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MUSIC IN THE BRAIN AND BODY
An introduction

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Recent neuroscience of music (2009-2013) provides studies of brain and body responses to REAL MUSIC

Previously, neuroscience focused mainly on simple stimuli

Overview in Christensen 2012: 64-104
Overview

1. Music activates the whole brain
2. Three levels in the brain
3. The pleasure connection: Neuromodulators
4. Timing in the brain: The Basal Ganglia
5. Timing in the brain: The Cerebellum
6. Timing in the brain: Electric and magnetic responses
7. Music and the Cortex
8. Music, Brain, and Health
9. The Beatles and Vivaldi in the Brain
1. MUSIC ACTIVATES THE WHOLE BRAIN
1.1. MUSIC INVOLVES

listening, watching, feeling, moving, coordinating, remembering, expecting

multisensory integration
attention
motor preparation and coordination
emotional response
bodily reactions:
heart rate, respiration, perspiration

Altenmüller & Schlaug 2012:12
1.2. The average brain contains 85.000.000.000 neurons
1.3. Activation of the whole brain
Music - Astor Piazzolla: Adios Nonino

Vinoo Alluri, Petri Toiviainen et al. (2012) Large-scale brain networks emerge from dynamic processing of musical timbre, key and rhythm.
1.4. Alluri et al. (2012): PROCEDURE:

1. Extraction of principal acoustic musical components by means of computer analysis (Music Information Retrieval)

2. A listening test results in the selection of six acoustic musical components: Fullness, Brightness, Timbral complexity, Key clarity, Pulse clarity, Activity

3. Recording of whole-brain activity of 11 persons while listening to Piazzolla: Adios Nonino, 8 minutes.

4. Comparison of acoustic musical components and brain activity: Calculation of correlations
1.5. Alluri et al. (2012): RESULTS

1. Processing of Timbre
involves cognitive areas of the cerebellum
and areas related to the “default mode network”,
which constantly monitors the sensory environment

2. Processing of Pulse
recruits limbic and reward areas

3. Processing of Tonality
involves cognitive and emotion-related brain areas

(Christensen 2012:133)
WHAT GOES ON IN YOUR MIND?

2. THREE LEVELS
IN THE BRAIN
2.1. Brain FRONT-BACK: ACTION and PERCEPTION

Motor  Somatosensory  Visual

Auditory
2.2. Brain UP-DOWN: Three levels
Brain stem - Thalamus - Cortex
2.3. The BRAIN STEM processes information needed to represent the body and control its life.

The THALAMUS disseminates signals from the BRAIN STEM to a widespread territory of the CORTEX.
2.4. The Brain stem and Thalamus
2.5. Six stations in the auditory pathway: Brain stem (1 2 3 4) Thalamus (5) Cortex (6)

6. Cortex

5. Medial Geniculate Nucleus
   Part of Thalamus

4. Inferior Colliculus

3. Nucleus of Lateral Lemniscus

2. Superior Olivary Nucleus

1. Cochlear Nucleus
2.6. Brain stem functions: Pitch, timbre, and timing have distinct representations in the brain stem

Kraus et al. (2009)
http://www.soc.northwestern.edu/brainvolts

Music - Arvo Pärt: Spiegel im Spiegel
2.7. SENSORY INTEGRATION: The Superior colliculus

The Superior colliculus contains superimposed maps of VISUAL, AUDITORY and SOMATIC information.

The Inferior colliculus conducts all auditory signals toward the cortex.

Stein et al. 1995:683-702; Damasio 2010:207-209
2.8. Brain UP-DOWN: Cortical appendages

Cerebellum  Basal ganglia  Hippocampus

subserve the cortex in specific functions. They are connected with the cortex by up-down loops (Edelman & Tononi 2000:45-46)
3. THE PLEASURE CONNECTION
Neuromodulators sprinkle the brain

3.1. The Brainstem produces NEUROMODULATORS

**Dopamine Pathways**
- Frontal cortex
- Nucleus accumbens
- VTA

**Functions**
- Reward (motivation)
- Pleasure, euphoria
- Motor function (fine tuning)
- Compulsion
- Perseveration

**Serotonin Pathways**
- Striatum
- Substantia nigra
- Hippocampus
- Raphe nuclei

**Functions**
- Mood
- Memory processing
- Sleep
- Cognition
3.2. The Pleasure Connection:

DOPAMINE is released during anticipation and experience of peak emotion to music

Valorie Salimpoor, Robert Zatorre et al. (2011)
3.3. Salimpoor et al. (2011)

The neuroscientific approach: 
Objective physiological measurements correspond with subjective musical experience

Music can induce experiences that can be measured in the body

PROCEDURE: Methods (1-2-3)
3. 4. Method (1): Body measurements of chill responses

- Respiration
- Electrodermal skin response
- Temperature
- Blood volume pulse amplitude
- Heart rate
3.5. Method (2): PET scanning
Positron emission tomography:
Brain imaging during music listening

PET creates images by measuring regional cerebral blood flow (rCBF), which correlates with activity of nerve cells (Koelsch 2012:79-80). PET scanning uses a radioactive tracer, injected in the blood.
3.6. Method (3): fMRI scanning
functional magnetic resonance imaging:
Brain imaging during music listening

fMRI measures blood-oxygen-level dependent (BOLD) contrast, which provides
an indirect measure of preceding neural activity in the brain (Koelsch 2012:78).
fMRI uses the change in magnetization between oxygen-rich and oxygen-poor blood.
3.7. Music that produces “chills” or “shivers down the spine”
The test persons’ self – selected musical excerpts that produce chills (1)

<table>
<thead>
<tr>
<th>Musical Excerpt</th>
<th>Composer</th>
<th>Genre</th>
</tr>
</thead>
<tbody>
<tr>
<td>Canon in D</td>
<td>Pachelbel</td>
<td>Classical</td>
</tr>
<tr>
<td>Clair de Lune</td>
<td>Debussy</td>
<td>Classical</td>
</tr>
<tr>
<td>Adagio for Strings</td>
<td>Barber</td>
<td>Classical</td>
</tr>
<tr>
<td>Requiem–Lacrimosa</td>
<td>Mozart</td>
<td>Classical</td>
</tr>
<tr>
<td>Second Symphony</td>
<td>Beethoven</td>
<td>Classical</td>
</tr>
<tr>
<td>New World Symphony</td>
<td>Dvorak</td>
<td>Classical</td>
</tr>
<tr>
<td>Moonlight Sonata</td>
<td>Beethoven</td>
<td>Classical</td>
</tr>
<tr>
<td>Swan Lake</td>
<td>Tchaikovsky</td>
<td>Classical</td>
</tr>
<tr>
<td>Romeo and Juliet</td>
<td>Prokofiev</td>
<td>Classical</td>
</tr>
<tr>
<td>Piano Concerto no. 2</td>
<td>Shostakovich</td>
<td>Classical</td>
</tr>
<tr>
<td>Fifth Symphony</td>
<td>Shostakovich</td>
<td>Classical</td>
</tr>
<tr>
<td>Symphonie Fantastique</td>
<td>Berlioz</td>
<td>Classical</td>
</tr>
<tr>
<td>Pines of Rome</td>
<td>Respighi</td>
<td>Classical</td>
</tr>
</tbody>
</table>
3.8. Music that produces “chills” or “shivers down the spine”
The test persons’ self-selected musical excerpts that produce chills (2)

<table>
<thead>
<tr>
<th>Musical Selection</th>
<th>Composer</th>
<th>Genre</th>
</tr>
</thead>
<tbody>
<tr>
<td>Second Symphony</td>
<td>Mahler</td>
<td>Classical</td>
</tr>
<tr>
<td>Rhapsody on a Theme of Paganini</td>
<td>Rachmaninoff</td>
<td>Classical</td>
</tr>
<tr>
<td>Morceaux de Fantasies</td>
<td>Rachmaninoff</td>
<td>Classical</td>
</tr>
<tr>
<td>Elegy</td>
<td>Elgar</td>
<td>Classical</td>
</tr>
<tr>
<td>Claressence</td>
<td>Holland</td>
<td>Jazz</td>
</tr>
<tr>
<td>Shine on You Crazy Diamond</td>
<td>Pink Floyd</td>
<td>Rock</td>
</tr>
<tr>
<td>Nyana</td>
<td>Tiesto</td>
<td>House</td>
</tr>
<tr>
<td>Hardstyle Disco</td>
<td>Biomehanika</td>
<td>Trance</td>
</tr>
<tr>
<td>Horns of a Rabbit</td>
<td>Do Make Say Think</td>
<td>Post-Rock</td>
</tr>
<tr>
<td>Lincolnshire Posy</td>
<td>Grainger</td>
<td>Folk</td>
</tr>
<tr>
<td>Jamedaran</td>
<td>Alizadeh</td>
<td>International</td>
</tr>
<tr>
<td>Vicious Delicious</td>
<td>Infected Mushroom</td>
<td>Psychedelic Trance</td>
</tr>
</tbody>
</table>

Music - Mozart: Requiem - Lacrimosa
3.9. “Chills” involve a center of the reward system:

The Human Basal Ganglia

- Basal Ganglia
- Thalamus
- Brainstem

Near the base of the brain is a small area called the substantia nigra which contains cells that produce dopamine.

Dopamine acts as a transmitter between the nerve endings.
3.10. The reward system is activated by dopamine

Dopamine Pathways
- Nucleus accumbens

Functions
- Reward (motivation)
- Pleasure, euphoria
- Motor function (fine tuning)
- Compulsion
- Perseveration

Serotonin Pathways
- Caudate nucleus & Putamen

Functions
- Mood
- Memory processing
- Sleep
- Cognition
3.11. Salimpoor et al. (2011) RESULTS:
Dopamine release during anticipation and experience of peak emotion to music

Caudate nucleus: Dopamine release during anticipation of peak emotion

Nucleus accumbens: Dopamine release during peak emotion

Music - Mozart: Requiem - Lacrimosa
3.12. Pleasure networks in the brains of rats and humans

Fig. 1. Pleasure networks in the mammalian brain. The figure shows pleasure regions in the adult rat (upper) and human (lower) brains. The hedonic circuitries have been revealed using behavioral and subjective measures of pleasure to food stimuli [9]. The pleasure networks (in the middle panel) include the orbitofrontal cortex (gray), the cingulate cortex (light blue), ventral tegmental area in the brainstem (light red), hypothalamus (yellow), periventricular gray/periaqueductal gray (PVG/PAG, green), nucleus accumbens (light green), ventral pallidum (light purple), amygdala (light red) and the insular cortices (not shown). The right-most panel shows the dopaminergic system in the human brain.
3.13. Music listening can evoke pleasure

However, this is not the whole story
3.14. Arousal evoked by music means more than pleasure

The neuroscience of arousal investigates change, uncertainty, unpredictability, and surprise (Donald Pfaff 2006:144)

These are characteristic features of music, together with the opposites; stability, security, predictability, and fulfilled expectation.
3.15 Music communicates more than pleasure

- the drama and grief in Bach’s St. Matthew Passion
- chaos and light in Haydn’s Creation
- fear in the Dies Irae of Verdi’s Requiem
- harsh dissonances in Bartok’s Concerto for Orchestra
- noisy percussion and wind instruments in Varèse’s Hyperprism
- vehemence in Debussy’s Prelude on the Western Wind
- the suffering of Jesus in Messiaen’s La Nativité du Seigneur
- chaotic and threatening sounds in Xenakis’ Metastasis
- the surrealistic variety of emotions in Ligeti’s Aventures
- the sharp, penetrating sounds of Japanese Gagaku
- the simultaneity of noise and tone in African instruments
- the rough interferent sound of heavy rock
- chaos, surprise, pleasure and noise in Zorn’s Forbidden Fruit

(Christensen 2000:32-33)
4. TIMING IN THE BRAIN:
The basal ganglia

Grahn et al. 2007, 2009
4.1 Timing in the basal ganglia: ENTRAINMENT - embodied listening

Music - Bamboo Gamelan
4.2. Timing in the basal ganglia:
BEAT PERCEPTION and BEAT GENERATION
- embodied listening

Music - Jelly Roll Morton: Black Bottom Stomp
5. TIMING IN THE BRAIN: The cerebellum

Janata & Grafton 2003; Levitin 2006; Schmahmann 2010
5.1 Musical movement: The Cerebellum plays an important role in movement-related functions

Music - Lutoslawski: Livre pour orchestre
5.2. Musical movement

The Cerebellum

Music - Gloria in excelsis Deo
5.3. The cerebellum contains more neurons than the rest of the brain

Jeremy Schmahmann 2010:246
5.4. Direct connection from the ear to the cerebellum

The cochlear nucleus, which is the first relay nucleus along the auditory pathway, sends nerve fibers directly to the cerebellum.

Huang et al. 1982; Petacchi 2005; Sens & Almeida 2007
5.5. TIMING IN THE BRAIN: Music Groove

Probable involvement of Cerebellum AND basal ganglia

Music - Stevie Wonder: Superstition

Levitin 2006:169-192; Witek 2009
6. TIMING IN THE BRAIN:

Pre-conscious and conscious responses in the brainstem, thalamus and cortex measured in milliseconds
6.1. Method (4) EEG: Electroencephalography

EEG records changes in electric potential originating from brain activity using electrodes situated on the scalp (Koelsch 2012:31-42)
6.2. Method (5) MEG: Magnetoencephalography

MEG records changes in magnetic fields produced by electrical currents occurring in the brain, using very sensitive helium-cooled magnetometers (Koelsch 2012:48-49)
47

6.3. Stefan Koelsch (2011) An updated model of music perception based on EEG and MEG timing in milliseconds
7. MUSIC and the CORTEX
7.1. Connections between the auditory and motor functions in the cortex
7.2. Music performance activates the auditory and motor cortices

Motor cortex

Premotor cortex (dorsal)

Superior temporal gyrus/auditory cortex

Frontal cortex

Premotor cortex (ventral)

Ear

Sound

Zatorre et al. 2007
7.3 Music listening activates motor areas in the brain

Even in studies where subjects only listen to rhythms, the basal ganglia, cerebellum, dorsal premotor cortex and supplementary motor area are often implicated

Zatorre et al. 2007:550
7.4. Melody and timbre:

Distinct pathways for

Sound MOVEMENT and Sound IDENTIFICATION
7.5. The upper (dorsal) pathway deals with MOVEMENT of sounds.

The lower (ventral) pathway deals with IDENTIFICATION of sounds (Timbre).

Music - Arvo Pärt: Spiegel im Spiegel
7.6. Musical memory
“The tune that runs through your head”

Edelman & Tononi 2000: 97-99; Damasio 2010: 130-153
7.7. “The tune that runs through your head”

Probable interactions between the frontal cortex and the auditory cortex (Zatorre & Halpern 2005)
8. MUSIC, BRAIN, and HEALTH Examples

Koelsch 2009; MacDonald, Kreutz & Mitchell (Eds.) 2012
8.1. Music therapy treatment for Parkinson’s Disease

Thaut 2010; Thaut & Abiru 2010
8.2. Receptive Music Therapy: Music Listening
Guided Imagery and Music (GIM)
treatment for chronic stress

Bolette Daniels Beck (2012): Guided Imagery and Music (GIM)
with adults on sick leave suffering from work-related stress –
a mixed methods experimental study

http://www.mt-phd.aau.dk/phd-theses/
8.3. Music Listening for Stroke Rehabilitation

Särkämö et al. (2008)

Søren Hald (2012) Music Therapy, Acquired Brain Injury and Interpersonal Communication Competencies. Randomized cross-over study on music therapy in neurological rehabilitation

http://www.mt-phd.aau.dk/phd-theses/
8.4. The Neurochemistry of Music

Music improves health and well-being through the engagement of neurochemical systems for

(i) reward, motivation, and pleasure;
(ii) stress and arousal;
(iii) immunity; and
(iv) social affiliation.

Chanda & Levitin 2013
9. Music with and without lyrics
The Beatles and Vivaldi in the Brain

Music - The Beatles: Abbey Road

Vinoo Alluri, Petri Toiviainen, Peter Vuust, et al. 2013
9.1. Music - Vivaldi: The Four Seasons - Spring
9.2. Alluri et al. (2013): PROCEDURE
- similar to Alluri et al. (2012)

1. Extraction of principal acoustic musical components by means of computer analysis (Music Information Retrieval)

2. Recording of whole-brain activity of 11 persons while listening to the B-side of Abbey Road, and 12 persons listening to a medley of instrumental music:
   Booker T and the MGs: Green Onions.  Vivaldi: Spring.
   Miles Davis: Straight, no chaser.  The Shadows: Apache.

3. Comparison of acoustic musical components and brain activity:
   Calculation of correlations
9.3. Alluri et al. 2013: Music with and without lyrics
The images display slices of the two hemispheres, seen from above

<table>
<thead>
<tr>
<th>A</th>
<th>Abbey Road, with lyrics</th>
<th>* *</th>
<th>#</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>Instrumental music</td>
<td>* *</td>
<td>#</td>
</tr>
</tbody>
</table>

Two of the results:
A & B: ** Activation of orbitofrontal “pleasure” regions by listening to full musical pieces
A: # Prevalent activation of right auditory cortex by music with lyrics (surprise)
Thank you for listening!
References: Books


Levitin, D. (2006). *This is your Brain on Music*.


References: Articles and book chapters


