

The Role of Cerebral Resonance Behavior in the Control of Music Performance.

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SUMMARY

Playing a music instrument requires complex sensori-motor transformations in the brain. Our hypothesis is that those cortical motor regions in which mirror neurons are active, are not only activated when playing a music instrument but are also activated by hearing the music. Listening to the instrumental music presentation might therefore be directly coupled to the programming of movements necessary to play this music oneself. This implies that such music performance is easily imagined. Although most individuals are able to sing a melody they have heard without difficulty, instrumentalists (even highly skilled) are frequently unable to play what they hear. They are score-dependent i.e. they are only able to play a new piece of music when they have access to the notes. On the other hand, musicians who are easily able to play by ear are non score-dependent; they are (frequently only) able to play without notes. Underpinning of this difference in musical skill may be of high value in the development of educational strategies concerning higher-level musical training.

Objective: To determine whether brain regions for motor preparation (and motor imagery), that contain mirror neurons, are responsible for the ability to play by ear.

Study design: During fMRI measurements, subjects listen to short recordings of music examples (20s) presented by headphone. Music is played on a keyboard. The following experimental conditions are distinguished: (1) unknown music (i.e. a new composition) requiring the subject to imagine that he/she is actually playing the music; (2) listening with internal verbal comments on the music (loudness, emotional expression, line of melody going up or down); (3;4) similar to 1 and 2 only now familiar music is presented. A voxelbased analysis of differences between the condition-related cerebral activations will be performed using Statistical Parametric Mapping.

Study population: (1) 15 score-dependent classically trained organists and pianists (conservatorium level of playing), (2) 15 non score-dependent classically trained organists and pianists and (3) 15 non musicians.

Participants are healthy, right-handed and aged between 18 and 65 y.

Main study parameters/endpoints: Localisation of increased cerebral activations (i.e. differences in BOLD responses) demonstrating enhanced motor functions during listening of music in specifically non score-dependent instrumentalist.

Playing a music instrument may superficially appear to be a somewhat difficult but straightforward task differing from other manual tasks only in its complexity. Functionally, however, instrumental playing is different from day-to-day grasping and pointing movements. In the sense that the goal of such movement is to produce sounds and that these sounds can be represented by a symbolic system, instrumental performance would seem more analogous to speech than to otherwise similar forms of manual dexterity.

Like language, music is a complex, rule-governed form of behavior (Lerdahl & Jackendoff 1983) and appears to be associated with specific brain architecture (Schlaug 2001). Just as native speakers invariably learn to speak their mother tongue before learning to read and write, jazz musicians generally learn to play an instrument competently before mastering the notational system, frequently never mastering it at all. As they are not dependent on written notation for the practice of their art, we may term these musicians *non score-dependent*.

Many classically trained musicians on the other hand are unable to play unless they have (had) access to the notes of the pieces they play. We may therefore term them score-dependent. Up till now neuroscience research into music performance has concentrated almost wholly on the professional classical musician and thus mainly on score-dependent musicians. Mismatch negativity (MMN) research in which the pre-attentive listening paradigm was applied suggests however that there could be a relevant distinction between score-dependent and non score-dependent musicians. Non score-dependency possibly facilitates recognition of melodic contour (Tervaniemi 2003).

The cerebral commands for fine-tuned movements are funneled through the motor cortex on the precentral gyrus. Beyond the primary motor cortex, the organization of goal-directed movement is particularly embedded in parietal-premotor circuitry (Wise et al. 1997; de Jong et al. 2001; Castiello 2005). Neuronal activity in these cortical regions is associated with the preparation of movement as well as imagining of movement without overt execution (Ehrsson et al. 2003). Moreover, this motor circuitry includes mirror neurons, characterized by their selective responsiveness to the observation of specific goal-directed movements performed by others (Gallese et al. 1996; Rizzolatti et al. 1999). In a wider sense, this motor circuitry can be elicited by the sound of specific actions performed by others (Kohler et al. 2002). Sensory stimuli thus facilitate the motor system to express 'resonance behavior'. These neuronal qualities fit the concept that the cerebral representation of movement includes a representation of its goal (Mountcastle et al. 1975; Rijntjes et al. 1999; Andersen & Buneo 2002). It has therefore been proposed that the 'motor ideas' represented in premotor and parietal cortex may provide the basis for space representation, understanding of actions, and object categorization and that these areas may contain a 'pragmatic body map' that emerges from tasks like mental

rotation, object categorization and music imagery (Schubotz & von Cramon 2003). These neuronal characteristics have been found in non-human primates by intracortical electrophysiological recordings and in human by functional brain imaging with Positron Emission Tomography (PET) and Functional Magnetic Resonance Imaging (fMRI), respectively.

Both the motor theory of speech perception (Lieberman & Mattingly 1985) and the direct-matching hypothesis (Buccino, Binkofski & Riggio 2004) propose that individuals are able to recognize goal-directed activity of others by 'mapping' the observed activity onto their own motor representation of that activity.

It is plausible that, when listening to music, not only musicians but also non-musicians map what they hear onto their own vocal motor representation of the melody, which would also explain why people either hum along with the melody of a popular song or tap the beat. Among instrumentalists, the aural imagination of a melody or chord progression is frequently accompanied by mimed playing movements (Haueisen & Knösche 2001). These movements are not instrument-specific. A pianist may 'feel' the chords in his hands while listening to a string quartet or a choir.

Instrumentalists who are not only able to play what they hear in the original key, but also in any other key, must code music in terms of action goals, making it possible to 'unpack' complicated movement patterns, very similarly to speech: transposition of a theme or chord progression to another key requires totally different motor commands, just as the translation of the meaning of a sentence to another language.

Non score-dependency could therefore be the manifestation of enhanced efficiency of sensori-motor transformation in premotor-parietal circuitry associated with activity of the hands; score-dependency on the other hand could point to reduced motor resonance in those areas implying that score-dependent musicians' listening might rely on different cognitive strategies. As verbal processing during auditory imagery is thought to take place in the left superior temporal cortex (Halpern & Zatorre 1999), trained musicians might subconsciously name tones and intervals (Haslinger et al. 2005) while listening.

While score-dependent instrumentalists are surely able to imagine the necessary movements involved in playing a piece they know by memory or even when only silently reading it from notes, they will be unable to imagine the movements necessary to play a piece when they have never played it before or had access to the notes.

Our main hypothesis is that, while listening to music, the non score-dependent musician will exhibit an automatic, non effector-related facilitation of the motor cortex manifesting itself in the recruitment of premotor and parietal cortical fields normally active when playing the instrument he has mastered. Score-dependent instrumentalists on the other hand will either not experience this facilitation or at least to a lesser extent.

Primary Objective: Identification with fMRI of increased cerebral activations in premotor regions of the brain, specifically related to music listening in non-score-dependent musicians, compared to score-dependent musicians.

3T fMRI will be used to measure task-induced Blood Oxygen Level Dependent (BOLD) responses that are the consequence of increases in regional perfusion. This measure provides an index for the distribution of local neuronal activations. During fMRI measurements, subjects listen to short recordings of music examples (lasting 20s each) presented by headphone. The following experimental conditions are distinguished: (1) unknown music (i.e. a new composition) requiring the subject to imagine that he/she is actually playing the music; (2) listening with making internal verbal comments on the presented music (concerning e.g. loudness, emotional expression, line of melody going up or down); (3;4) similar to 1 and 2 only now familiar music is presented. Recordings of these examples will be sent to subjects 14 days prior to the scan allowing them to become familiar with them. In an auditory baseline condition natural noise (waves of the sea) will be presented.

Classically trained score-dependent organists and pianists, classically trained non-score-dependent organists and pianists and musically unskilled control subjects will be studied in order to identify specific increases of activations in (pre)motor-related regions in the non score-dependent musicians during condition one. The study will exclude style differences as a possible cause of differences in cerebral resonance by including only classical music fragments en by recruiting subjects from the field of classical music only.

In this study it will be attempted to exclude cerebral resonance that may not be due to instrumental skill. For that reason we will be including non-musically trained controls. In addition it is important to be able to contrast the results of this study with other investigations, most of which contrast musically skilled subjects with non musically trained controls. The four experimental conditions are presented in (pseudo-randomized) balanced order, divided in two blocks of 24 music examples of about 20s. A subject will be for about 30 min. in the scanner. An anatomical (T1

weighted) scan will be made between the two blocks. At the onset and at the end of scanning the baseline with natural noise will be presented.

Following the scan procedure, musically skilled subjects will be tested at the keyboard on their ability to replicate by ear a random selection of music examples from among those they have just heard. Recordings of their attempts will be made for later analysis. This behavioral test is designed to corroborate the results of the scan.

A voxel-based analysis of differences between the condition-related cerebral activations will be performed using Statistical Parametric Mapping (version SPM5) (Friston et al., 1995). Within-group analysis of differences in the condition-related activations will be assessed as well as between-group differences.

Task-related cerebral activations will be studied in the three subgroups of healthy right-handed subjects (18-65 y):

1. skilled non-score-dependent (classically trained) organists and pianists
2. skilled score-dependent (classically trained) organists and pianists
3. musically unskilled controls.

Each group consists of 15 subjects.

All subjects are healthy, right-handed and aged between 18 and 65 year. The musically unskilled subjects (in group 3) are unable to play a musical instrument. Groups 1 and 2 are characterized as 'skilled musicians'. Schlaug (2003) defines the 'professional musician' as someone who is either enrolled as a student in a full time music program in music school or conservatory or someone who is a graduate of a music program and derives his or her main income from a professional career in music. Groups 1 and 2 will consist of organ- and pianostudents from the classical department of Dutch conservatoires or graduates from the same schools who derive their income from a professional career in music.

Non score-dependent skilled musicians are those musicians who are characterized by the mastery of all stages of audiation Types 1, 4, and 6 as measured by the Advanced Measures of Music Audiation (Gordon 1989a) (Table 1) and tested by a panel of experts. Audiation is the process of mentally hearing and comprehending music. It includes the necessary understanding of music to enable the conscious prediction of patterns in unfamiliar music (Gordon 1989b). Types of audiation are not hierarchically related to one another. Stages of audiation (Gordon 1989a), by contrast, are hierarchically related, each stage acting as prerequisite for the next (Table 2). All stages of audiation pertain to all types.

Table 1: Types of Music Audiation (Gordon 1989a):

Type 1	Listening to	familiar or unfamiliar music
Type 2	Reading	familiar or unfamiliar music
Type 3	Writing	familiar or unfamiliar music from dictation
Type 4	Recalling and performing	familiar music from memory
Type 5	Recalling and writing	familiar music from memory
Type 6	Creating and improvising	unfamiliar music
Type 7	Creating and improvising	unfamiliar music while reading
Type 8	Creating and improvising	unfamiliar music while writing

Table 2: Stages of audiation as they occur in Type 1 audiation (Gordon 1989a):

Stage 1	Momentary retention
Stage 2	Initiating and audiating tonal patterns and rhythm patterns AND recognizing and identifying a tonal center and macrobeats
Stage 3	Establishing objective or subjective tonality and meter
Stage 4	Consciously retaining in audiation tonal patterns and rhythm patterns that we have organized
Stage 5	Consciously recalling patterns organized and audiated in other pieces of music
Stage 6	Conscious prediction of patterns

We will define score-dependent organists or pianists as those who experience difficulty with all stages of audiation Types 1, 4, and 6 as measured by a panel of experts. In particular score-dependency will be defined as difficulty with all stages of Types 1, 4, and 6 audiation with respect to two-part harmony.

Non score-dependent pianists or organists on the other hand will be able to demonstrate audiation skills at the instrument itself not only by skill in keyboard improvisation, but also by the ability to replicate two-part harmony by ear as well as the ability to harmonize and transpose melodies.

Individuals suffering from specific neurological disorders will be excluded as well as those who are excluded from participation in MRI scans. By neurological disorders we are referring to disorders for which consultation of a medical specialist was necessary: epilepsy, serious concussions, and temporary paralysis. Exclusion criteria for MRI are, for example, the presence of ferromagnetic material in or on the body, for example tattoos with ferrous ink, pregnancy and claustrophobia.

The number of 15 subjects per subpopulation (45 total) is adequate for the execution of a random-effects analysis with SPM (version SPM5) (Friston et al. 1995; Desmond and Glover, 2002).

Subjects will be recruited from student and teacher populations and alumni from the Dutch conservatoires. They will be approached with permission of the administrations of those institutes. Posters will be hung in conservatoires. An interval of minimally 2 weeks between initial briefing on the experiment (including appraisal of exclusion criteria) and actual participation in the scan will be maintained in which subjects can carefully reconsider their participation. In addition, they may retract at any time.

Musically unskilled controls will be recruited via a poster campaign in the buildings of the University of Groningen and the Hanze University of Applied Sciences.

Before participation participants will sign an informed consent document which they will have received in advance. Before signing they will have the opportunity of consulting an independent physician whose name and contact information will be listed on the informed consent document.

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