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Mirror neuron activation of musicians and non-musicians in response to motion captured piano performances

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ABSTRACT

Mirror neurons (MNs) activate when performing an action and when an observer witnesses the same action performed by another individual. Functional magnetic resonance imaging (fMRI) and presentation of motion captured piano performances were used to identify differences in MN activation for musicians/non-musicians when viewing piano pieces played in a "Correct" mode (i.e., emphasis on technical correctness) or an "Enjoyment" mode (i.e., simply told to "enjoy" playing the piece). Results showed greater MN activation in a variety of brain regions for musicians, with these differences more pronounced in the "Enjoyment" mode. Our findings suggest that activation of MNs is not only initiated by the imagined action of an observed movement, but such activation is modulated by the level of musical expertise and knowledge of associated motor movements that the observer brings to the viewing situation. Enhanced MN activation in musicians may stem from imagining themselves actually playing the observed piece.

1. Introduction

Mirror neurons (MNs) are a particular class of neurons originally discovered in area F5 of the monkey premotor cortex (Halsband, Matsuzaka, & Tanji, 1994). They have been shown to activate when the animal performs a particular action and/or when an observing animal witnesses the same action being performed by another individual, even though they are not performing the task themselves (Di Pellegrino, Fadiga, Fogassi, Gallese, & Rizzolatti, 1992; Rizzolatti & Craighero, 2004; Rizzolatti & Luppino, 2001). It is thought that MNs similar to those found in monkeys are also represented in the human brain and are considered prominent in the inferior frontal gyrus (Kristeva, Chakarov, Schulte-Mönting, & Spreer, 2003), premotor cortex, supplementary motor area, primary somatosensory cortex and inferior parietal cortex (Molenberghs, Cunnington, & Mattingley, 2009). Although the existence of MNs has been documented, their function is still a matter of some debate. However, the literature does suggest that MNs, in addition to providing motor information, may also provide a physiological mechanism for some aspects of higher order cognition, including perception/action coupling (Iacoboni, 2008), imitating/understanding the actions of others (Arbib, Billard, Iacoboni, & Oztop, 2000) and may underlie theory of mind capacity (Arbib, 2006). MN are also thought to play a role in mediating speech perception and some aspects of language acquisition (Théoret & Pascual-Leone, 2002), as well as contributing to the detection and expression of emotion (Cheng, Yang, Lin, Lee, & Decety, 2008; Koelsch, Fritz, Müller, & Friederici, 2006; Morrison, Lloyd, di Pellegrino, & Roberts, 2004). For these reasons, it has been hypothesized that MN impairment may be the neural basis for a variety of cognitive and/or psychological disorders, including autism and other neuro-developmental disabilities (Dapretto et al., 2006; Dinstein, Thomas, Behrmann, & Heeger, 2008).

Previous research indicates that certain aspects of brain structure and function (potentially involving MNs) play an important part in music cognition and the attainment of performance-level musical ability (Arbib, 2013). Gaser and Schlaug (2003) report gray matter differences between musicians and non-musicians in the motor, auditory and visuospatial regions of the brain. Schmithorst and Wilke (2002) found greater white matter connectivity in musicians, while Han et al. (2009) found both gray matter and white matter enhancements in professional pianists. Interestingly, Broca's area (i.e., left inferior frontal gyrus) and its right hemisphere homologue have been suggested to support the processing of the "syntax" associated with reading music

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during musical performance (Koelsch, 2006; Koelsch et al., 2002; Kristeva et al., 2003; Maess, Koelsch, Gunter, & Friederici, 2001) just as the decoding of linguistic syntax is important for speech perception and language acquisition (Friederici, Wang, Herrmann, Maess, & Oertel, 2000). One additional function of Broca's area is the mediation of sensory-motor transformations underlying imitation (Heiser, Iacoboni, Maeda, Marcus, & Mazziotta, 2003; Koski, Iacoboni, Dubeau, Woods, & Mazziotta, 2003; Rizzolatti & Craighero, 2004). Damage to this region can lead to conjoint impairments of aphasia and amusia, the latter being a selective deficit in both perceiving and interpreting music (Patel, 2003, 2005). Note that the success of several speech therapy methods such as *Melodic Intonation Therapy* (a technique based on singing and its imitative elements) is thought to involve the conversion of MN sensory information into a motor plan via recruitment of Broca's area, thus providing a "musical" delivery system to assist in the production and understanding of spoken language (Molnar-Szakacs & Overy, 2006).

In addition to music cognition, MNs are also thought to play an important role in producing and detecting emotion and are often considered the neural basis for the experience of empathy (Carr, Iacoboni, Dubeau, Mazziotta, & Lenzi, 2003; Gazzola, Aziz-Zadeh, & Keysers, 2006; Leslie, Johnson-Frey, & Grafton, 2004; Overy & Molnar-Szakacs, 2009). There is neuroimaging evidence that MNs localized to the inferior frontal gyrus are particularly active during the imitation of emotional facial expressions. This finding supports the notion of MN mediation of sensorimotor-affective coupling during the production and comprehension of emotions (Carr et al., 2003). Moreover, it is well known that musical training has a significant impact on the neural plasticity of the inferior frontal gyrus, premotor cortex, supplementary motor area, somatosensory cortex, parietal cortex, and temporal lobes, all of which are hypothesized to house MNs (Fujioka, Ross, Kakigi, Pantev, & Trainor, 2006; Koelsch & Siebel, 2005; Overy & Molnar-Szakacs, 2009; Zatorre, Chen, & Penhune, 2007). Interestingly, Kristeva et al. (2003) used electroencephalography (EEG) to investigate the temporal sequence and time course of brain activation when violinists were imagining the performance of a musical piece and when actually performing it. They found significant activation bilaterally in the frontal opercula, localized to the inferior frontal gyri (BA 44) as well as a variety of motor and supplementary motor areas. Each of the above regions is thought to house MNs, suggesting their importance for mediating both the imagining and actual execution of musical performances.

In the present study we use a novel approach to the study of MN activation by employing a combination of sophisticated motion captured piano performances (visual movement) and their accompanying musical segments (audio), in an effort to identify differences in regional MN activation for musicians compared to non-musicians. In addition, we also investigate MN activity when viewing each piano piece played in two different musical modes: (1) the Correct mode in which the performer emphasizes playing the piece with as much technical correctness as possible, and (2) the Enjoyment mode in which the performer is simply told to "enjoy" themselves while playing the piece (Westney, 2003; Westney et al., 2015). Although a large corpus of previous work has shown that MN activation tends to differ in musicians compared to non-musicians (Bangert et al., 2006; Baumann et al., 2007; Lahav, Saltzman, & Schlaug, 2007; Wanderley, Vines, Middleton, McKay, & Hatch, 2005), most previous studies have focused primarily on MN activation in response to auditory (musical) perception, with less emphasis on the actual movements exhibited by the musician when performing the music. Thus, our use of sophisticated motion capture videos extends previous research by including (and accentuating) the gestural movements of the pianists that accompanies their musical performance (not just the perception of musical stimuli alone) and its impact on the MN system. Note that our motion capture methodology is novel in that it visually represents the pianist as a "stick-like" avatar (rather than a real performer), which eliminates a myriad of potentially confounding factors (e.g., performer's sex, hair style, facial expression, clothing and other aspects of their performance context), thus providing a more direct measure of MN activity that is elicited in response to a combination of relatively pure motor movements (visual) as well as a musical (auditory) accompaniment –not just in response to musical stimuli per se.

It is important to note that our previous motion capture research using the same audio/video clips as those in the present study, has empirically demonstrated that musical performance in our Enjoyment mode condition (in contrast to the Correct mode), consistently produces a greater number and differing degrees of movement in each of the pianists (e.g., head rocking, torso moving front-to-back and side-to-side, as well as greater arcing of the hands, see Cloutier, Boothby, & Yang, 2011), which in turn is judged by observers to render such performances more aesthetically pleasing (see Westney, 2003; Westney et al., 2015; Westney, Grund, O'Boyle, & Yang, 2016). Given the extensive range of movement known to be associated with the Enjoyment mode, in the current study we present both Enjoyment and Correct mode performance videos in an effort to determine if the former generates more corresponding MN activation, and if this increase in MN activity is unique to musicians as compared to non-musicians.

In light of previous research, we predicted that activation of MN regions would be greater in musicians compared to non-musicians when viewing our combination visual/audio motion capture piano videos (Haslinger et al., 2005; Wanderley et al., 2005), and that this MN activation would be particularly evident in musicians (compared to non-musicians) when observing pieces played in the Enjoyment mode (as compared to the Correct mode). And if so, we speculate that this increased MN activity may reflect the extent to which learning by imitation is selectively taking place in musicians (who know how to play the piano). To that end, it may be that increased MN activation contributes to performance enhancement by assisting in the neural reconstruction of the content and emotional valence of an observed musical piece, thus aiding musicians (but not non-musicians) in the perception and subsequent coupling of imagined with actual musical execution (Overy & Molnar-Szakacs, 2009).

2. Materials and methods

2.1. Participants

Four classical piano performers (3 males, 1 female) ranging in age from 35 to 64 years-old (mean = 46.5, SD = 12.87) served as participants; the 4 non-musician participants (all males) ranged in age from 22 to 75 years-old (mean = 48.25, SD = 22.17) and had expressed interest in classical music, but did not play an instrument themselves. All participants had normal or corrected-to-normal vision, were without a history of neurological or psychiatric diseases and were right-handed as determined by a modified version of the Edinburgh Handedness Questionnaire (Oldfield, 1973). The study received prior approval of the University Institutional Review Board and informed written consent was obtained from all participants.

2.2. Materials and procedure

Participants viewed 16 different motion captured piano recordings taken from our previous work (Westney et al., 2015, 2016). Each piece was performed by 4 different graduate students, who were all majoring in classical piano performance. Each of the students played 2 different piano pieces selected on the basis of their relative obscurity, so that prior performance history would be minimized or non-existent (i.e., a section of "Cowherd's Song", Opus 17 by Edvard Grieg and the "Scherzo" by Johann Hummel). Pieces were played in two modes: the "Correct" mode and "Enjoyment" mode. In the Correct mode the pianist was instructed to play the piece emphasizing technical correctness, while in the Enjoyment mode the pianist was asked to relax and simply