Brain and Cognition 74 (2010) 123–131

Contents lists available at ScienceDirect

Brain and Cognition

journal homepage: www.elsevier.com/locate/b&c

Neural mechanisms involved in the oral representation of percussion music: An fMRI study

Chen-Gia Tsai [a,*], Chien-Chung Chen [b], Tai-Li Chou [b], Jyh-Horng Chen [c]

[a] Graduate Institute of Musicology, National Taiwan University, Taiwan
[b] Department of Psychology, National Taiwan University, Taiwan
[c] Department of Electrical Engineering, National Taiwan University, Taiwan

ARTICLE INFO

Article history:
Accepted 27 July 2010
Available online 19 August 2010

Keywords:
fMRI
Percussion music
Syllable sequence
Mirror neuron
Efference copy
Association mechanism

ABSTRACT

Numerous music cultures use nonsense syllables to represent percussive sounds. Covert reciting of these syllable sequences along with percussion music aids active listeners in keeping track of music. Owing to the acoustic dissimilarity between the representative syllables and the referent percussive sounds, associative learning is necessary for the oral representation of percussion music. We used functional magnetic resonance imaging (fMRI) to explore the neural processes underlying oral rehearsals of music. There were four music conditions in the experiment: (1) passive listening to unlearned percussion music, (2) active listening to learned percussion music, (3) active listening to the syllable representation of (2), and (4) active listening to learned melodic music. Our results specified two neural substrates of the association mechanisms involved in the oral representation of percussion music. First, information integration of heard sounds and the auditory consequences of subvocal rehearsals may engage the right planum temporale during active listening to percussion music. Second, mapping heard sounds to articulatory and laryngeal gestures may engage the left middle premotor cortex.

1. Introduction

There are two modes of music transmission: written tradition and oral tradition. Written systems of music notations associate graphical symbols with sounds, whereas oral transmission of music relies on motor imitation via vision and audition. Like written traditions, oral traditions in some music cultures use representative symbols, which are nonsense syllables representing percussive sounds. In Chinese opera, for example, the rhythmic/timbral patterns of the percussion music are symbolized in terms of syllable sequences, which not only mimic the percussive sounds but also serve as oral mnemonics widely used in music pedagogy and appreciation. Students of this music genre are taught various representative syllables and syllable sequences, and then learn to associate them with hand movements. Covert reciting of these syllable sequences along with music aids active listeners in keeping track of music. However, little is known about the neural correlates of the oral representation of percussion music.

The oral representation of percussive sounds provides a novel example to explore the processing of external events by the human motor system, and may shed new light on the auditory–motor matching mechanism supported by the *mirror neuron system*. Mirror neurons discharge when an individual executes, sees, or hears an action (Gallese, Fadiga, Fogassi, & Rizzolatti, 1996; Kohler et al., 2002; Rizzolatti, Fadiga, Gallese, & Fogassi, 1996). A sound sequence can evoke simulation of the body movements that have been previously associated with those sounds, and therefore the auditory–motor network is engaged in active listening. Active listening to music is best exemplified by a musician listening to a well-rehearsed piece with co-activation of auditory and hand motor regions (Bangert et al., 2006; D'Ausilio, Altenmuller, Olivetti Belardinelli, & Lotze, 2006; Haslinger et al., 2005; Haueisen & Knosche, 2001; Jancke, Shah, & Peters, 2000; Popescu, Otsuka, & Ioannides, 2004). In the present study, well-learned associations between movements and music are still the criteria to distinguish active listening from passive listening, but the motor simulation during active listening is not directly related to music performance. Instead, it is related to the oral rehearsal of instrumental music, and listeners who tend to covertly recite/hum along with music are regarded as active listeners.

Oral rehearsals of instrumental music by listeners serve as internal models for processing external events with the vocal motor system. Schubotz (2007) discussed such oral rehearsals within the framework of "prediction of external events with our motor system", arguing that active listening to piano music by a piano novice may activate fractions of his/her vocal motor system. It has been suggested that motor simulation of external events feeds

* Corresponding author. Address: Graduate Institute of Musicology, National Taiwan University, No. 1, Sec. 4, Roosevelt Road, Taipei 106, Taiwan. Fax: +886 2 23696773.
E-mail address: tsaichengia@ntu.edu.tw (C.-G. Tsai).

0278-2626/$ - see front matter © 2010 Elsevier Inc. All rights reserved.
doi:10.1016/j.bandc.2010.07.008

back into perceptual processing, creating top-down expectations and constraining predictions (Schubotz, 2007; Schutz-Bosbach & Prinz, 2007; Skipper, Goldin-Meadow, Nusbaum, & Small, 2007). This view is consistent with the experience of active listening to familiar music. The sequential nature of subvocal rehearsals provides a top-down mechanism for keeping track of music, with the listener building predictions based on the prior musical events within a sequence.

Some previous studies have suggested the neural substrates of the oral rehearsal of melodic music. Halpern and Zatorre (1999) examined the cerebral activity pattern associated with auditory imagery for familiar tunes. Their study discovered the involvement of the right auditory association cortex, bilateral frontal cortices, and supplementary motor area (SMA). Hickok and colleagues (2003) investigated neural processes common to both perception and covert production for speech and tonal sequences, showing the involvement of the left superior parietal temporal region, left posterior superior temporal sulcus (STS), and bilateral premotor cortices (PMC). Later, it was suggested that these regions constitute the dorsal stream of speech processing (Hickok & Poeppel, 2007), which maps acoustic speech signals to frontal lobe articulatory networks.

The oral representation of percussion music is substantially different from that of melodic music in the mapping between external sounds and internal rehearsals. For melodic music, humming along with unlearned tunes is made possible by the well-established audio-vocal link for pitch processing. The mapping between pitch and the muscle activity that determines vocal fold tension is biomechanical in nature, and establishment of this mapping is likely to start at the earliest stage of speech learning. In contrast, if unfamiliar, one is unable to recite along with percussion music that is not embedded in a musical scale. Typically, the syllable representation of percussion music is not identical to the referent percussive sound, although they sometimes share a few common acoustic features. For instance, the big gong in Beijing opera produces pitch glides (Fletcher, 1985), and its sound is orally represented by /guang4/, with the fourth lexical tone in Mandarin mimicking the downward pitch glide of the gong sound. Fig. 1 compares the spectrograms of these two sounds. Both sounds have the characteristic of downward pitch glide (indicated by an arrow in the spectrogram of the big gong sound), but the representative syllable lacks the broadband noise of the referent percussive sound.

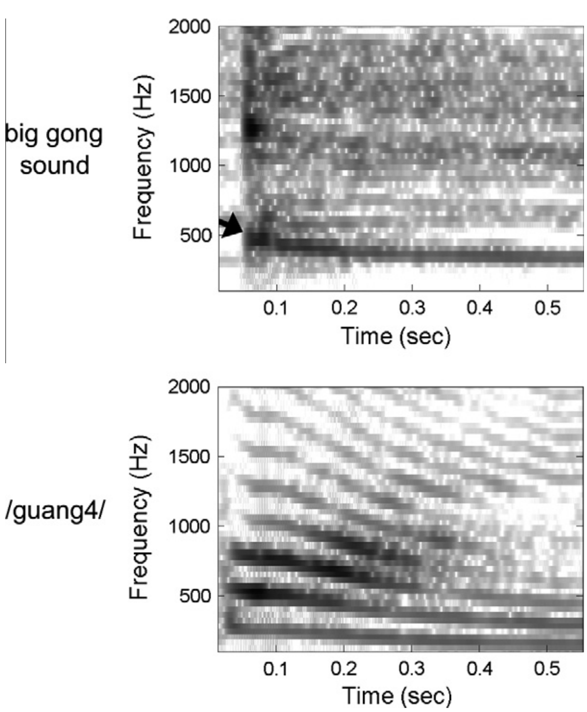

Fig. 1. Spectrograms of a big gong sound in Beijing opera (upper panel) and its representative syllable /guang4/ (lower panel). The arrow indicates the downward pitch glide of the gong sound. See the text for details.

Owing to the acoustic dissimilarity between the representative syllables and the referent percussive sounds, the oral representation of percussion music involves two association mechanisms. The first mechanism mediates stimulus–response (S–R) associations. Since rhythmic/timbral patterns of percussion music are often repeated and combined in performance with ornaments and flexible tempo, the internal model only anticipates a set of possible upcoming events. The presence of musical sounds further enables the internal model to select the appropriate motor plan among competing alternatives through S–R associations. External sounds not only guide subvocal rehearsals at the jointing point of two rhythmic/timbral patterns, but also within the repetition of a single rhythmic/timbral pattern. During active listening to percussion music, the auditory consequences of subvocal rehearsals are sent to a neural network, where the covertly recited syllables and the heard sounds are integrated. This integration may be mediated by stimulus–stimulus (S–S) associations.

Although there have been studies on oral imitation of music and speech, no imaging experiments have examined the neural correlates of covertly reciting representative syllables along with percussion music. Using Beijing opera percussion music as stimuli, this study addressed the issue of how the auditory mirror neuron system cooperates with the neural circuitry underlying association learning for processing external sounds with the vocal motor system. Compared to active listening to the syllable representation of percussion music, active listening to percussion music (with subvocal rehearsals of syllables) was expected to increase the activation of the regions that integrate the heard percussive sounds with the auditory consequences of subvocal rehearsals. A candidate is the right posterior superior temporal region, where the perceived actions may interact with the sensory consequences of internal rehearsals made by the imitator (Iacoboni et al., 2001). In regard to the S–R associations for the oral representation of percussion music, previous studies have implicated several frontal regions in this task, such as the lateral prefrontal cortex (e.g. Boettiger & D'Esposito, 2005; Hoshi, Shima, & Tanji, 1998), SMA/pre-SMA (e.g. Bunge, Kahn, Wallis, Miller, & Wagner, 2003; Cavina-Pratesi et al., 2006; Donohue, Wendelken, & Bunge, 2008), and dorsal PMC (e.g. Amiez, Kostopoulos, Champod, & Petrides, 2006; Cavina-Pratesi et al., 2006; Toni et al., 2002). We predicted that these frontal regions would show greater activation during active listening to learned percussion music compared to active listening to the syllable representation of the music.

2. Materials and methods

2.1. Participants

15 right-handed native Taiwanese speakers participated in this study (20–26 years old, 13 females and 2 males). Each participant gave written informed consent, and received monetary compensation for participation. Three female participants were excluded from data collection because of large head movements or hardware glitches during fMRI scans. 12 participants were thus included in the final analyses. All participants were right-handed, as assessed by the Edinburgh handedness scale (Oldfield, 1971). They had received music training for more than 4 years and were familiar with the timbres and melodies of Chinese opera music. None of them