Brain Science and Music-Research on Pitch Perception Based on Brain Evoked Potential

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ABSTRACT

At the end of the last century, humans' research in the field of brain science advanced rapidly. Brain science is becoming one of the key science fields researched by different countries. The analysis on neural network of brain is used to research the work mechanism of brain in different tones. In analysis result, the change of brain evoked potential can really reflect the perception of brain to different pitch levels. At different pitch levels, especially for before and after the change, the power spectrum energy density of brain evoked potential signal at different frequency band and the clustering and information absorption of brain's functional network are obviously different. They are very significant methods of researching music perception at different pitch levels. The two methods complement each other.

Key Words: Brain Science, Pitch Perception, Brain Evoked Potential, Music Perception

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Introduction

Music is a widespread common phenomenon in the whole history of humans. The perception to and performance of music involve series of brain activities, including consciousness, feeling, visual sense, memory and emotion processing. Therefore, the research on music perception is an advantageous breakthrough point of having an insight into complex brain tissue and functions. Basic elements of music include sound speed, pitch, timbre and sound intensity. Pitch means the high or low tone. It is determined by the vibrational frequency of sound source. High frequency of vibration produces high pitch; low frequency of vibration produces low pitch. It is one of the important modules of music. Music can be divided to be complex signal that is comprised of a component of fundamental frequency and several components of harmonic wave. Fundamental frequency is the psychological parameter of pitch. The recognition of brain to sound is based on pitch information in large degree. More and more researches on music perception focus on pitch (Sreedevi *et al.*, 2009). So the research on pitch is very important in the research on music perception. Starting from spontaneous brain evoked potential, this paper researches different status of brain at different levels of pitch to further research neural mechanism of pitch perception. Like language, music conveys information relying on the change of frequency domain and time domain. As for any music system, the change of tone quality is very important. Musicians compose melodious tone and change division of music phrases by adjusting pitch. Under the background of modern neurosciences and information science, the research on brain mechanism has been involved in neurosciences. As one of the important elements of music, pitch has become an indispensable part in the research on music brain mechanism and even been called a central problem in music research. Although other elements, such as time organization of melody, are also important,

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it is certain that any factor involves pitch. Generally speaking, the frequency and amplitude of brain wave can reflect the status of brain in certain degree. The change of humans' psychological state and stimulus received can cause the change of corresponding frequency of brain wave. In the research on the recognition on pitch, experiment design and behavior test or the experiments of physiology and psychology shall be used to find the factors and laws of the change (Bleichner *et al*., 2016).

General situation and present situation of the study on phonetic altitude

In the latest fifty years, there are the following main modes of the research on pitch perception:

(1) Research the brain evoked potential, magnetic resonance or PET when subjects listen to pure sound or sound series (a piece of music) in passive concern status. (2) The subjects are requested to judge whether the pitch of single tones are same. The tons to be compared can be successive two tones, two separate tones with long interval between them or two separate tones with other interferential tones between them (such as the work memory tasks of music). (3) The subjects are requested to distinguish whether two pieces of melody are similar. (4) Judge the change of musical interval melody contour and research the status of subject's brain when a piece of music goes out of tune or has wrong tune. (5) Research the brain mechanism that processes pitch taking advantage of the people with absolute ability of pitch and the people with illness of brain. Prominent research achievements have been got from above researches (Amelia *et al*., 2011). In research, the processing mechanism of music needs the participation of right hemisphere. Especially, elementary auditory cortex may be the key area of the elaborate expression of pitch information.

Structure of brain and the physiological basis of pitch

Brain is a tissue with complex structure. It is comprised of a large quantity of nerve cells. As for cerebral cortex, its area is about 2500 cm^2. There are about 14 billion nerve cells in various types. The relations among different nerve cells are complex. Figure 1 shows the structure of brain.

Music is specific ability of humans like language. In the research on neuropsychology, especially that based on pathology, brain has special area that processes music. Brain's function of processing music is not the product of other important functions (such as language) but the instinctive of humans. The specialization of brain to music does not mean a "music center" that exists in brain. It is widely distributed in large quantity of loops of nervous system. Considering the mechanisms of music information processing, some physical and anatomical features inevitably exist to support processing of the information in auditory nervous system and relevant cognitive system (Van Hese *et al*., 2009). In one aspect, the research based on the structural feature of auditory cortex indicates that distribution of grey matter / white matter and other anatomical features of left hemisphere are different from those of right hemisphere. Auditory cortex of left hemisphere is suitable for processing the stimuluses that change rapidly and have wide range of frequency, such as voice. Auditory cortex of right hemisphere specially processes the stimuluses that change slowly and have narrow range of frequency, such as music. Therefore, right hemisphere dominates the perception to elements of music. In another aspect, humans' preliminary auditory cortex and its neighboring areas have a logarithmic audio location map that specially treats pure tune, arranged by step length 3.5mm/octave. Along right temporal lobe, low frequency is mainly processed by the front side; high frequency is mainly processed in the center and back of audio location map. As for the processing of complex sound, audio location map corresponds with base frequency of every tune rather than the whole frequency spectrum of complex sound.

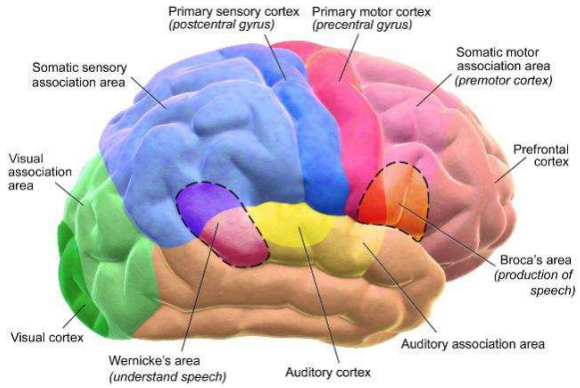

Figure 1. The structure of the brain

The theoretical basis of pitch

Pitch is one of the four "psychological attributes" of music. It corresponds with the physical attribute produced from the vibration of objective

substances. However, they are not in pure linear relation. Musicians define pitch of a tune in the following way: Pitch is comprised of two parts: one is its absolute pitch, namely continuous definition of the height of tune from the high to the low; the other is the family of pitch, namely a family of pitch that is comprised of tunes of the same name in all different octaves (Hinterberger *et al*., 2005). According to the definition, people put forward a method that could express absolute pitch of tune and family of pitch at the same time long time ago. This was pitch spiral shown in Figure 2. A rotation of a complete circle on the pitch spiral means an octave. Positions of tunes with octave relation in horizontal direction of the spiral are similar. The spiral supposes an orthometric relation between absolute pitch dimension and dimension of pitch family. When recognizing a piece of music, both its general features and detailed information are usable. Detailed information includes general range of pitch, size of musical interval, proportion of rising musical interval and proportion of descending musical interval. When detailed information, such as size of musical interval, changes, melody can be expressed by its general feature—outline.

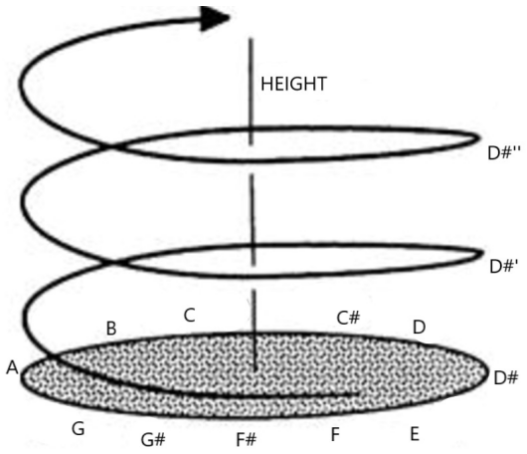

Figure 2. Pitch spiral

Research on the neuroscience of pitch

Brain is the commander of all our thoughts and behaviors. Through learning functions of brain, we expect to know more about humans' cognition and the processing of pitch. Neuropsychology is a subject for the purpose. It aims at relating neuro-mechanism with psychological function. The research on the neurosciences of pitch is also in the scope (such as Peretz).

In research, the patients whose temporal lobe at both sides have been hurt lose their ability of singing and cannot recognize the tunes they are familiar with before. In some systematic researches, the function of perceiving pitch and processing information in frequency domain is mainly performed by the temporal lobe of right hemisphere (Hartmann *et al*., 2014). Like language, music follows its intrinsic complex laws and has precise structure (Wang *et al*., 2017). Before performance of musicians, every action of their hands has been practiced repeatedly. Only cognition resources of small quantity are needed for them to control every action of hands at free will. Relatively, the common people who are not trained professionally have to consume more cognition resources to complete the complex task of playing the violin (Swaminathan *et al*., 2008).

Analysis on perception of pitch based on the functional network of brain evoked potential

Construction of functional neural network

The neural network of brain is a complex network that can perfectly get and integrate information from external and internal stimuluses at real time. At present, the levels of complex brain network include structural network based on neuroanatomy, the functional network produced from statistics dependence mode of the nonlinear dynamic behaviors of cluster of neurons, and the efficiency network that especially emphasizes the mutual functions among nodes. Functional network of brain is an abstract network. Measured area of every lead of B brain evoked potential is a node of network. Its action is several time series. Through calculating correlation among the time series, a correlation matrix can be got. Every ijC represents the correlation value between brain area i and brain area j. A correlation threshold cr can be defined. When a correlation value is larger than the threshold, it means functional correlation between two brain areas and the value of matrix element of brain's functional network is 1; conversely, there is no functional correlation between two brain areas and the value of matrix element of brain's functional network is 0. It shall be noted that "relevant" and "irrelevant" do not involve actual anatomical connection between two brain areas (Petermann *et al*., 2016). Therefore, a complete complex functional network based on data of brain evoked potential can be built. Figure 3 shows the process of building functional brain network.

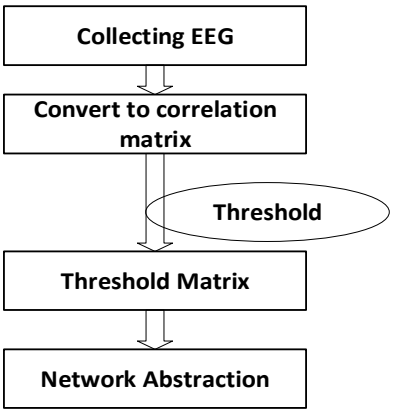

Figure 3. The process of building functional brain network

Analysis on functional brain network

(1) Distributed experiment based on degree

Degree is a very important concept in complex network theory. Its computational formula is very simple. As for node i, if k(i) nodes connect it, its degree is k(i). As for the whole network, the distribution of degrees is shown below:

$$k = \frac{\sum_i k(\mathrm{i})}{n} \quad (1)$$

The distribution of node degrees in network is p(k), meaning the probability that a random node is k. Generally speaking, degree distribution of random network follows Poisson distribution. It has a distribution probability of clock type. However, actual network has scale-free feature, following the following power-law distribution:

$$p(k) \sim k^{-\gamma} \quad (2)$$

Therefore, based on above analyses, we calculate brain network under the music background with tune change and corresponding random network degree. In the calculation, k is degree; n(k) is the number of nodes of corresponding degree; n is total number of nodes of network (n=16). The number of nodes connecting certain node is small in network. Our result accords with the theory. The brain network with a much larger number of nodes shall be calculated to eventually verify whether it has scale-free feature (Ou and Law, 2016). Besides, in our calculation result, when subject listens to the music at different levels of pitch, degree distribution of brain network is different.

(2) Assessment based on information entropy

In 1948, Shannon put forward the concept of information entropy when researching uncertain problem of information transmission process. The information got was defined to be the decrease of uncertainty (namely degree of disorder); uncertainty can be assessed by entropy. It is supposed that uncertainty of a probability information system is H0 before getting information. A part of uncertainty is eliminated after getting information and the uncertainty is decreased to be H1. Therefore, the uncertainty eliminated (H0-H1) is the amount of information I got in system. In other words, the (amount of) information got by the system from the external equals the negative value of increase of entropy, negative entropy for short. The rule of calculating information entropy of brain's neural network is used in experiment. The values of information entropy of brain's neural network when subject listens to the music at different levels of pitch are compared to offer a new method for the basic research on nerve information of pitch and promote development of research on brain music and cognition neurosciences.

Obviously, when the network is regular with complete connection,

$$E_{\max} = \ln n \quad (3)$$

When the network is a star network with only one central node,

$$E_{\min} = \frac{\ln 4(\mathrm{n}-1)}{2} \quad (4)$$

To eliminate the influence of node n on E, it is normalized. Namely, standard information of neural network of brain is defined.

$$E_a = \frac{E - E_{\min}}{E_{\max} - E_{\min}} \quad (5)$$

Based on the above, functional network of brain is calculated. The results are shown in table 1. Besides, the brain evoked potential standard information entropies when subject listens to music at different levels of pitch are compared and analyzed: the brain neural network information entropy while listening to original music and the value of standard information entropy of brain neural network. In the situation of tone alteration, corresponding standard information entropy of brain neural network at different levels of pitch are different significantly.

Table 1. The information E and Ea of different modes and different octaves music

	Incentive condition	Different modes	Incentive condition	Different octaves
		Entropy information		Entropy information
E	7 Semitation Lower	4.512	OctLower	4.526
Ea		0.825		0.868
E	Origin	4.567	Origin	4.602
Ea		0.985		0.871
E	7 Higher	4.489	OctHigher	4.492
Ea		0.806		0.865

The standard information entropy of brain neural network when subject listens to the music that 7 semitones are lowered is much smaller than that when listening to original music. The standard information entropy of brain neural network when subject listens to the music that 7 semitones are raised is much smaller than that when listening to original music. Both standard information entropy of brain neural network and information entropy of brain neural network when listening to the music that 7 semitones are raised almost equal those when listening to the music that 7 semitones are lowered. In the situation of frequency multiplication transformation, standard information entropy of brain neural network when listening to the original music is larger than that when listening to the music that octave is raised or lowered. In analysis on repeated measurement variance, main effect is not prominent. Besides, in general judgment, both standard information entropy of brain neural network and information entropy of brain neural network of frequency multiplication transformation are close to the values under background of the original music. They are larger than the values corresponding with tone transformation (Song *et al*., 2015).

Conclusions

The research on pitch perception mechanism of brain is an interdisciplinary field. It involves psychology of music, experimental psychology, signal analysis and processing, physiology and neurosciences. Especially, psychology of music plays key functions in the process of experiment design and analysis. Brain neural network analysis method is used in this paper to research brain activity mechanism in tone transformation. In research result, as for distribution of degrees, the number of connections when listening to the original music is smallest and obvious scale-free feature is shown. In the calculation of information entropy parameters, when the subject listens to the music with tone transformation, the amount of information got by brain when listening to the original music is largest; it becomes much smaller after transformation. When listening to the music with frequency multiplication transformation, brain evoked potential data of the subject has no significant difference with the parameter. This paper suggests that the two methods are mutually complementary and refer to each other. Both of them reflect change and change trend of brain evoked potential features in the exploratory research on perception to pitch. The two methods verify each other, prove reliability of analysis result and offer important physiological basis for the research on traditional cognition similarity.

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