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·Original Article·

Differential cognitive responses to guqin music and piano music in Chinese subjects: an event-related potential study

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Abstract: Objective To compare the cognitive effects of guqin (the oldest Chinese instrument) music and piano music. **Methods** Behavioral and event-related potential (ERP) data in a standard two-stimulus auditory oddball task were recorded and analyzed. **Results** This study replicated the previous results of culture-familiar music effect on Chinese subjects: the greater P300 amplitude in frontal areas in a culture-familiar music environment. At the same time, the difference between guqin music and piano music was observed in N1 and later positive complex (LPC: including P300 and P500): a relatively higher participation of right anterior-temporal areas in Chinese subjects. **Conclusion** The results suggest that the special features of ERP responses to guqin music are the outcome of Chinese tonal language environments given the similarity between Guqin's tones and Mandarin lexical tones.

Keywords: music; guqin; piano; cognitive process; event-related potential (ERP); N1; LPC; P300

1 Introduction

Music is considered as a culturally specific phenomenon and characterized with ethnic background, social environment and traditions. A lot of studies about the cross-cultural music have been reported by ethnomusicologists and to a lesser extent by cognitive neuroscientists. For example, in a study about musical scale structures, German musicians respond to the seventh deviant Thai tone with a clear P300 component and a long-lasting positivity after presentation of the eighth deviant Thai tone in oddball paradigm. Event-related potential (ERP) reactions have revealed that universal listening strategies per se are modified by culture, and music tone from a different culture causes larger P300 and long-lasting positivity[16]. There are some other studies available regarding about the effects of cross-cultural music on the musical synchronization[7], music phrase perception [15] and music scale structure[16]. These studies proved culture-specific factors outside the domain of music may also influence music cognition processes, and this impact can extend to other cognitive processes. An oddball response was recorded from Turkish subjects in the ney and violoncello music environment. Larger P300 amplitudes were observed in the ney background as compared to violoncello. Thus researchers concluded that hearing music of a culturally familiar style increased the allocation of attention resources during memory updating processes[1]. And a musicogenic epilepsy case showed only Turkish music triggered seizures in Turkish subjects but not other musical styles[10].

In contrast, some researchers proved that some aspects of musical perception were universal and not culturally dependent, such as the perception of musical temporal processing[8], emotion[2] and meaning[18]. Morrison and partners

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compared the activation patterns of subjects reared in the United States as they listened to music from their culture (Western) and from an unfamiliar culture (Chinese) by using fMRI. The result indicated that listening to culturally different music might activate similar neural resources[14]. They interpreted this lack of difference in activation from musical semantics as that all listeners universally apply their own comprehension strategies to all music[6].

All the studies mentioned above did not have consistent results about the cultural difference on music perception or other cognitive processes. The controversy about the neural substrate for the processing of culturally familiar and unfamiliar music still exists, and further research into cross-cultural responses to music is necessary to clarify this point.

The aim of this study is to further explore whether the psychological effects and neural activation from music of different cultural environments are varied in Chinese subjects. Guqin and piano music were selected for the experiment. Guqin is the oldest, the most profound art in China and thus the symbol of Chinese civilization. On the other hand, piano is one of the most popular instruments in the West, owning to its immense expressive power. These two instruments are considered to represent two distinctive cultures, Chinese and Western.

In the present study, subjects' EEG were recorded when they were solving a simple cognitive task (two-stimulus auditory oddball paradigm) in different backgrounds (guqin, piano and silent environment). The oddball paradigm was used because more complex tasks are less suitable for a time domain analysis, and there are many studies available describing the meaning of oddball paradigm through recording ERPs. It was expected that the influence of different music would be reflected in different components of the recorded ERP.

2 Materials and Methods

2.1 Subjects Fifteen right-handed subjects took part in the experiment (7 females and 8 males). Their mean age is 23 years (SD = 1.3355, range 20-29). All the subjects are from the same cultural background: they are reared in China and educated at a formal university. None of the subjects got any formal training in music or a music instrument. Subjects reported no history of neurological disease and reported normal hearing and vision. Each subject was informed of the procedure of the experiment and gave a written consent to the participation. The subjects were paid for participating in the experiment.

2.2 Materials and procedure Subjects performed a standard two-stimulus auditory oddball task. It consisted of frequent standard stimuli (1 000 Hz tone, P = 0.8) and infrequent target stimuli (2 000 Hz tone, P = 0.2), and the duration of stimuli is 50 ms. The experimental session consisted of three blocks of one hundred trials, presented at an inter-stimulus interval of 900-1 100 ms, and the frequent and infrequent stimuli were randomly presented during each block. In each case, the subject was instructed to press a button by the first right finger in response to the target stimulus. Subjects' EEG was recorded in three conditions: (1) guqin music condition when they were listening to Yang Guan San Die by Zi-Qian Zhang; (2) piano music condition when they were listening to sonata K.311 by Mozart; and (3) silence condition when they were listening to nothing. The order of conditions was balanced between the subjects. To decrease the physical differences between two music conditions, the piano musical piece and the guqin musical piece have similar physical properties as their main powers are both concentrated around 700 Hz (Fig. 1)[1]. When the experiment stimuli (80 dB) and sound backgrounds (60 dB) were presented via headphones, the subjects were asked to keep their eyes closed, not to move, and to relax during the experiment. To familiarize subjects with the task, several examples were tried before the actual experiment.

2.3 Event-related potential recordings The subjects were seated in a quiet room and fitted with a Quik-Cap (Neuroscan, USA). Electroencephalograms were recorded with the Neuroscan system from 64 channels based on the international 10-20 system. The montage included 8 midline sites (FPZ, FZ, FCZ, CZ, CPZ, PZ, POZ, OZ), 27 sites over the left hemisphere (FP1, AF3, F1, F3, F5, F7, FC1, FC3, FC5, FT7, C1, C3, C5, T7, CP1, CP3, CP5, TP7, P1, P3, P5, P7, PO3, PO5, PO7, O1, CB1), and 27 sites over the right hemisphere (FP2, AF4, F1, F4, F6, F8, FC2, FC4, FC6, FT8, C2, C4, C6, T8, CP2, CP4, CP6, TP8, P2, P4, P6, P8, PO4, PO6, PO8, O2, CB2). All the electrode sites referred to the electrodes placed on the left and right mastoid (the impedance between left and right mastoids was kept below 5 kΩ). Eye movements and blinks were monitored by electrodes placed near the outer canthus of each eye called Horizontal-electrooculograms (HEOG), and above and below the left eye called vertical-electrooculo-

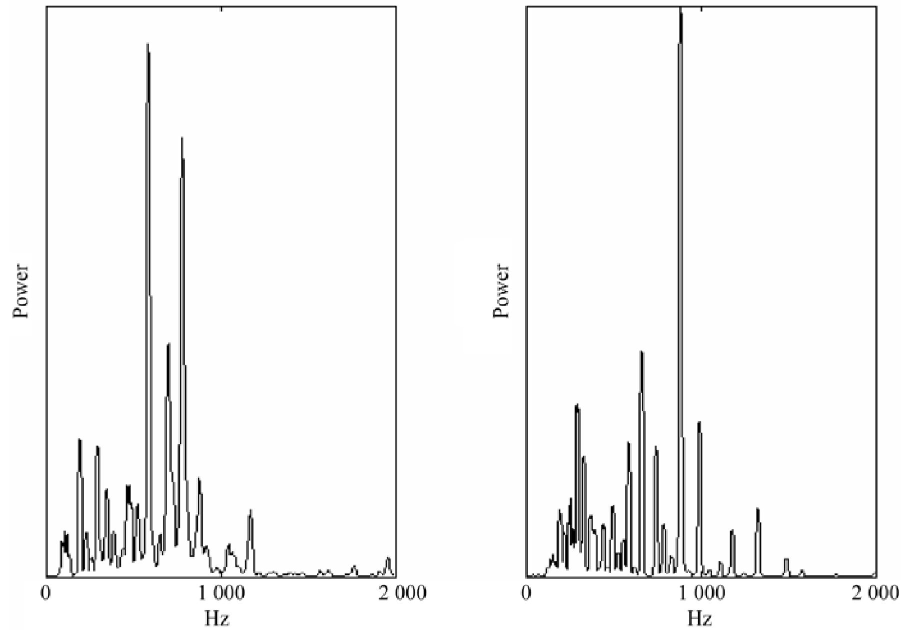

Fig. 1 The power spectra of guqin musical pieces (left) and piano musical pieces (right).

gram (VEOG). Inter-electrode impedance levels were kept below 5 kΩ.

During the experiment, the EEG was continuously recorded and bandpassed from 0.05 to 100 Hz with a sampling rate of 1 000 Hz. After completing data collection, the EEG was segmented into 1 200-ms epochs beginning 200 ms prior to stimulus onset. Epochs contaminated with artifacts (threshold for artifact rejection was ±80 μV in all channels) were rejected before averaging. The EEG was averaged for non-target and target stimuli separately. The ERP was digitally filtered with a bandwidth from 0.1 HZ to 30 Hz prior to peak detection.

3 Results

3.1 Behavioral results The mean reaction time for target stimuli (the time interval between the stimuli presence and subject's press of button) and accuracy (the percentage of correct responses through pressing button) were tested by a MANOVA design for repeated measure in three conditions (guqin music, piano music and silence). Greenhouse± Geisser correction was applied to MANOVA results.

Figure 2 shows the reaction time (left) and accuracy (right) in three sound backgrounds. The reaction time in the guqin music condition (mean = 489.8 ms, SD = 135.9) and in the piano music condition (mean = 485.2 ms, SD = 119.0) are both longer than in the silence condition (mean = 428.2 ms, SD = 109.5). These differences were both statistically significant (guqin: $P < 0.001$, piano: $P < 0.001$). There is no significant difference between the guqin music condition and the piano music condition ($P = 0.768$). The mean accuracy in the guqin music condition was 0.946 (SD = 0.078), in the piano music condition was 0.979 (SD = 0.039) and in the silence

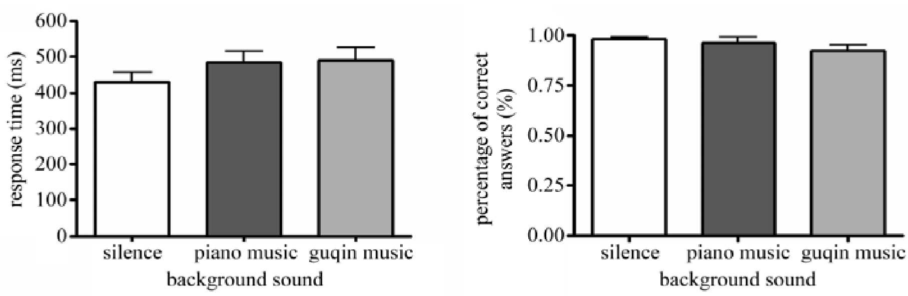

Fig. 2 Behavioral data: mean response time for target stimuli (left) and percentage of correct answers (right) in three sound backgrounds.

condition was 0.982 (SD = 0.039). Although the accuracy in the silence condition and in the piano condition was slightly higher than that in the guqin condition, the difference was not statistically significant [F (2, 28) = 2.21, P = 0.157].

3.2 ERP results The 15 subjects' grand average waveforms from three middle-line electrodes (FZ, CZ, PZ) for the stan-

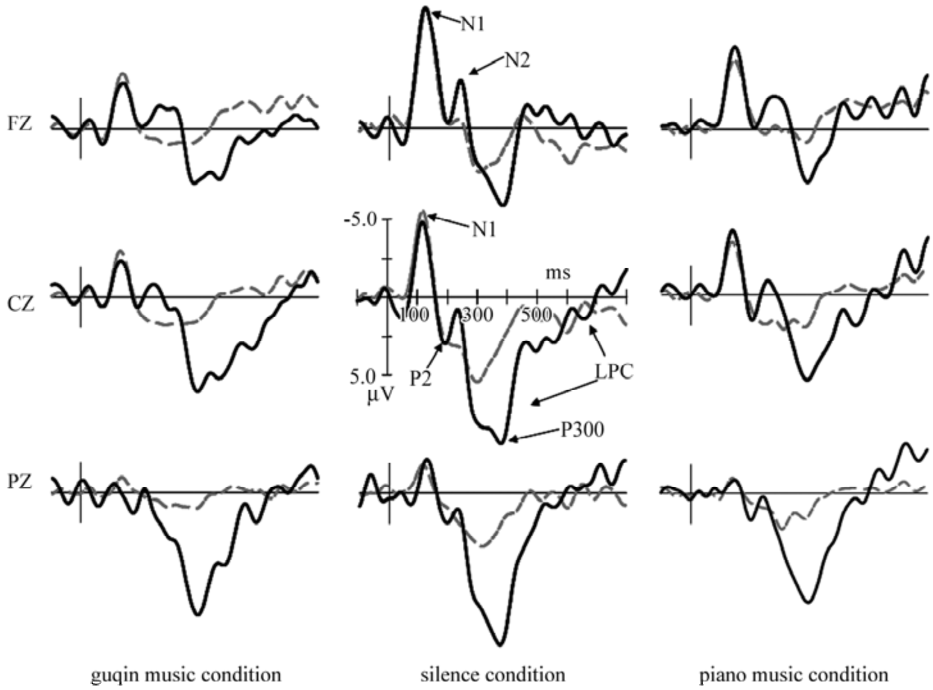

Fig. 3 Grand averages of 15 subjects for frequent standard stimuli (gray dot line) and rare target stimuli (black line) in three conditions: guqin music background (left), silence (middle) and piano music background (right).

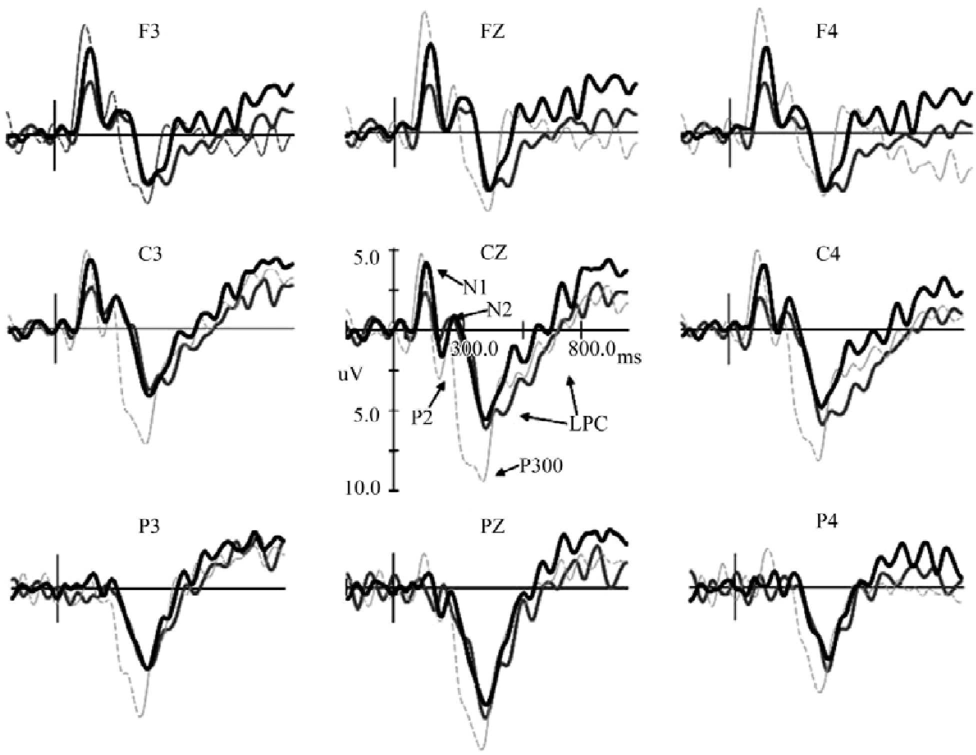

Fig. 4 Fifteen subjects' grand averages of target responses during exposure to three background sounds: piano music (black line), guqin music (gray line) and silence (gray dot line).

dard and target stimuli in three conditions are shown in Fig. 3. It can be seen that in both music and silence conditions the target stimuli elicited clear N1, P2, N2, P300 and LPC/P500. In order to assess whether the presentation of the two kinds of music had any effects on these ERP components, the data from the target stimuli was analyzed separately.

Figure 4 showed fifteen subjects' grand average waveforms for target stimuli in three conditions obtained from nine electrodes. The time windows for N1 (80-180 ms), P2 (150-250 ms), N2 (180-300 ms), P300 (300-500 ms) and LPC/

Tab. 1 Results of statistical analysis of peak amplitude in three conditions over all the subjects (n = 15)

ERP components	N1	P2	N2	P300
Condition	F = 7.36 P = 0.05	No significance	No significance	No significance
Condition*brain	F = 8.35 P = 0.03	F = 3.3 P = 0.032	F = 3.9 P = 0.028	F = 5.01 P = 0.006
Condition*lateralization	No significance	No significance	No significance	No significance
Condition*brain*lateralization	No significance	No significance	No significance	No significance
Brain	F = 39.5 P < 0.001	F = 3.8 P = 0.05	F = 10.8 P < 0.001	F = 21.58 P < 0.001
Lateralization	No significance	F = 4.3 P < 0.001	F = 4.79 P = 0.028	F = 14.82 P < 0.001

Tab. 2 Results of statistical analysis of peak latency in three conditions over all the subjects (n = 15)

ERP components	N1	P2	N2	P300
Condition	F = 4.36 P= 0.036	No significance	F = 7.7 P = 0.004	F = 24.6 P < 0.001
Condition*brain	F = 3.09 P = 0.023	No significance	No significance	No significance
Condition*lateralization	No significance	No significance	No significance	No significance
Condition*brain*lateralization	No significance	No significance	No significance	No significance
Brain	No significance	No significance	No significance	No significance
Lateralization	No significance	No significance	No significance	No significance

Tab. 3 Results of statistical analysis of amplitude in guqin condition and piano condition over all the subjects (n = 15)

ERP components	N1	P300	LPC-I	LPC-II	LPC-III
Condition	No significance	No significance	No significance	No significance	No significance
Condition*brain	F = 16.87 P < 0.001	No significance	No significance	No significance	No significance
Condition*lateralization	No significance	F = 7.241 P = 0.018	F = 4.84 P = 0.045	F = 5.29 P = 0.037	No significance
Condition*brain*lateralization	No significance	F = 3.758 P = 0.04	No significance	No significance	No significance
Brain	F = 19.76 P < 0.001	F = 13.11 P < 0.001	No significance	No significance	No significance
Lateralization	No significance	F = 4.87 P = 0.044	No significance	No significance	No significance

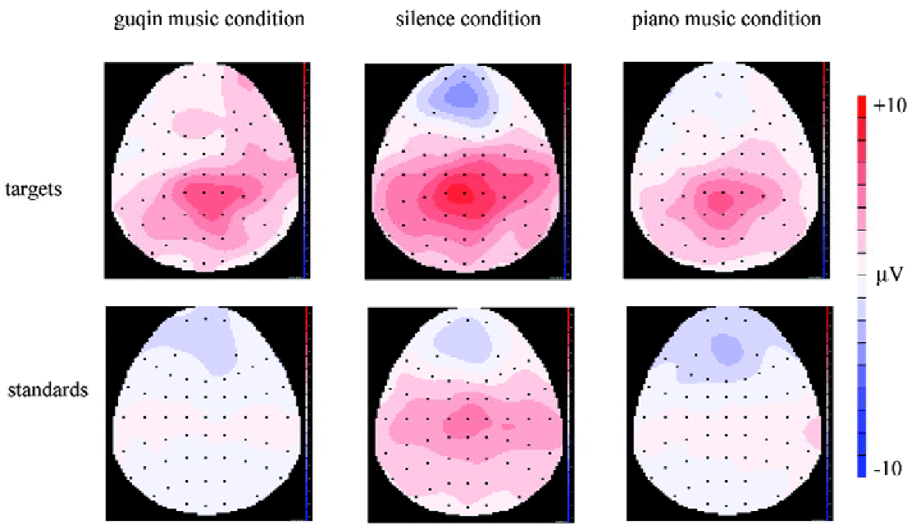

Fig. 5 Topographic maps for the target stimuli (top) and standard stimuli (bottom) in three conditions. The ERPs were integrated over the time windows between 300 and 500 ms. The maps are viewed from above, the nose is pointing upwards.

P500 (450-700 ms) were determined by visually inspecting individual and grand averaged waveforms. The amplitudes and latencies of the ERP components were analyzed by a MANOVA design for repeated measures with three factors: condition (three levels: guqin music, piano music and silence), brain site (three levels: frontal, central, parietal) and lateralization (three levels: left, midline, right). Greenhouse±Geisser correction was applied to MANOVA results. Tables 1-3 list the results of the statistical analysis.

For three background conditions, we observed a biphasic N1-P2 pattern, peaking at about 100 and 200 ms after target stimulus onset, respectively. The amplitude of N1 reduced for target stimuli in two musical conditions (condition: $F = 7.36$, $P = 0.05$), especially in frontal brain site (condition*brain: $F = 8.35$, $P = 0.03$). While the P2 shows no difference between background conditions, in the musical condition, the P2 amplitude increased in frontal areas and decreased in central and parietal areas (condition*brain: $F = 3.3$, $P = 0.032$). Meanwhile, in frontal areas, we observed the maximum amplitude of N1 (brain: $F = 39.5$, $P < 0.001$) and minimum amplitude of P2 (brain: $F = 3.8$, $P = 0.005$). And P2 showed greater amplitude in middle than in left or right areas (lateralization: $F = 3.8$, $P = 0.05$) (Tab. 1). The latency of N1 is longer in the music condition than in the silence (condition: $F = 4.36$, $P = 0.036$), especially in frontal and central areas (condition*brain: $F = 3.09$, $P = 0.023$) (Tab. 2). Furthermore, we observed greater N1 amplitude in piano condition than in guqin condition, especially in frontal areas (condition*brain: $F = 16.872$, $P < 0.001$) (Fig. 4 and Tab. 3) .

N2 was observed peaking at about 220 ms after target stimulus onset. N2 showed no difference between background conditions, but in frontal areas, the N2 amplitude increased in musical conditions (condition*brain: $F = 3.9$, $P = 0.028$). We got the maximum amplitude of N2 in frontal (brain: $F = 10.8$, $P < 0.001$) and middle areas (lateralization: $F = 4.79$, $P = 0.028$) (Tab. 1). The N2 latency is longer in music conditions than in silence condition (condition: $F = 7.7$, $P = 0.004$) (Tab. 2).

In the time window from 300 to 500 ms, a positive component P300 was observed. P300 amplitude reduced in the music condition in central and parietal areas (condition* brain: $F = 5.01$, $P = 0.006$). Meanwhile, the maximum amplitude observed in middle (lateralization: $F = 14.825$, $P < 0.001$) central and parietal areas (brain: $F = 21.583$, $P < 0.001$) (Tab. 1). The P300 latency is longer in the music condition than in the silence (condition: $F = 24.601$, $P < 0.001$) (Tab. 2). The topological maps (Fig. 5) showed a greater P300 amplitude in the guqin condition than in the piano condition in the right hemisphere (condition* lateralization: $F = 7.241$, $P = 0.018$), especially in frontal areas (condition*brain*lateralization: $F = 3.758$, $P = 0.04$) (Tab. 3). While the maximum amplitude is in central and parietal areas (brain: $F = 13.113$, $P < 0.001$), the right hemisphere had a greater amplitude than the left (lateralization: $F = 4.877$, $P = 0.044$).

In Fig. 4, the grand average ERP traces showed a clear late positive complex (LPC) between 350 and 650 ms. The mean amplitude was conducted in three time windows: I: 350-450 ms; II: 450-550 ms; III: 550-650 ms. It did not show any main effects of condition, brain and lateralization. But in the time interval of 350-550 ms, we got a clearer LPC in right frontal and temporal areas in the guqin music condition than that in piano music condition (condition* lateralization: I: F=4.837,P=0.045;II:F=5.292,P=0.037;III:no significant), and we named this LPC P500 (Tab. 3).

4 Discussion

In our experiment, the accuracy did not show any difference in three conditions on the auditory two-stimulus oddball task. A possible explanation for this absence of difference is the ceiling effect: since subjects discriminated target at high accuracy in three conditions (Fig. 2), the oddball task is too easy to show the effect of music on performance. The reaction time showed the difference between the silence and two music conditions. We explain the longer reaction time in the music condition as the interference of sound background.

The results of ERP show that N1, P2, N2 and P300 elicited in the oddball task are different between music and silence conditions, especially in frontal areas. The greater amplitudes in the silence condition can be explained for a masking effect, which was generated by the 60 dB sounds in the non-silence environment (music conditions) and resulted in a relative decrease of the stimulus intensity.

The difference between guqin and piano music showed mainly in N1, P300 and LPC/P500 components. In frontal areas, we observed a smaller N1 amplitude in the guqin condition than in the piano condition. In the previous studies, a smaller N1 amplitude was found in the presence of music[5], and N1 was related to selective attention at an early stage of processing[3]. Thus we conclude that guqin music has more effect on the early stage of selective attention than piano music.

And again in frontal areas, we found that guqin music increased the P300 amplitude and generated a clear P500 in the right hemisphere compared with piano music. Our results are consistent with the previous study in Turkish subjects, in which the P300 amplitude was significantly larger in the ney (their ethical music) background than in cello (foreign music) background, and the topography of the P300 response indicated a relatively higher participation of frontal areas during hearing ney[1]. The amplitude of P300 generally was interpreted as the reflection of selective attention and memory updating process[17], thus our experiment confirmed the inference that cultural familiar music had positive effects on selective attention and memory updating process, especially in frontal areas. The specialization of brain hemispheres for processing cultural familiar music in Chinese subjects is demonstrated by their right hemisphere lateralization.

LPC is the representation in working memory and was proved to relate to syntax and semantic processing[4, 9, 11-13, 17], thus we infer that guqin music has positive effects on syntax and semantic processing in the right anterior-temporal area in Chinese subjects. On the other hand, two previous studies found that larger long-lasting positivity was caused by Thai tone[16] and Chinese music[15]. These music stimuli come from the country with tonal language environment. In our experiment, subjects showed anterior-temporal right-hemisphere lateralization in guqin music condition, and this brain area was correlated with syntax and semantic process[17]. Thus we conclude that the greater music-induced LPC is related to language environment. Furthermore, we speculate that because of the consistency of guqin music's pentachord and Mandarin tones: high-level, high-rising, low-dipping, high-falling and one special gentle tone, guqin music leads to more activation in the anterior-temporal right-hemisphere than piano music in Chinese subjects. This inference needs further investigation. For example, does the anterior-temporal right predominance induced in the guqin music condition only exist in Mandarin Chinese speakers or in other tonal language speakers as well? Does the right predominance of guqin music exist in non-tonal language speakers? All these questions may be explored in further research.

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古琴音乐与钢琴音乐对中国被试认知反应的不同影响：事件相关电位研究

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摘要: 目的 研究古琴(一种古老的中国乐器)和钢琴音乐对认知的影响。**方法** 记录和分析了中国被试在两种音乐背景(古琴音乐，钢琴音乐)下完成听觉 oddball 任务的行为和事件相关电位(event-related potential, ERP)数据。**结果** 中国被试在本土文化的音乐环境(古琴音乐)下，前额区诱导出更大的 P300，这一结果和已有的相关研究是相符的。同时，不同音乐背景对 ERP 产生的影响在 N1 和 LPC(包括 P300 和 P500)上也表现出差别：中国被试在古琴音乐背景下比钢琴音乐背景下表现出更多的右前侧颞叶的参与。**结论** 因为古琴音乐的五声调式和汉语发音的音调具有对应关系，因此我们推断在古琴音乐下所表现出的这种特性与被试的汉语环境有关。

关键词：音乐；古琴；钢琴；认知过程；事件相关电位(ERP)；N1；LPC；P300