds.

In the musicians, the ERP permutation comparison displayed more negative amplitudes in the Cz channel between 486 to 630 milliseconds during the major incongruent condition (vs the congruent condition). No significant differences were found during the minor incongruent condition when compared to the congruent condition, despite visual inspection showed similar trend, Figure 3.

In the non-musicians, the ERP permutation comparison shows a more negative amplitude in the Cz channel between 518 to 806 milliseconds during the minor incongruent condition (vs the congruent condition). No significant differences found during the major incongruent condition when compared to either the congruent condition or the minor incongruent condition was revealed, despite visual inspection showed similar trend.

The conventional N400 analysis indicated a significant main effect of group, $F(1,49)$ =

14.76, $p<0.001$, $\eta^2 = 0.201$, suggesting that there were significant differences among the groups, and there is a more negative component in musicians compared to non-musicians, $t(49) = -3.642$, $p< 0.001$. And there is a significant main effect of conditions, $F(2, 93) = 4.38$, $p<0.01$, $\eta^2 = 0.007$. Major incongruent condition is more negative than congruent condition, $t(49) = 2.901$, $p<0.05$. However, no interaction between these two factors, $F(2,93) = 0.05$, $p=0.944$, $\eta^2 < 0.001$. All results were corrected by Tukey method.

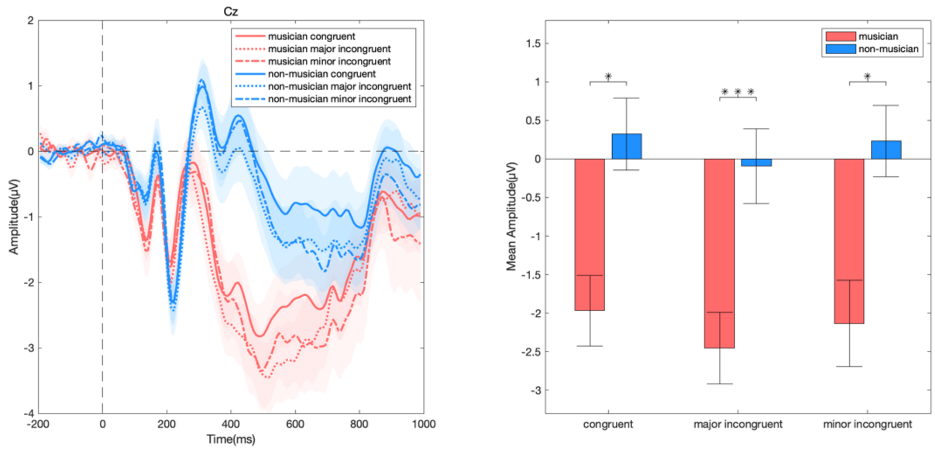

Figure 3. Left: the time courses of N400 in Cz in different conditions. Right: averaged N400 amplitudes in three conditions (using the Cz channel from 300-500ms time-window). * p <0.05; *** p < 0.005

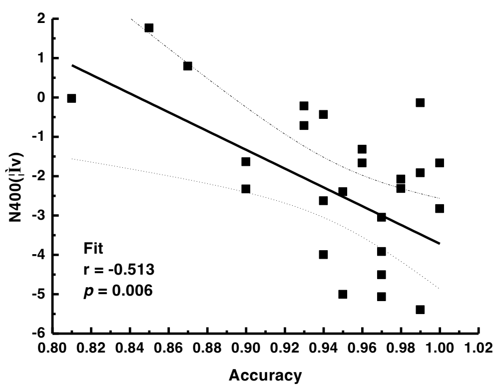

Figure 4. Significant negative correlation was found between the accuracy and N400 in the major incongruent condition.

Correlations between accuracies, RTs, and N400

A further correlation analysis revealed that the RTs of the congruent condition, major incongruent condition and minor incongruent condition were positively correlated with the N400, r=0.433, $p = 0.024$; r=0.391, $p = 0.044$; and r=0.418, $p = 0.030$, respectively. The accuracy of the major incongruent condition was also negatively related with the N400 component, r=-0.513, $p = 0.006$. In nonmusicians, none of the correlations turned out significant, r<0.368, $p > 0.076$.

Discussion

In the present study, we found that the fast-“same " effect still existed in a cross-modal SDJ of pitches in non-Musicians. Further ERP results revealed that the N400 was significant different between the incongruent condition and congruent condition. Moreover, the N400 component was downregulated by music expertise. Furthermore, we found that the cross-modal SDJ of pitches was still presented in the musicians, but weakened by music expertise, in that only a slight increase in the reaction time in the minor incongruent condition compared with congruent condition was found, but not in in accuracy. More important, differences in N400 was also found between the major incongruent condition and congruent condition in musicians. Our results hence revealed that there was a cross-modal fast-“same” effect, as well as its underlying neural correlates; and further showed this effect was shaped by music expertise.

Behavioral evidence of Cross-modal fast-"same" effect and the effects of music expertise

As displayed in Figure 2 and Table 1, the mean accuracies of all the three conditions were greater than 85%, indicating that after a short time practicing period, non-musicians can learn the associations between the notations and auditory pitches. Moreover, the RTs recorded were typically longer than other SDJs using only visual stimuli, even in the acoustic confusion condition [18]. These results are in line with our hypothesis that the cross modal SDJ is processed in a later phase.

The behavioral data showed that RTs were faster in the "same" condition compared to both the "minor incongruent" condition and the "major incongruent" condition, indicating an obvious fast-"same" effect in this cross-modal SDJ task. The large increase in average RT to "different" or incongruent stimuli supports the idea that acoustic confusability will interfere with "different" responses. We also found that RTs were shorter in the "major incongruent" condition compared to both the "minor incongruent" condition, and the accuracies of the "major incongruent" condition are higher than the "minor incongruent" condition, indicating higher level of cross-modal confusability can increase the latency while decrease the accuracies of judgment of non-matching responses. The accuracy of the minor incongruent was also the lowest, in line with Bamber's finding that the false "same" responses appear to result from a failure to detect the difference between the two stimuli and most false "same" responses occurred when the two stimuli differenced minimally [10]. These results are in line with results from that behavioral results to visual stimuli are affected by confusability from acoustic code [18], and further extend the fast-"same" effect from one modal [2, 40-42] to cross-modal SDJ tasks.

In musicians, the behavioral data showed that RTs were faster in the “same” condition compared to the “minor incongruent” condition, indicating that the cross-modal fast-“same” effect also occurred in musicians. We note that no significant difference was found in the RT between the “same” condition and the “major incongruent” condition, and there were no significant differences in the accuracies, indicating the fast-“same” effect is weakened by music training compared to nonmusicians. Note the acoustic confusability not only will interfere with “different” responses, but may also interfere with “same” responses. As higher level of cross-modal confusability can increase the latency while decrease the accuracies of judgment of non-matching responses with visual stimuli [18, 43], we speculate that the RT to the “same” condition will increase due to confusability, hence the difference between the major incongruent condition and same condition is diminished. i.e., the fast-“same” effect [3-5]. Another factor is that the fast-“same” effect is less inconsistent when the auditory stimuli are not readily codable [6].

Surprisingly, the mean RTs were not significant different between musicians and nonmusicians. It is possible that the enhanced pitch discrimination abilities in musicians without AP are related to more central stages of the auditory system [44], and musical expertise may exert its effects merely at later, attentive levels of processing and not necessarily already at the preattentive levels [45]. We speculate that there might be a speed-accuracy tradeoff in the musicians, the musicians prefer accuracy over speed as the mean accuracies of all the three conditions were greater than 92% in musicians. Indeed, the musicians spent more time in the congruent condition compared to non-musicians

(p=0.005). Another possibility is that the specific direction of sensory dominance depends on the level of processing: vision dominates at earlier stages, whereas audition dominates at later stages of cognitive processing [46]. Indeed the fast-"same" effect is less inconsistent with auditory stimuli [6-8] with similar decision latency for "same" and "different" were reported when the stimuli are not readily codable [6].

Combined, our results revealed that there was a cross-modal fast-"same" effect in nonmusicians, which was weakened by music expertise. We think that our results can be best explained by Cohen et al's account for speeded SJD among integral-dimension stimuli [47] that based on the exemplar-based random-walk (EBRW) model of speeded classification [48]. According to the model, an important component process of SDJ is that people store individual examples of experienced same and different pairs of objects in memory, i.e., neural representations of stimuli, which may be reflected by the N400. These exemplar pairs are retrieved from memory on the basis of how similar they are to a currently presented pair of objects [47]. Studies revealed that hearing a task-irrelevant sound during object encoding can improve visual recognition memory when the sound is object-congruent at the same time [49-51]. Different areas of auditory and visual cortex are specialized in processing several types of articulations and that brain activity is greater when coherent stimuli were used [52]. We argue that compared with musicians, the cross-modal links between the visual notations and the auditory pitches were not well established in non-musicians, reflected by the amplitudes of N400. The exemplar pairs are retrieved from memory on the basis are weak, hence we observed an obvious fast-"same" effect in the non-musicians, which was weakened in musicians.

Neural Mechanism of cross-modal SDJ

The cluster-based permutation test revealed that compared to the congruent condition, both the major and minor incongruent conditions elicited more negative N400 amplitudes in the C2 and Cz channel, indicating that the N400 plays a crucial role in the SDJ. These results are also confirmed by permutation analysis of both the musicians and nonmusicians. In non-musicians, there was significantly lower N400 amplitude under incongruent condition (minor) compared to congruent condition, indicating more effort is need in the minor incongruent condition. Similar results were also found in musicians, as the ERP permutation comparison displayed more negative amplitudes during the incongruent condition (major vs the congruent condition). These results indicate that the N400 plays a significant role in the cross-modal SDJ in both musicians and nonmusicians. Note previous studies have linked the N400 component to conflict monitoring [53-56]. The N400 component were captured in many matching task [57, 58] and was thought to be linked to the conflict detection [59]. The amplitude difference of N400 also was found in audiovisual cross-modal priming task as an index of integration process of audio and visual information. In this process, the sematic association between visual and audio was derived from long-term memory in the human brain [60, 61]. In our study, participants have to matching two modalities' information, and higher conflict level should result in more negative N400, as found in the present study.

Moreover, the amplitudes of N400 of musicians were significantly lower than N400 of non-musicians in all three conditions. These results suggest that the N400 is downregulated by music expertise. We speculate that as N400 is also related perceptual/sematic association of pitches [62], musicians have a better memory or link between neural representations for auditory and visual information of pitches/notation [63]. In line with this explanation, the RTs were significantly correlated with the amplitudes of N400 in musicians in the three conditions. Also, the accuracy was also significantly correlated with the amplitudes of N400 in the major incongruent condition, the easiest condition. Note similar correlation was not found in nonmusicians, perhaps due to larger variations in them. We argue that this mechanism helps musicians accomplish the cross-modal SDJ task. In line with this explanation, we noticed that the ERP permutation comparison displayed more negative amplitudes during the major incongruent condition (the congruent condition), but not the minor incongruent condition (although a similar trend was revealed), likely reflecting a difference in perceptual/sematic processing between major/minor difference.

We noted that previous studies observed that in the early stage of note reading, the musician/non-musician differences emerged in the latencies of the N1 and N2 [64]. Zheng et al. argued that long-term music training facilitates "bottom-up" auditory information processing in the sensory system [65]. In the present study, however, we did not find significant differences in these early components. One possible reason is that a cross-modal SDJ task was used in this study, which led to greater variations in early perceptual processing, hence renders the differences harder to detect.

Taken together, our results indicated that N400 plays a crucial role in the fast-“same” effect in nonmusicians. As the N400 was affected by music expertise, hence the fast-“same” effect in the musicians was affected behaviorally, who therefore displayed a weak cross-modal fast-“same” effect than nonmusicians.

Conclusions

In the present study, we investigated whether the fast-“same” effect exists with a cross-modal SDJ of pitches/notations as well as its underlying neural correlates in nonmusicians and musicians. Two lines of evidence indicated the existence of the cross-modal fast-“same” effect of notations/pitches. First, both musicians and nonmusicians displayed fast-“same” effect behaviorally, and differences between “same” and “different” judgment in the N400 were found. Second, the N400 was downregulated by music expertise, as well as a weakened fast-“same” effect in musicians. We conclude that the present study provides evidence of the existence of the cross-modal fast-“same” effect, and highlights the critical role of N400 as its underlying neural correlates.

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