University of Southern Denmark
September 5, 2013

MUSIC IN THE BRAIN AND BODY
An introduction

Erik Christensen
Aalborg University

erc@timespace.dk http://www.mt-phd.aau.dk/phd-theses/

http://aalborg.academia.edu/ErikChristensen

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

Previously, neuroscience focused mainly on
simple stimuli

Grewe et al. 2009; Salimpoor et al. 2009, 2011; Alluri et al. 2012, 2013
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

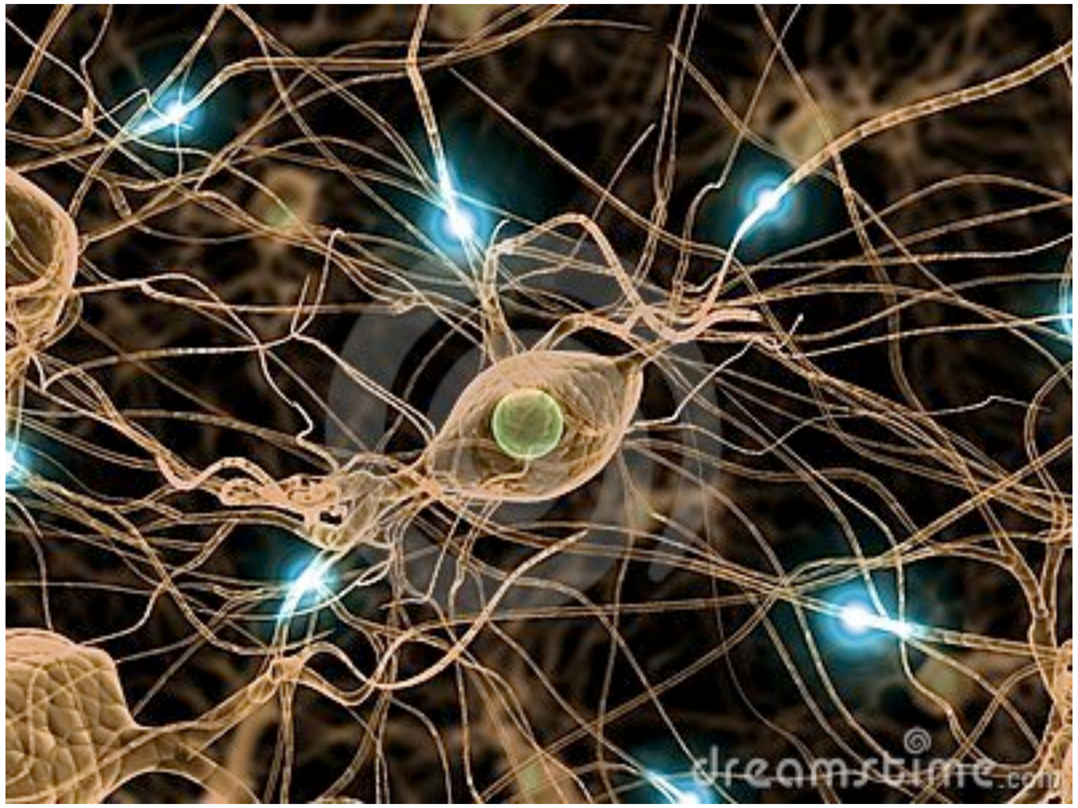
1.1. MUSIC INVOLVES

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

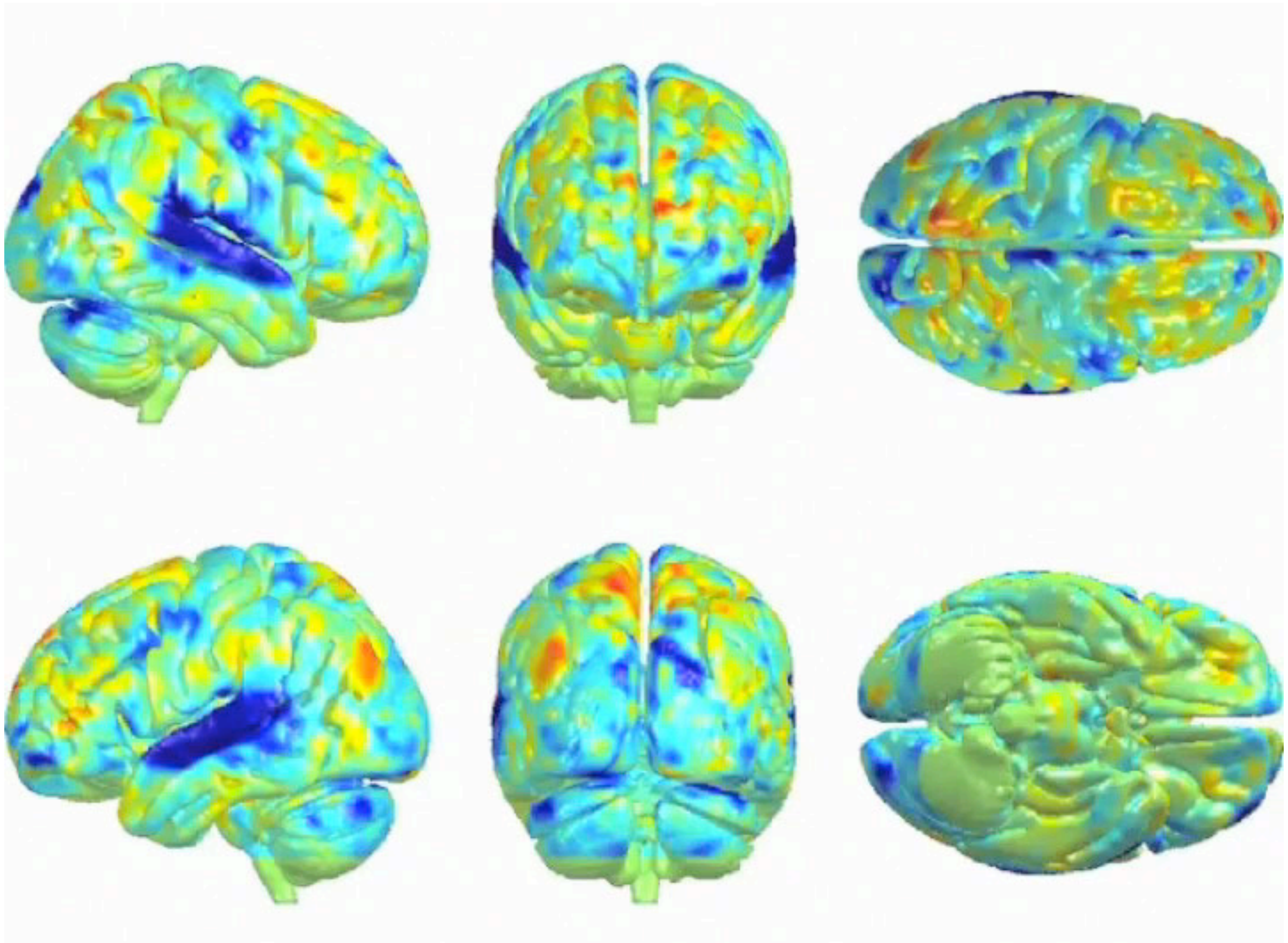
multisensory integration
attention
motor preparation and coordination
emotional response
bodily reactions:
heart rate, respiration, perspiration

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 Piazolla: 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

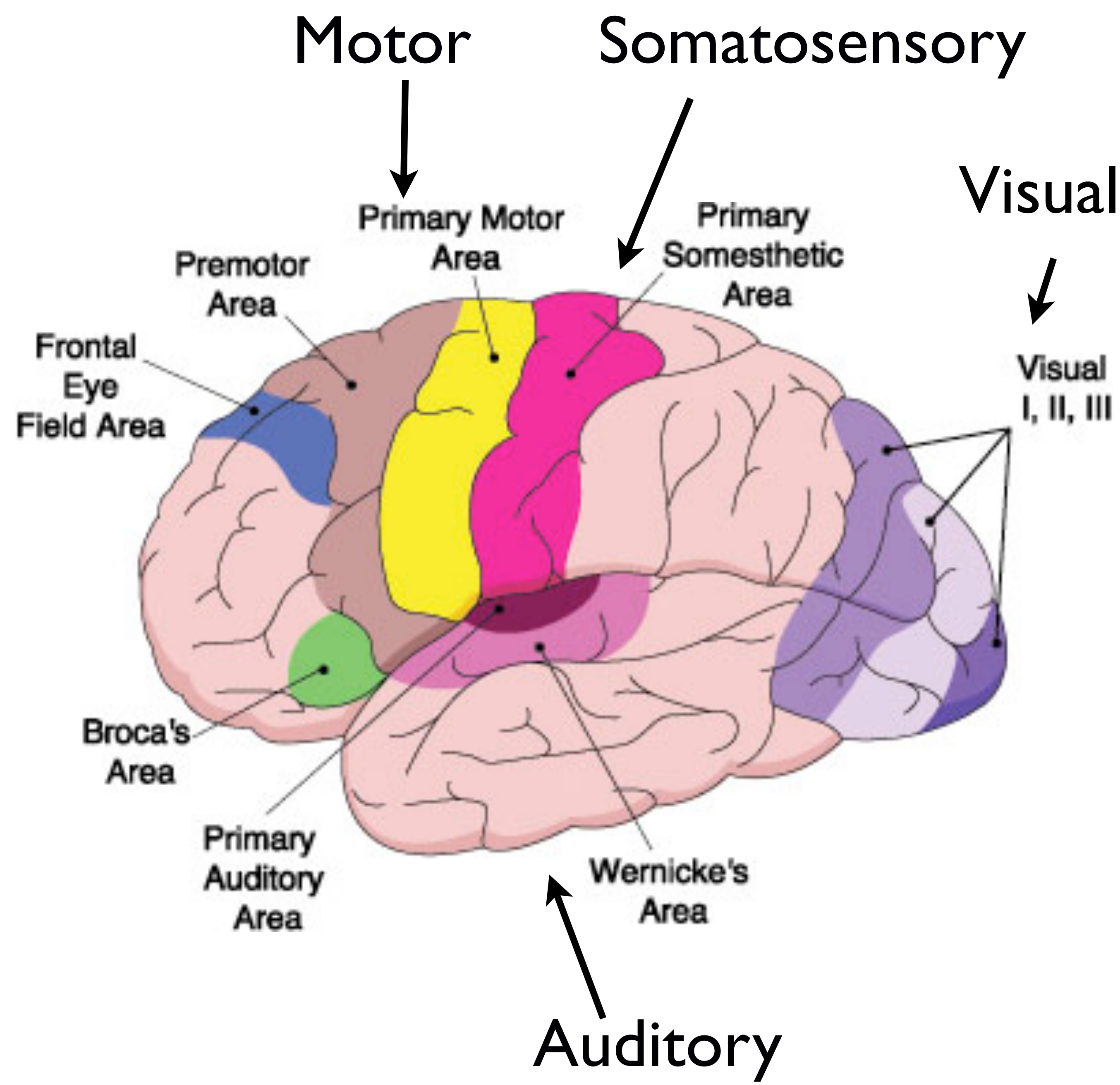
(Christensen 2012:133)

WHAT GOES ON IN YOUR MIND?

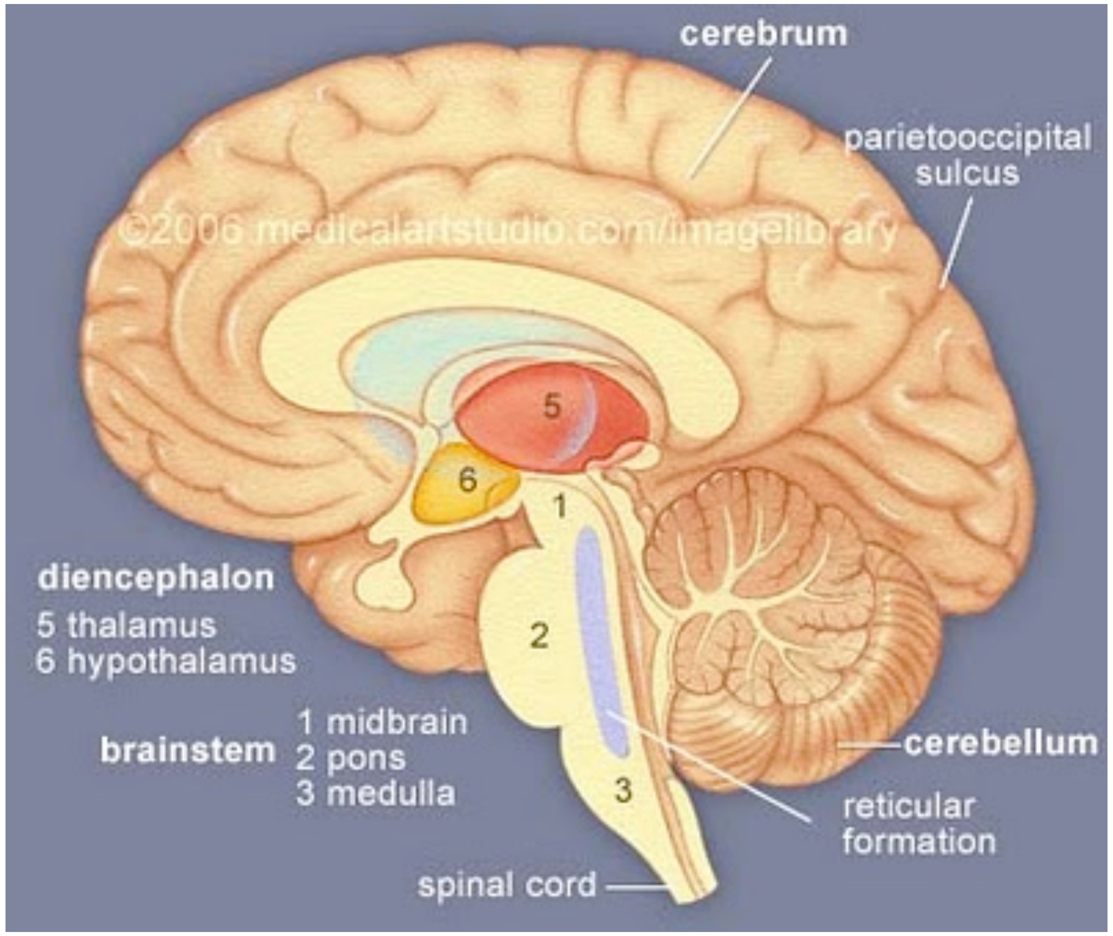
2. THREE LEVELS IN THE BRAIN

10

2.1. Brain FRONT-BACK: ACTION and PERCEPTION



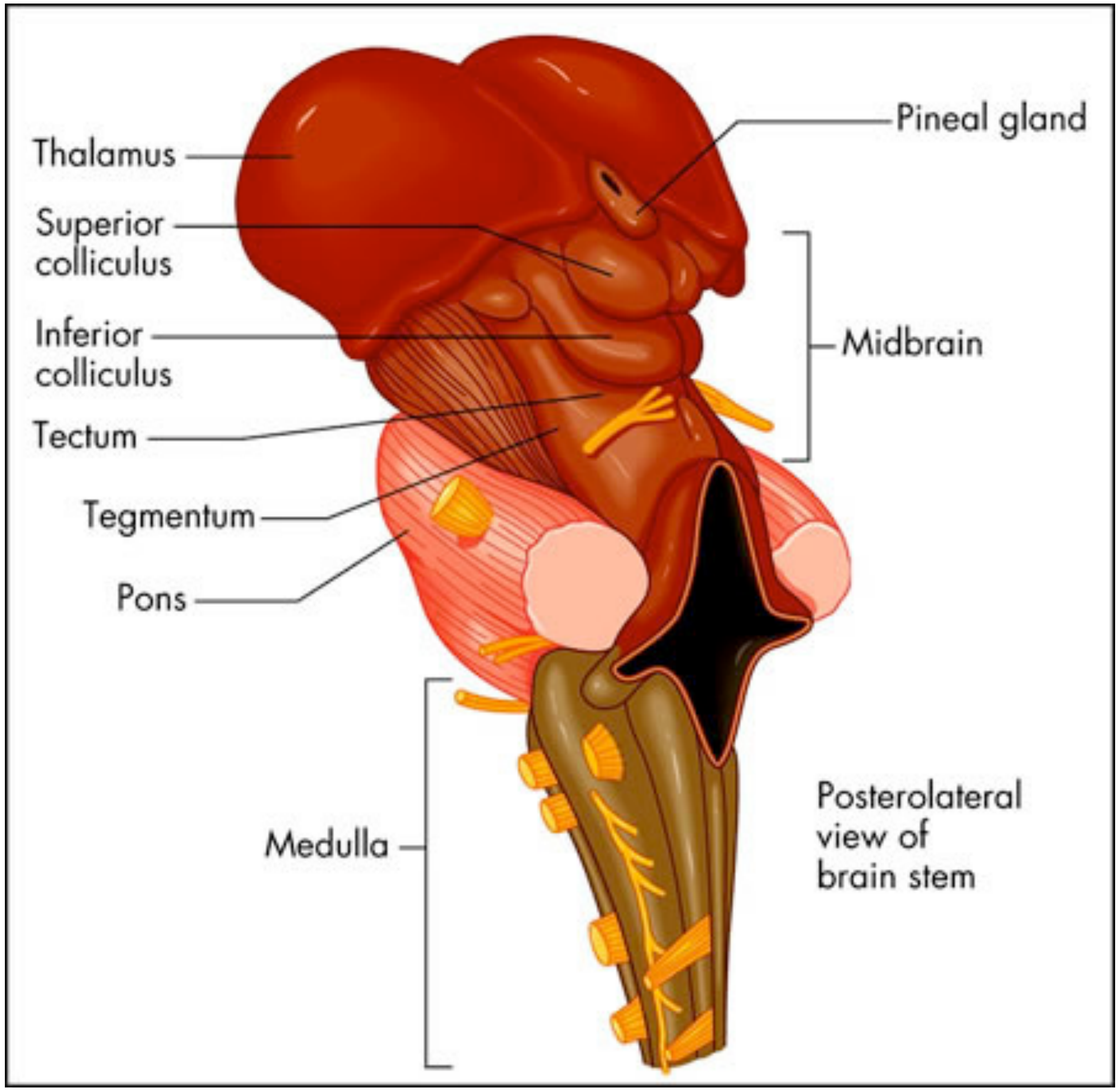
2.2. Brain UP-DOWN: Three levels
Brain stem - Thalamus - Cortex



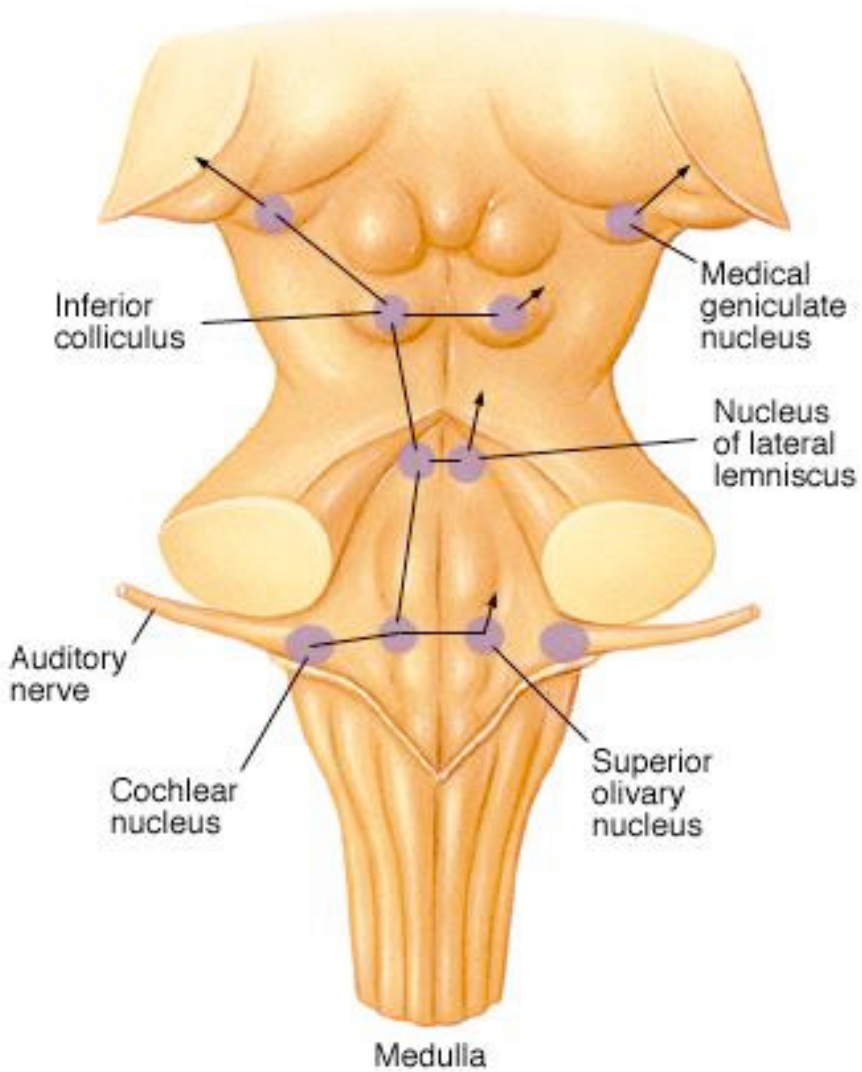
2.3.
The BRAIN STEM
processes information needed to represent the body and control its life

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

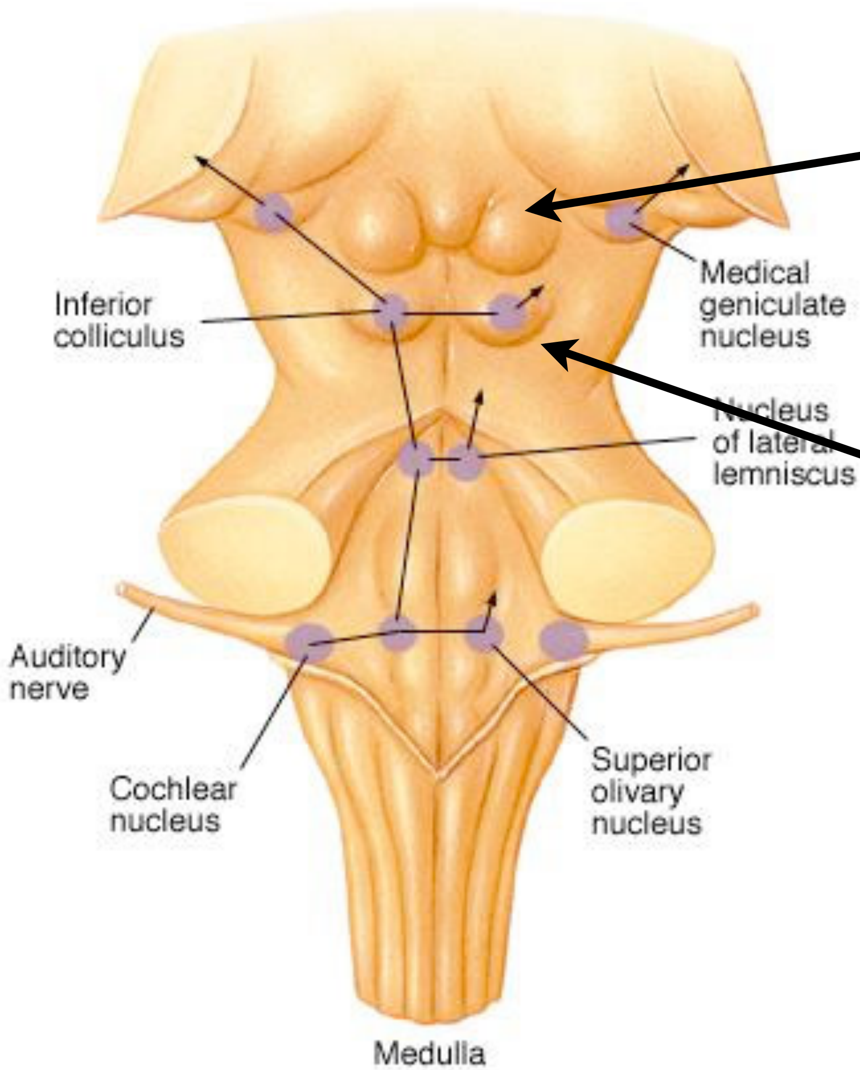
2.6. Brain stem functions: Pitch, timbre, and timing have distinct representations in the brain stem

Kraus et al. (2009)

http://www.soc.northwestern.edu/brainvolts

Music - Arvo Pärt: Spiegel im Spiegel

2.7. SENSORY INTEGRATION: The Superior colliculus



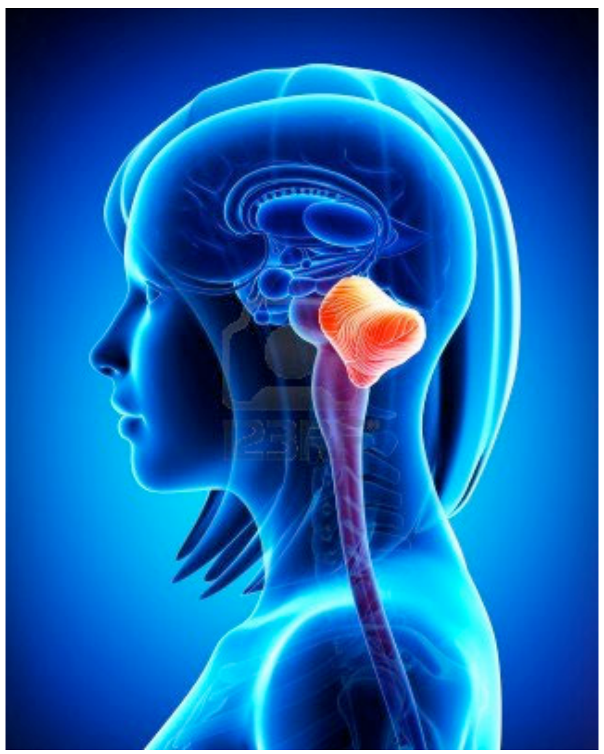
The Superior colliculus contains superimposed maps of VISUAL, AUDITORY and SOMATIC information

The Inferior colliculus conducts all auditory signals toward the cortex

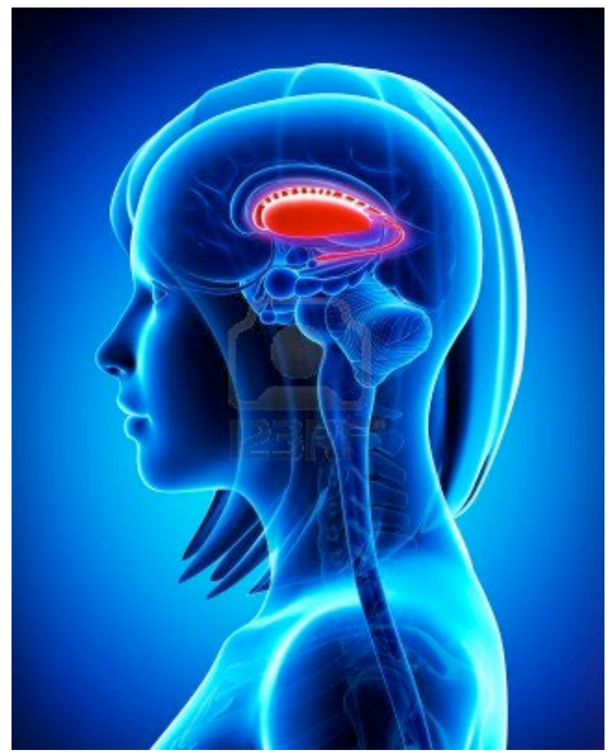
Stein et al. 1995:683-702; Damasio 2010:207-209

2.8. Brain UP-DOWN: Cortical appendages

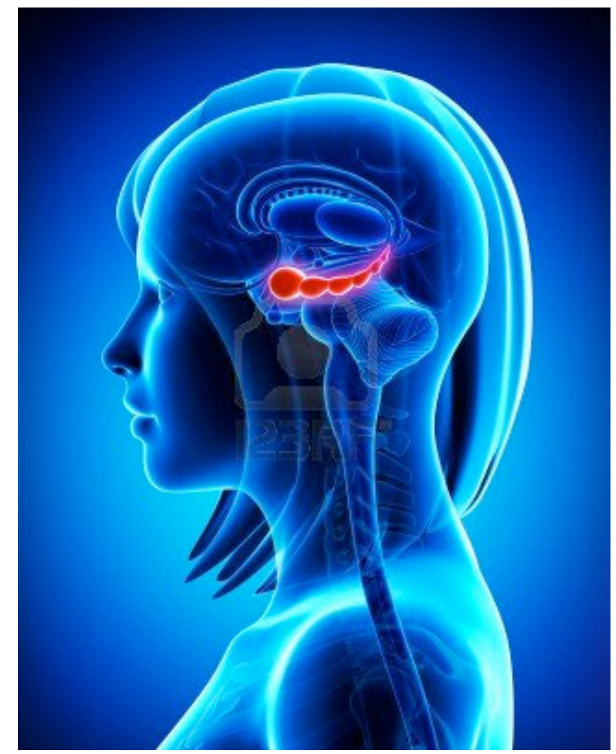
Cerebellum



Basal ganglia



Hippocampus



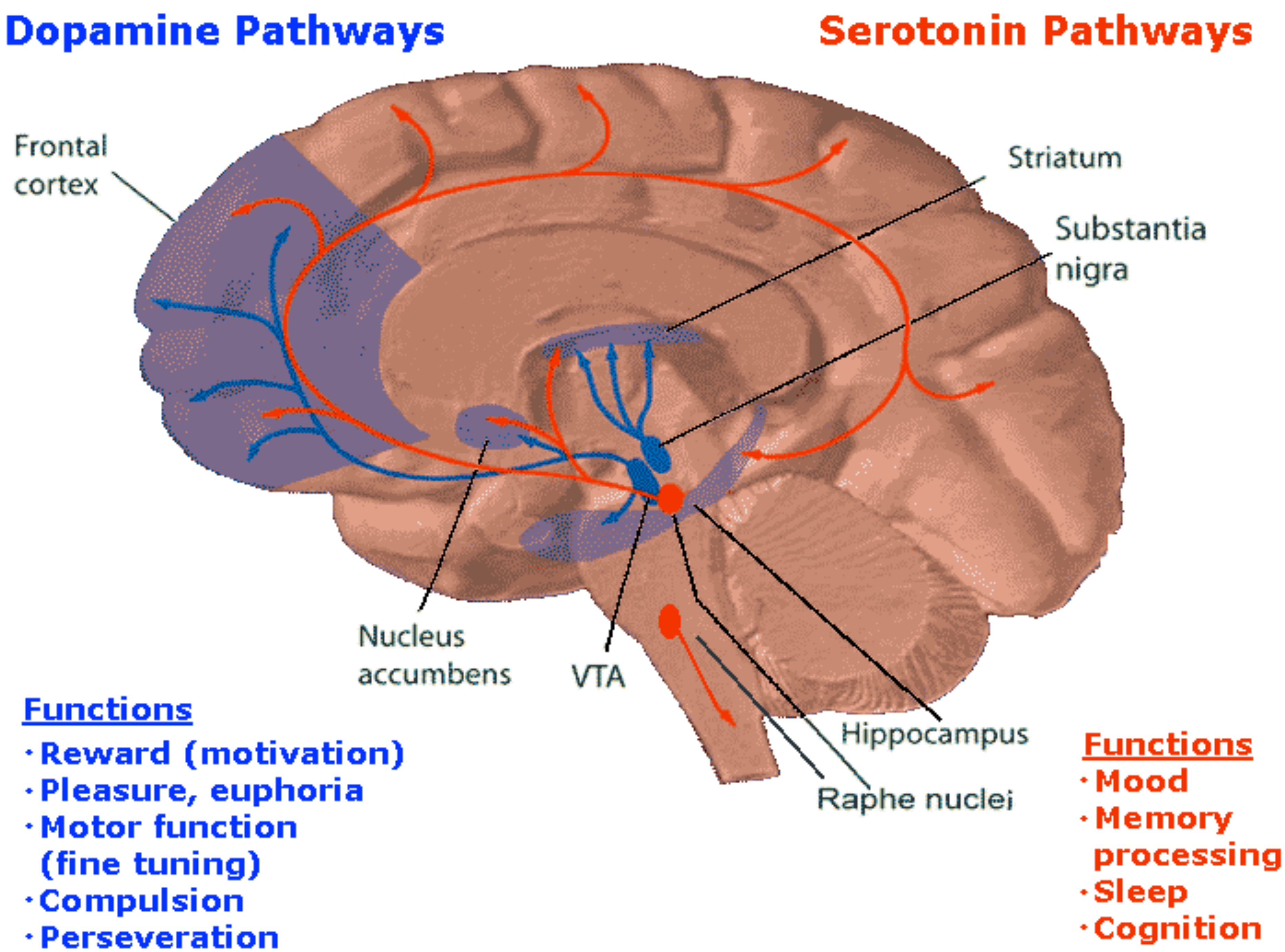
subserve the cortex in specific functions. They are connected with the cortex by up-down loops (Edelman & Tononi 2000:45-46)

3. THE PLEASURE CONNECTION
Neuromodulators sprinkle the brain

Blood & Zatorre 2001; Menon & Levitin 2005;
Grewe et al. 2009; Salimpoor et al. 2009, 2011;
Kringelbach & Berridge (Eds.) 2010; Chanda & Levitin 2013

19

3.1. The Brainstem produces NEUROMODULATORS



3.2. The Pleasure Connection:

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

Valorie Salimpoor, Robert Zatorre et al. (2011)

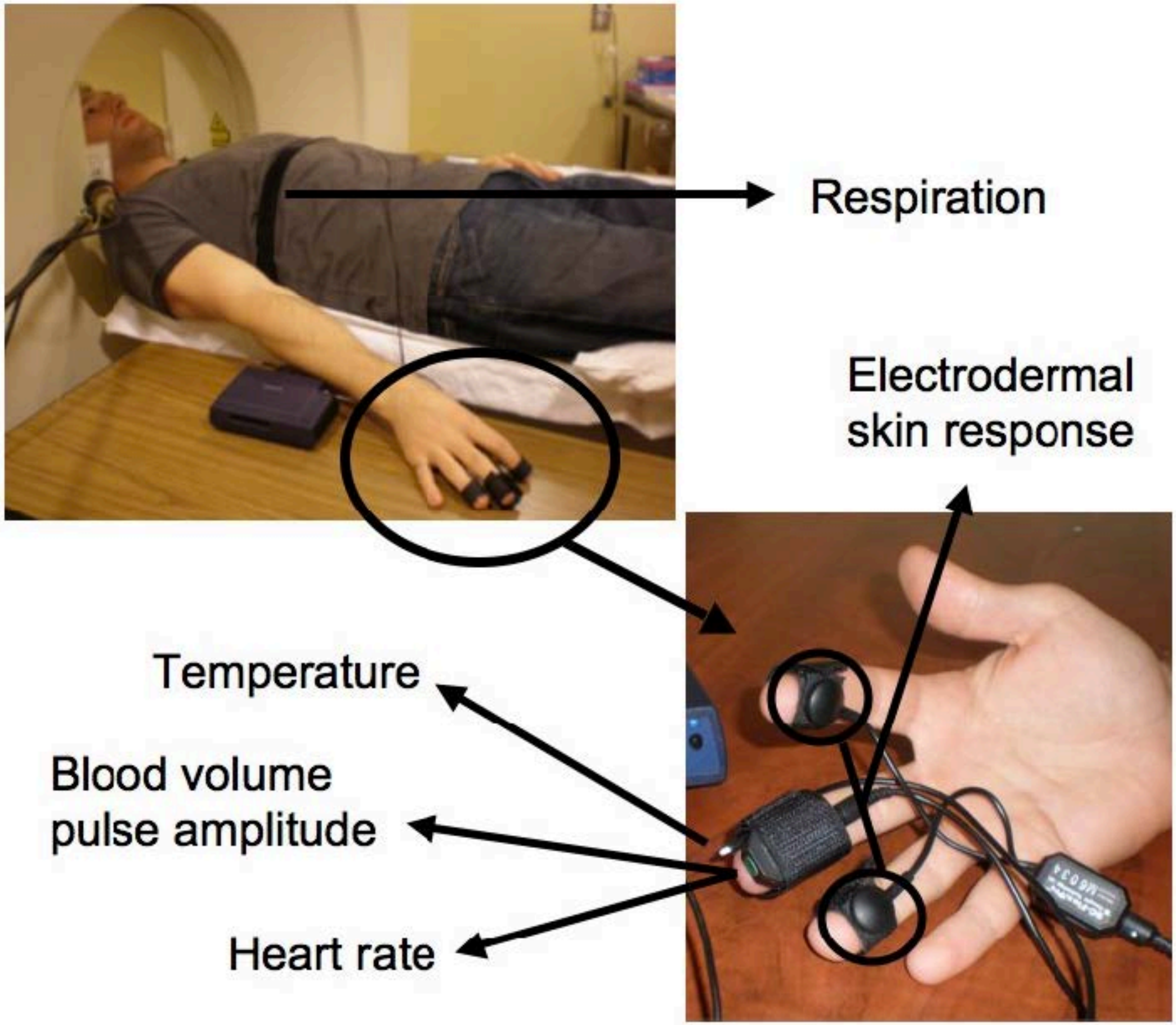
3.3. Salimpoor et al. (2011)

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)

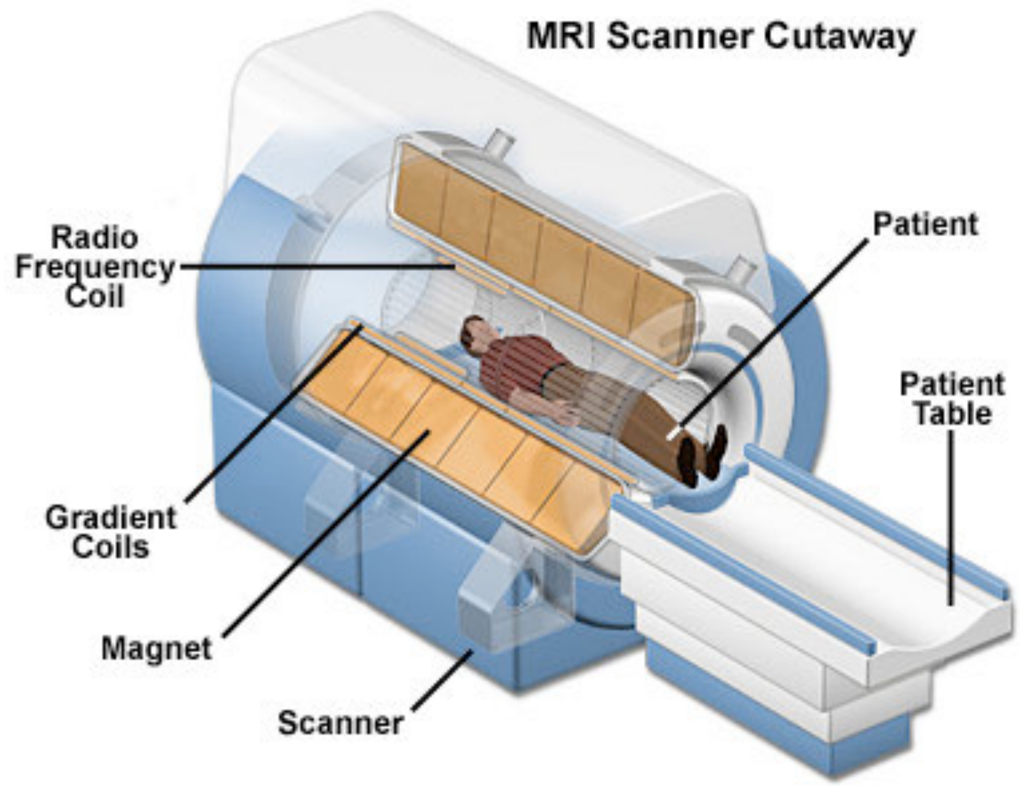
3. 4. Method (1): Body measurements of chill responses



3.5. Method (2): PET scannning
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)

Canon in D	Pachelbel	Classical
Clair de Lune	Debussy	Classical
Adagio for Strings	Barber	Classical
Requiem–Lacrimosa	Mozart	Classical
Second Symphony	Beethoven	Classical
New World Symphony	Dvorak	Classical
Moonlight Sonata	Beethoven	Classical
Swan Lake	Tchaikovsky	Classical
Romeo and Juliet	Prokofiev	Classical
Piano Concerto no. 2	Shostakovich	Classical
Fifth Symphony	Shostakovich	Classical
Symphonie Fantastique	Berlioz	Classical
Pines of Rome	Respighi	Classical

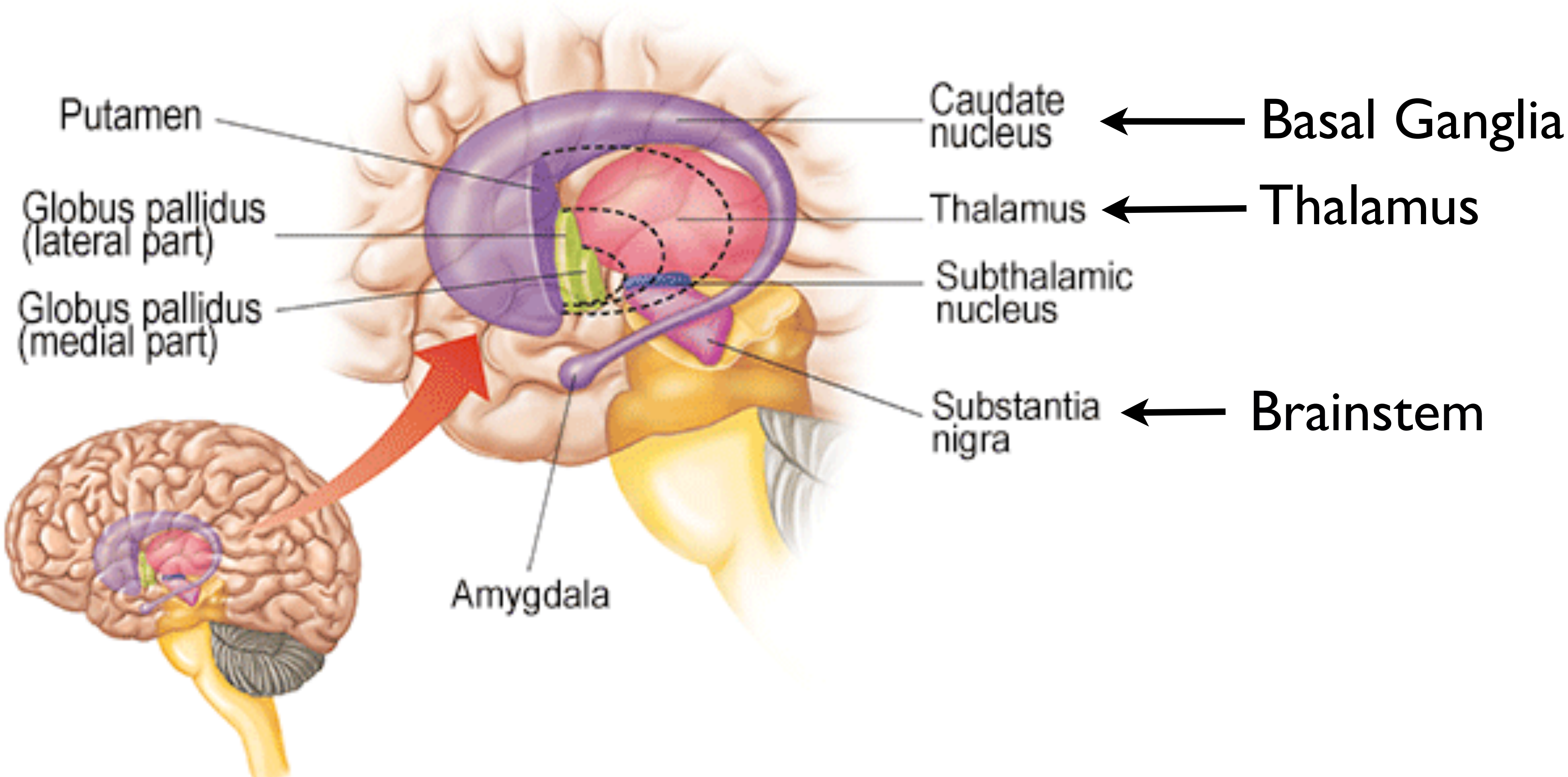
3.8. Music that produces “chills” or “shivers down the spine”
The test persons’ self – selected musical excerpts that produce chills (2)

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

Music - Mozart: Requiem - Lacrimosa

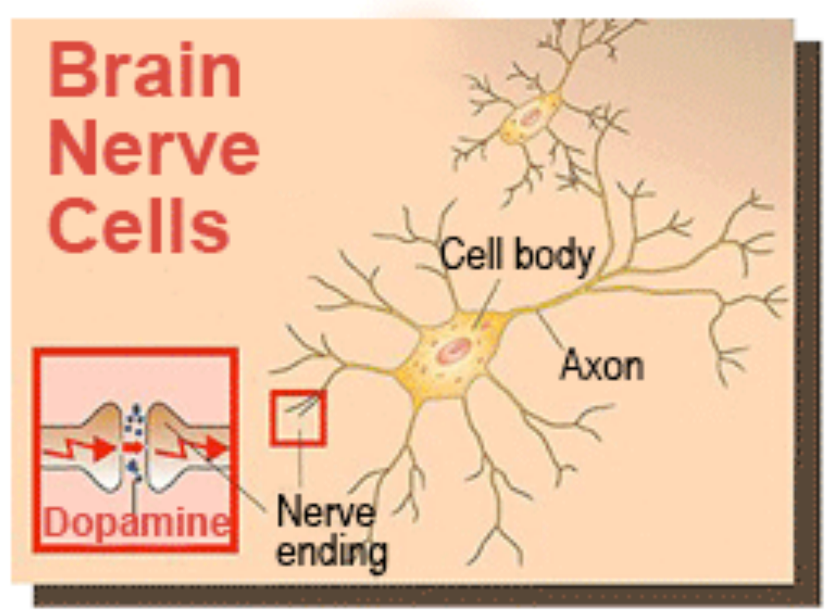
3.9. “Chills” involve a center of the reward system:

The Human Basal Ganglia



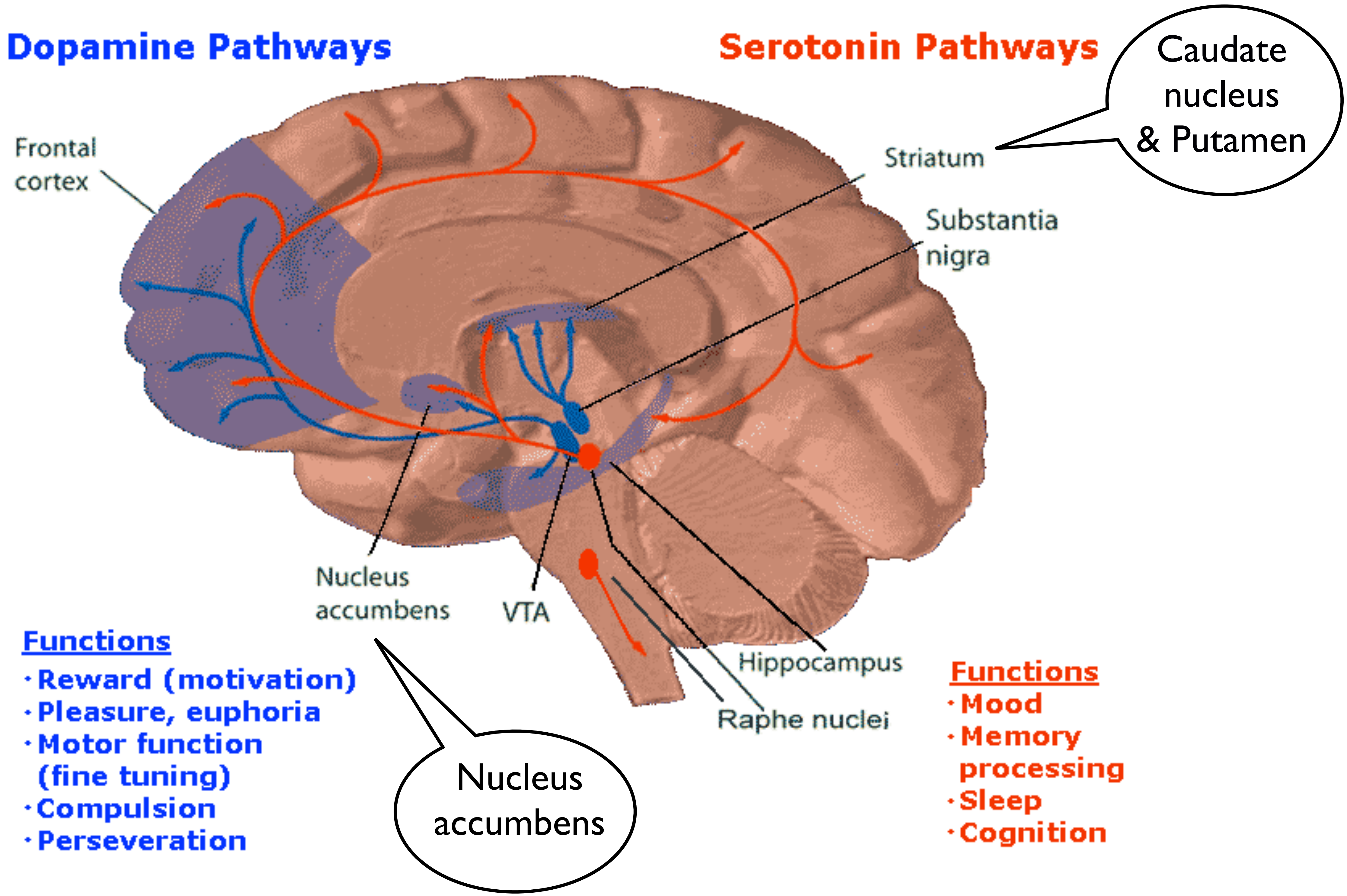
Near the base of the brain is a small area called the substantia nigra which contains cells that produce dopamine.

Dopamine acts as a transmitter between the nerve endings.

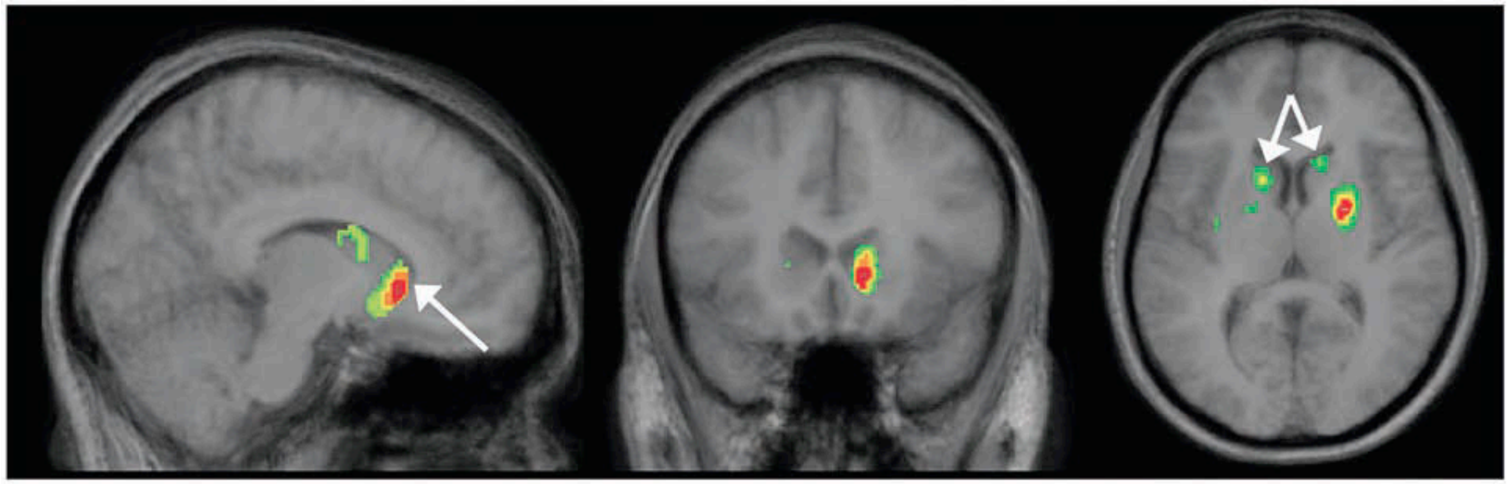


28

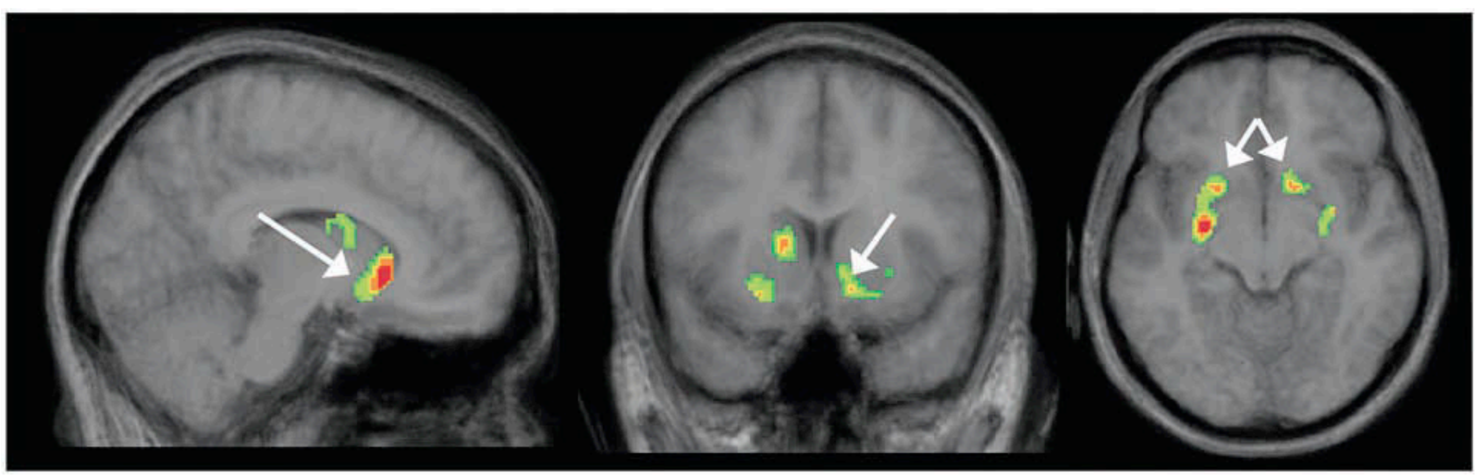
3.10. The reward system is activated by dopamine



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

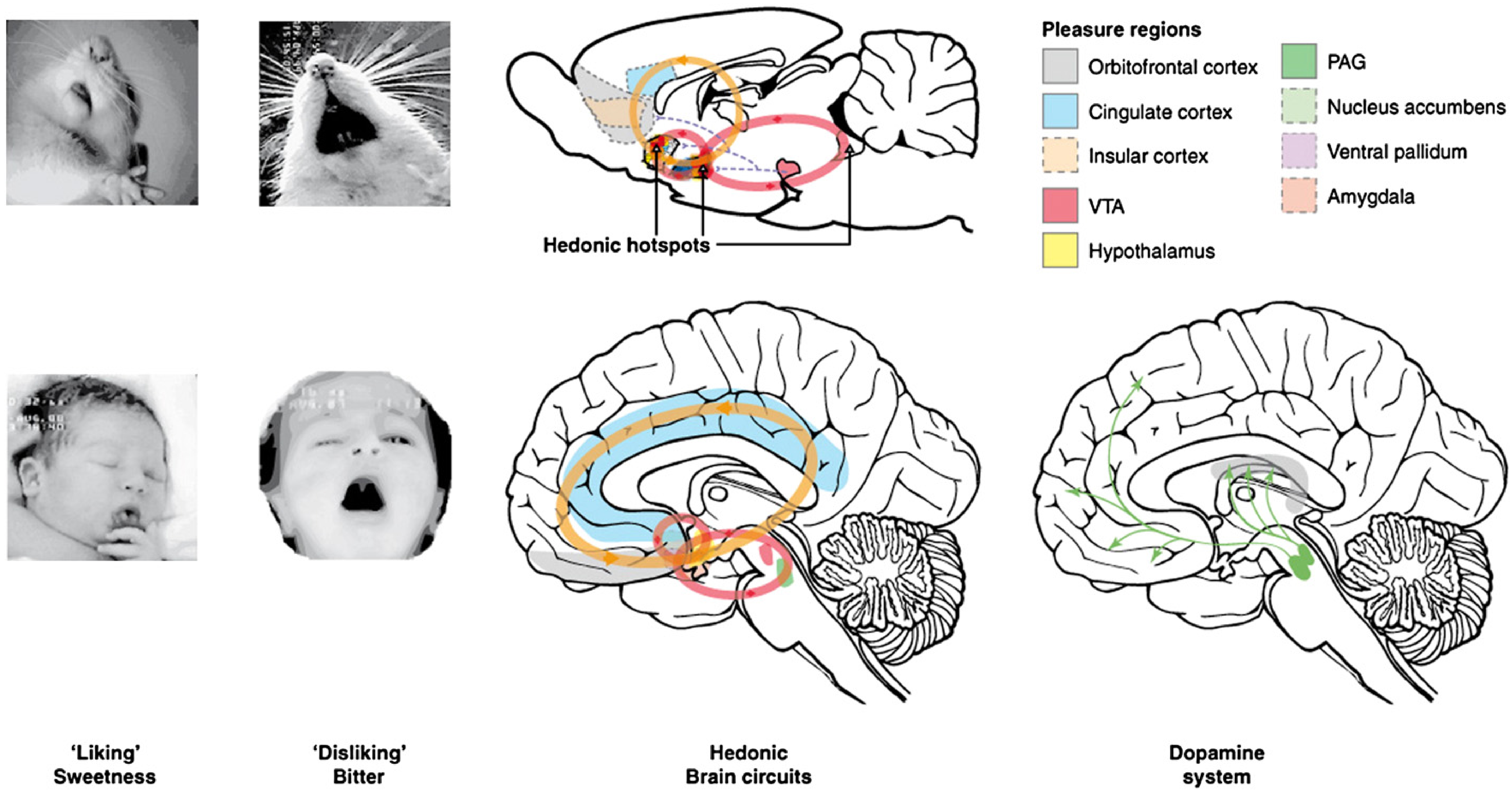


Fig. 1. Pleasure networks in the mammalian brain. The figure shows pleasure regions in the adult rat (upper) and human (lower) brains. The hedonic circuitries have been revealed using behavioral and subjective measures of pleasure to food stimuli [9]. The pleasure networks (in the middle panel) include the orbitofrontal cortex (gray), the cingulate cortex (light blue), ventral tegmental area in the brainstem (light red), hypothalamus (yellow), periventricular gray/periacqueductal 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.

Kringelbach et al. 2012:308

3.13. Music listening can evoke pleasure

However, this is not the whole story

32

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)

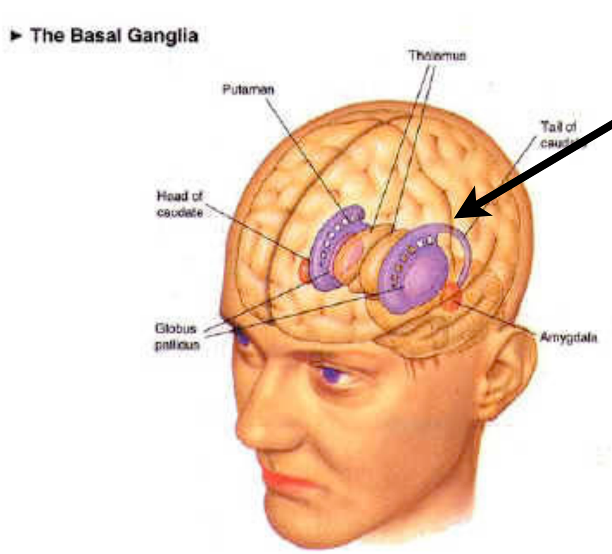
Music - John Zorn: Forbidden Fruit

4. TIMING IN THE BRAIN:
The basal ganglia

Grahn et al. 2007, 2009

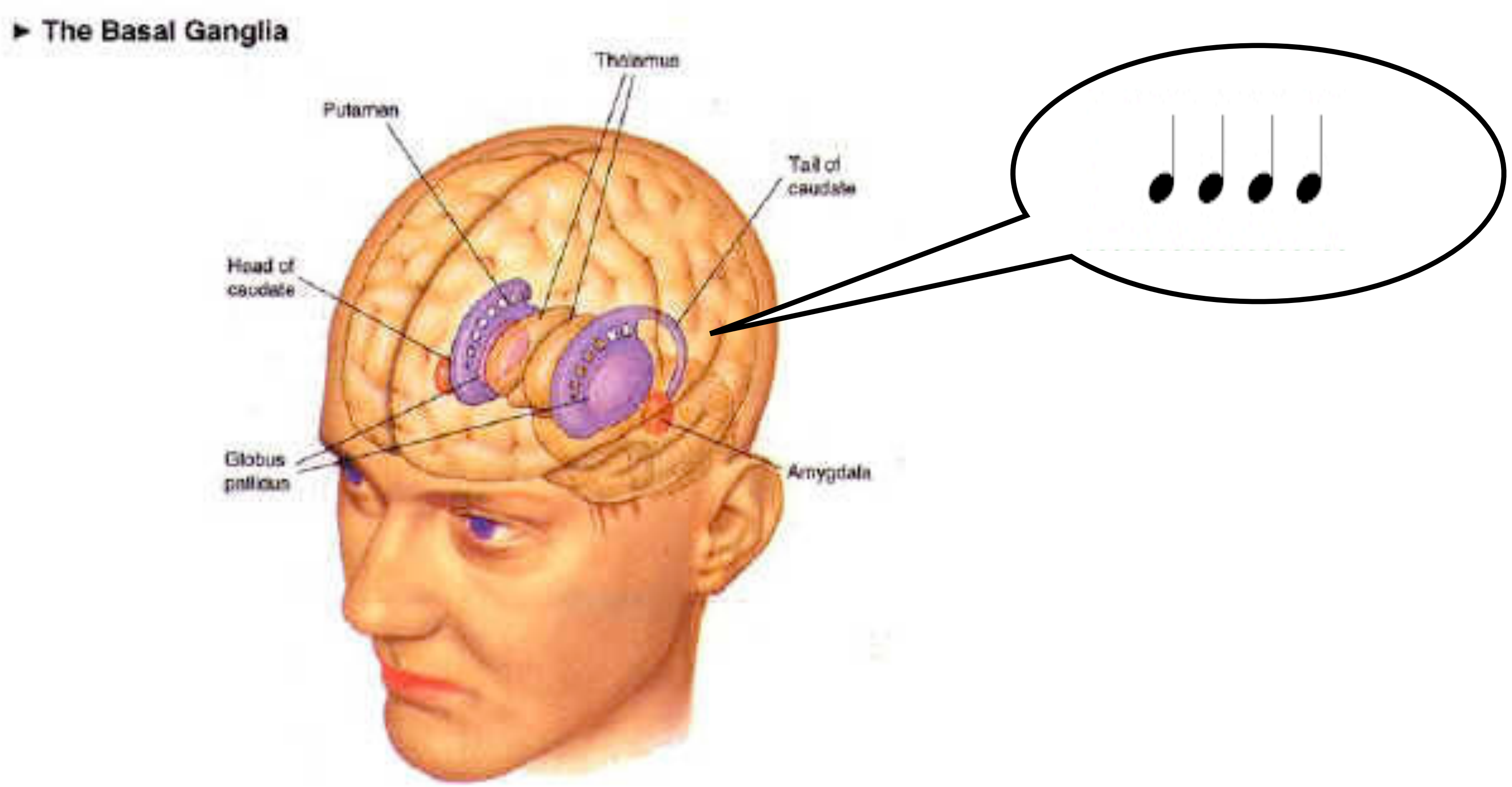
35

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

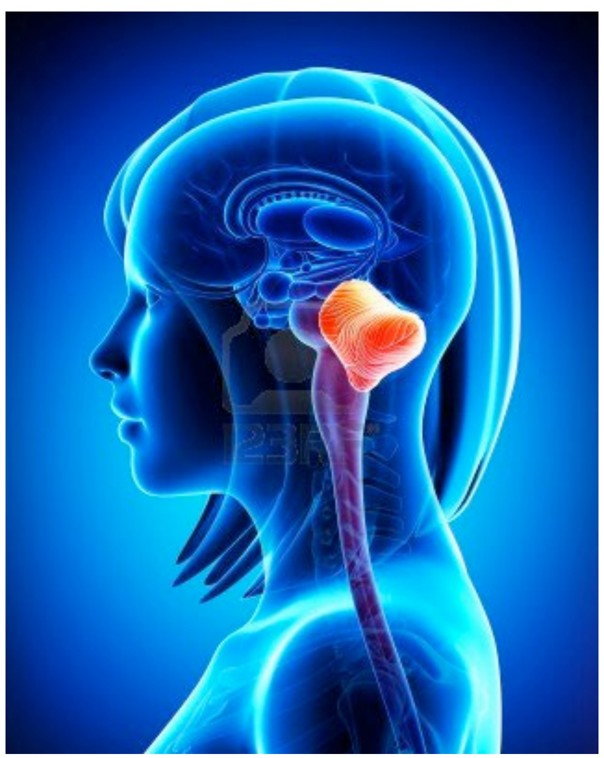
Janata & Grafton 2003; Levitin 2006;
Schmahmann 2010

5. 1 Musical movement: The Cerebellum plays an important role in movement-related functions

Music - Lutoslawski: Livre pour orchestre

39

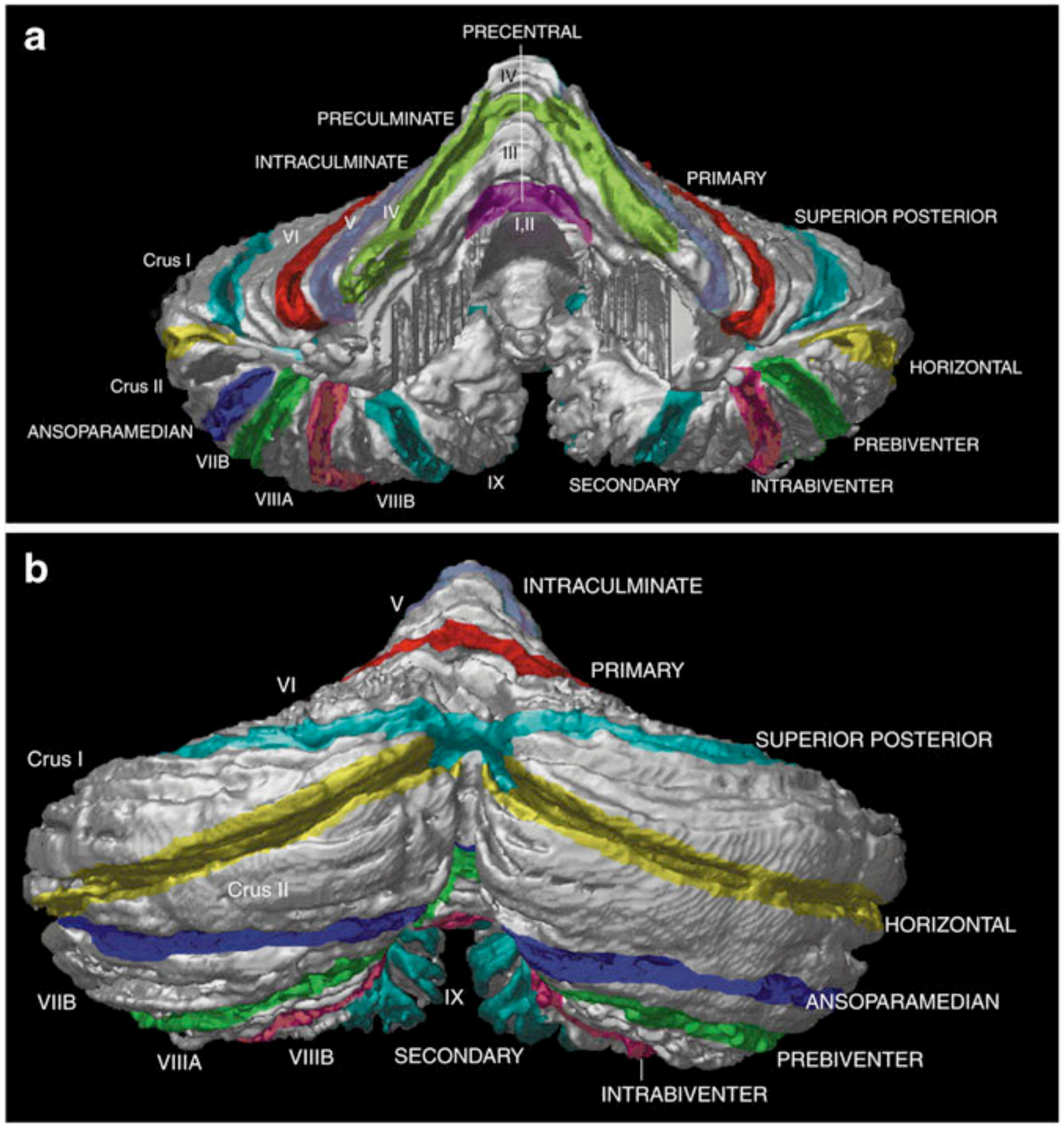
5.2. Musical movement



Music - Gloria in excelsis Deo

The Cerebellum

5.3. The cerebellum contains more neurons than the rest of the brain

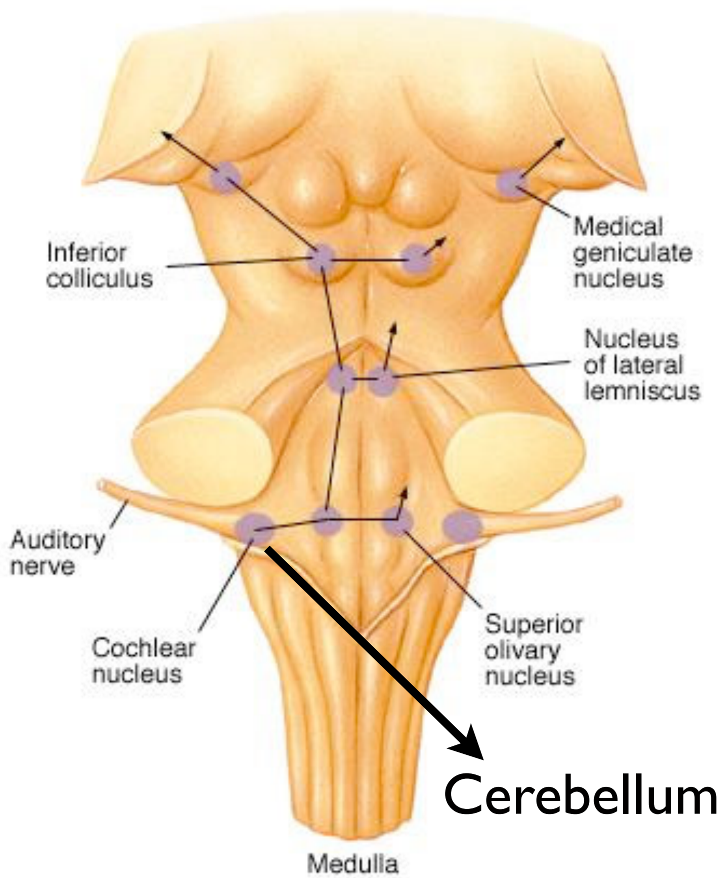


c

VERMIS Lobule	FISSURE	HEMISPHERE Lobule
I,II		I,II
	Precentral	
III		III
	Preculminate	
IV		IV
	Intraculminate	
V		V
	Primary	
VI		VI
	Superior Posterior	
VIIAf		Crus I
	Horizontal	
VIIAt		Crus II
	Ansoparamedian	
VIIB		VIIB
	Prepyramidal /Prebiventer	
VIIIA		VIIIA
	Intrabiventer	
VIIIB		VIIIB
	Secondary	
IX		IX
	Posterolateral	
X		X

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)

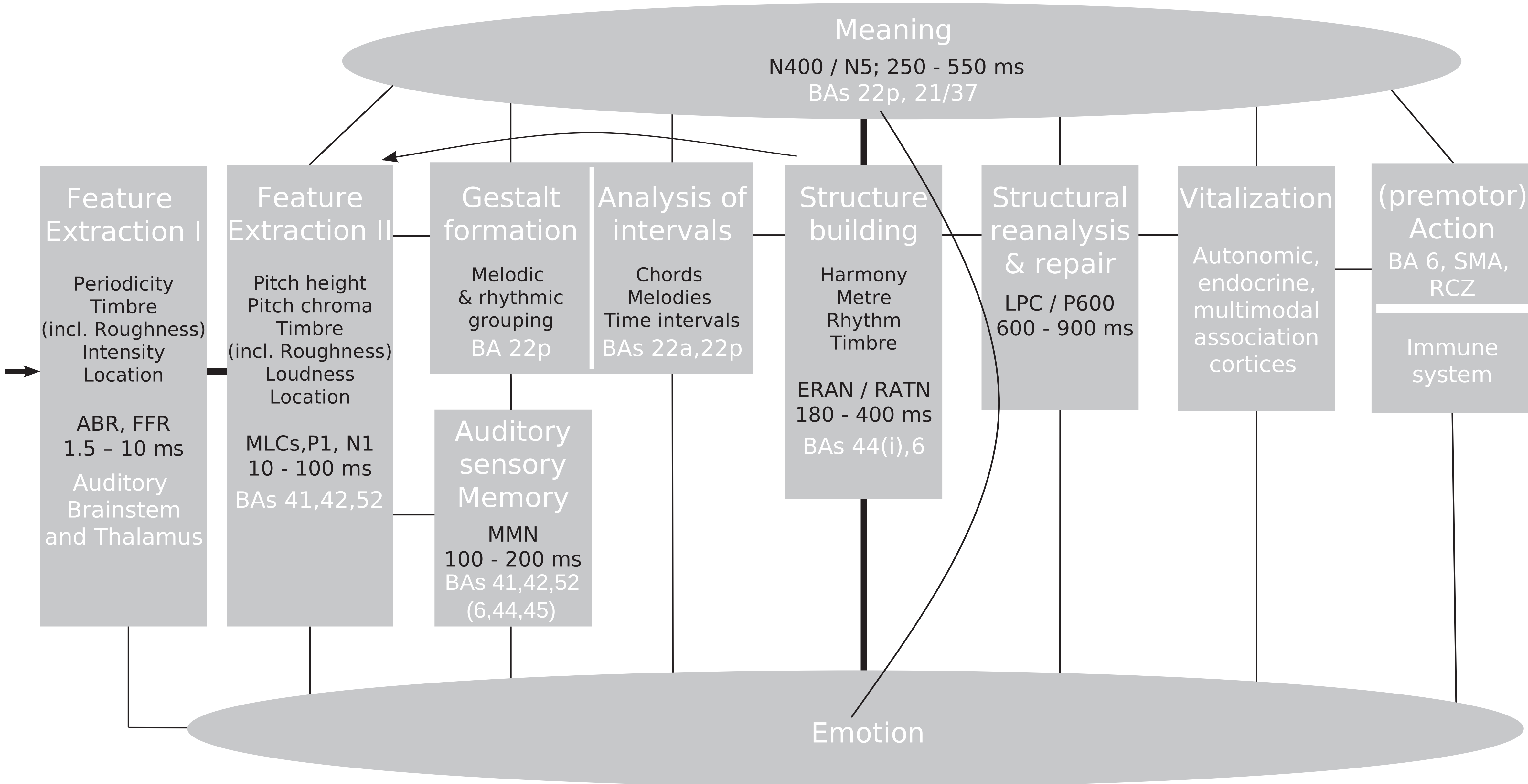


FIGURE 1 | Neurocognitive model of music perception. ABR, auditory brainstem response; BA, Brodmann area; ERAN, early right anterior negativity; FFR, frequency-following response; LPC, late positive component; MLC, mid-latency component; MMN, mismatch negativity; RATN, right anterior-temporal negativity; RCZ, rostral cingulate zone; SMA, supplementary motor area. Italic font indicates peak latencies of scalp-recorded evoked potentials.

6.3. Stefan Koelsch (2011) An updated model of music perception based on EEG and MEG timing in milliseconds

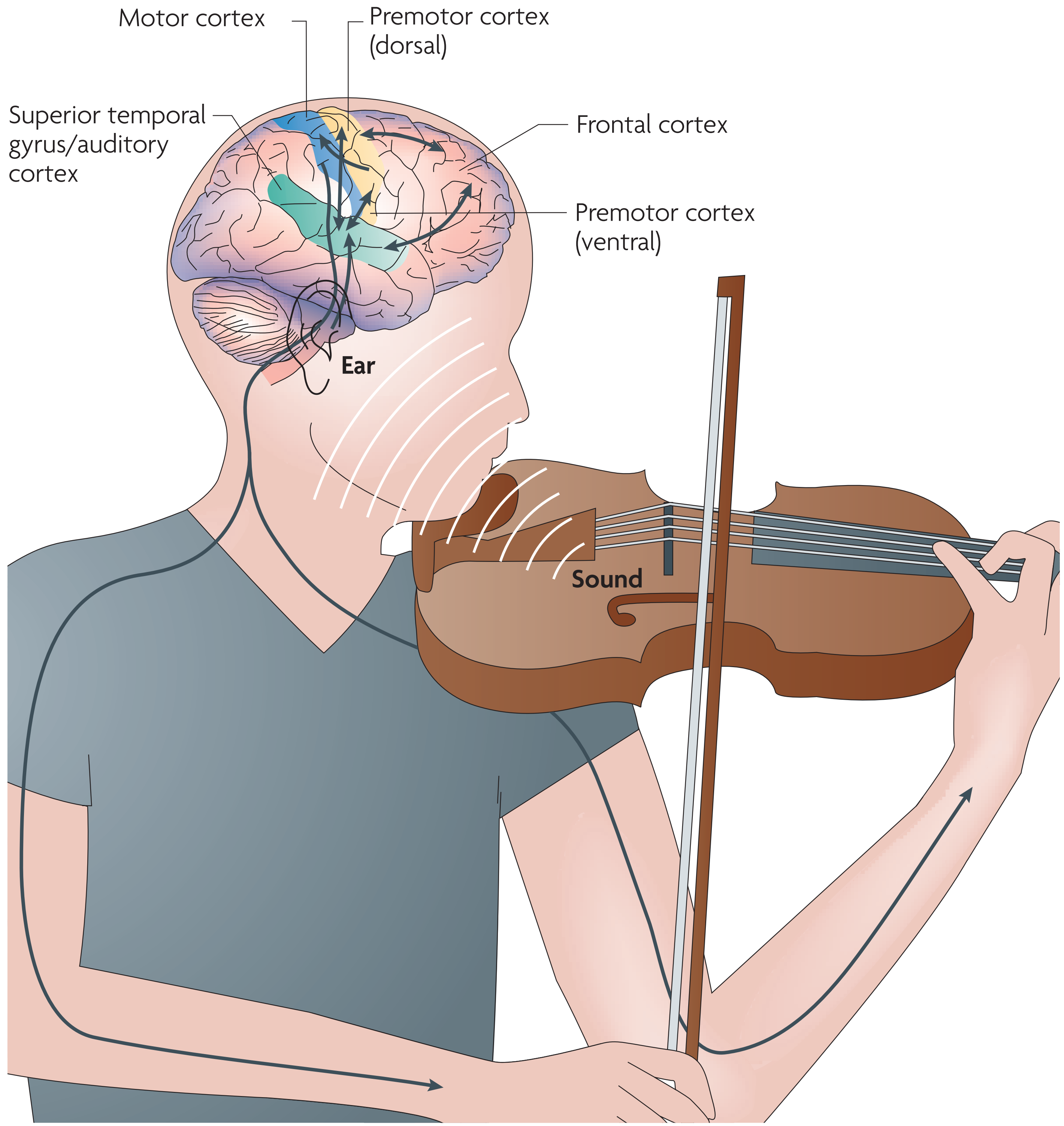
7. MUSIC and the CORTEX

48

7.1. Connections between the auditory and motor functions in the cortex

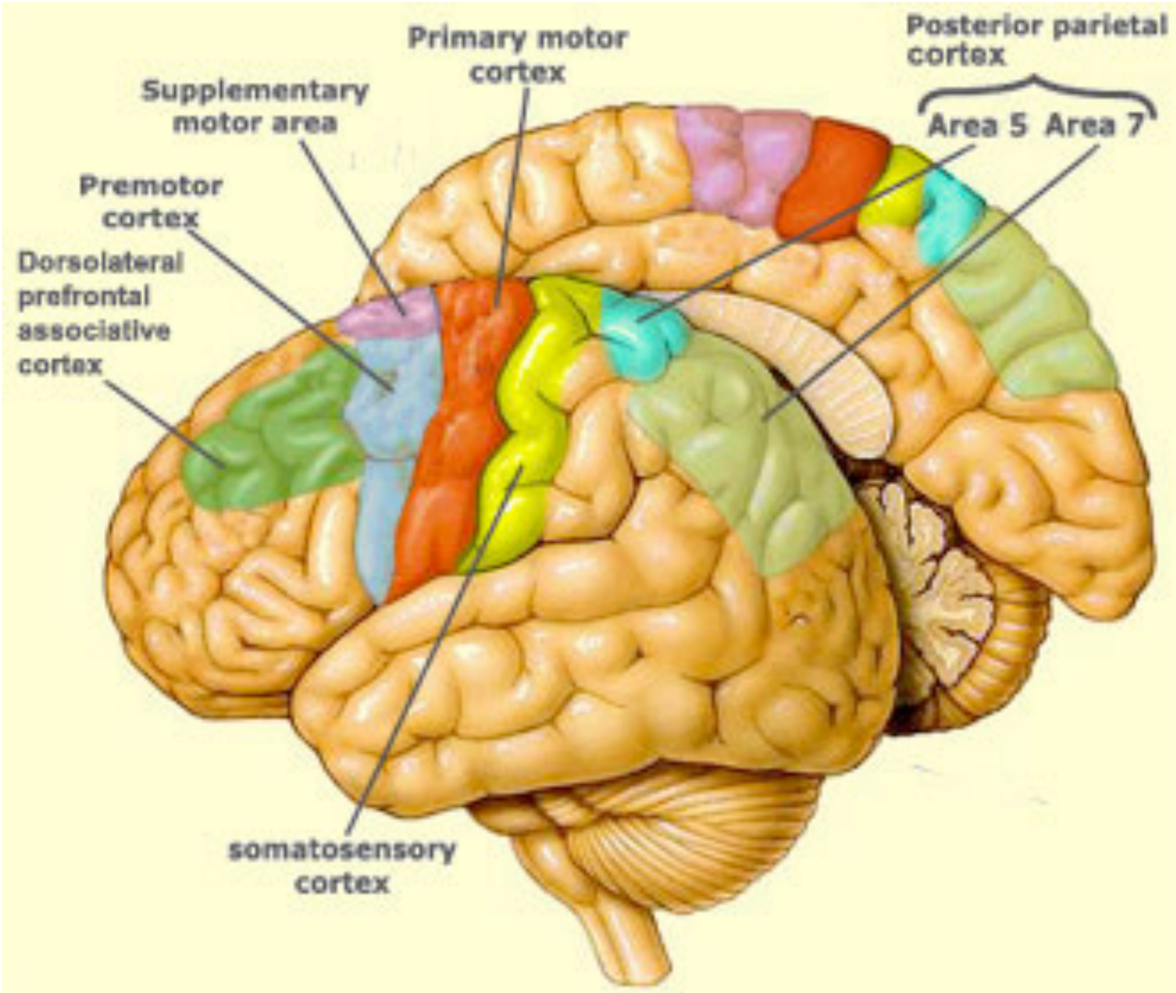
49

7.2. Music performance activates the auditory and motor cortices



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

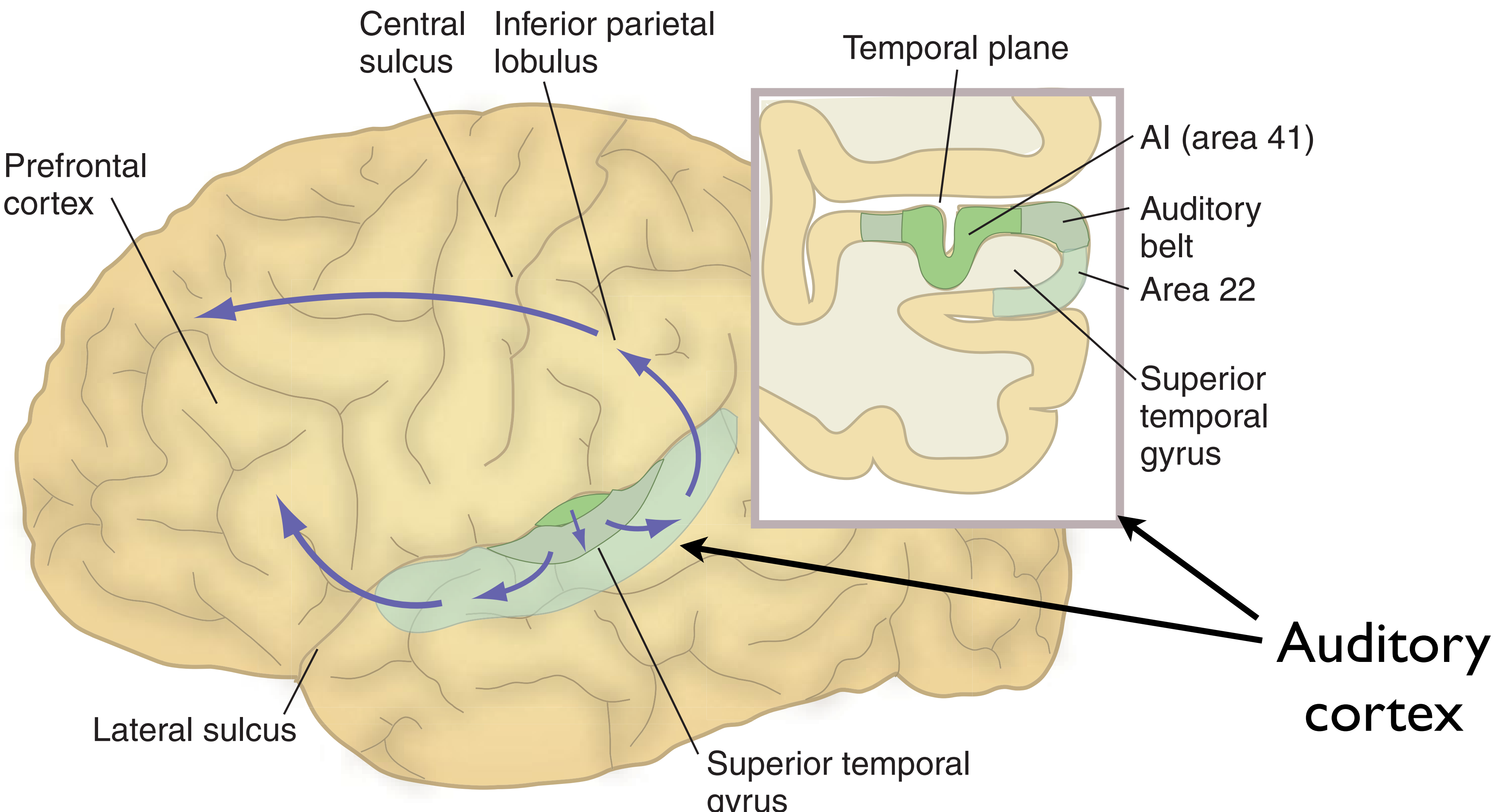
7.4. Melody and timbre:

Distinct pathways for

Sound MOVEMENT and Sound IDENTIFICATION

52

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



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

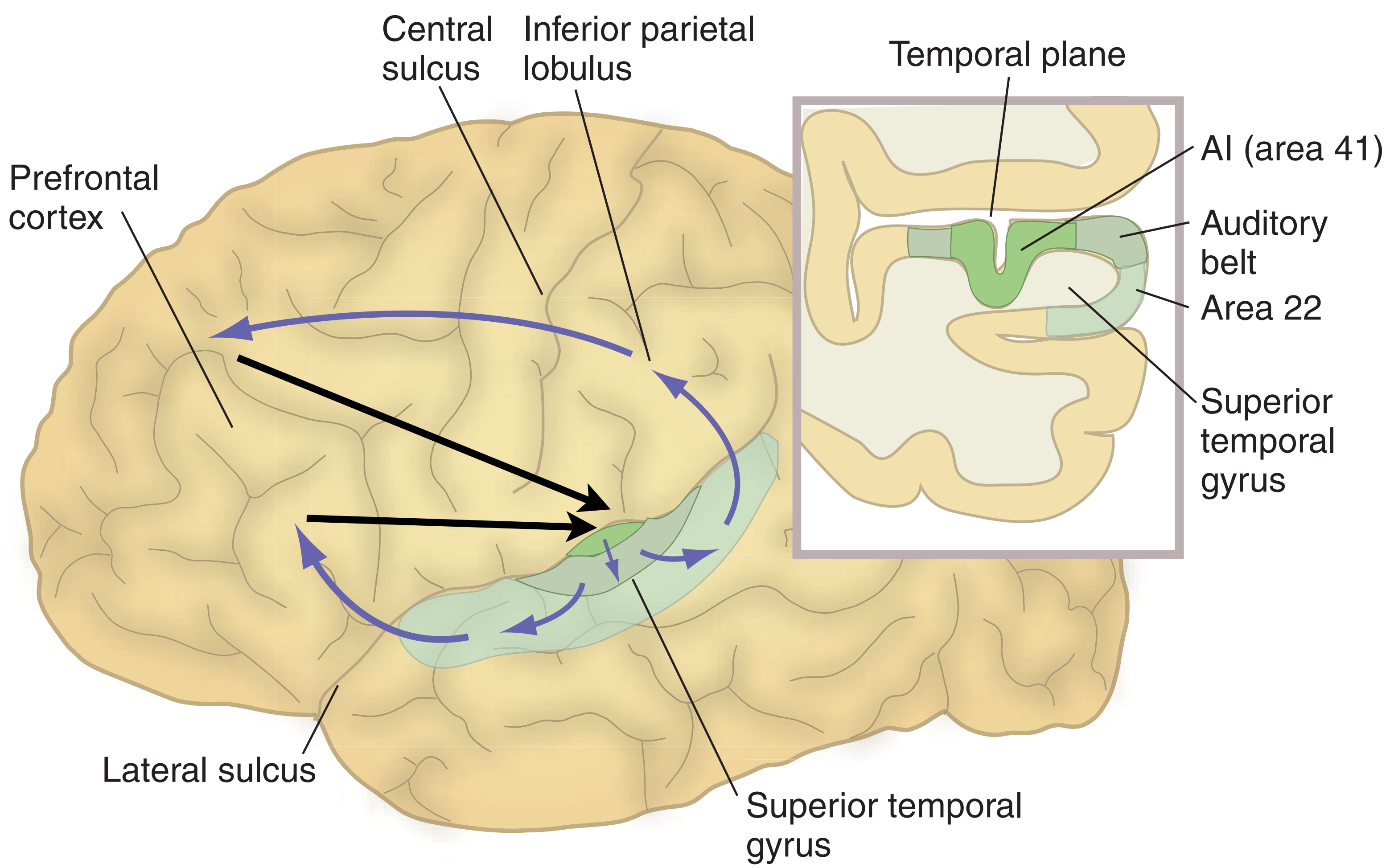
Music - Arvo Pärt: Spiegel im Spiegel

7.6. Musical memory
"The tune that runs through your head"

Edelman & Tononi 2000: 97-99; Damasio 2010: 130-153

54

7.7. "The tune that runs through your head"



Probable interactions between the frontal cortex and the auditory cortex (Zatorre & Halpern 2005)

55

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

57

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/

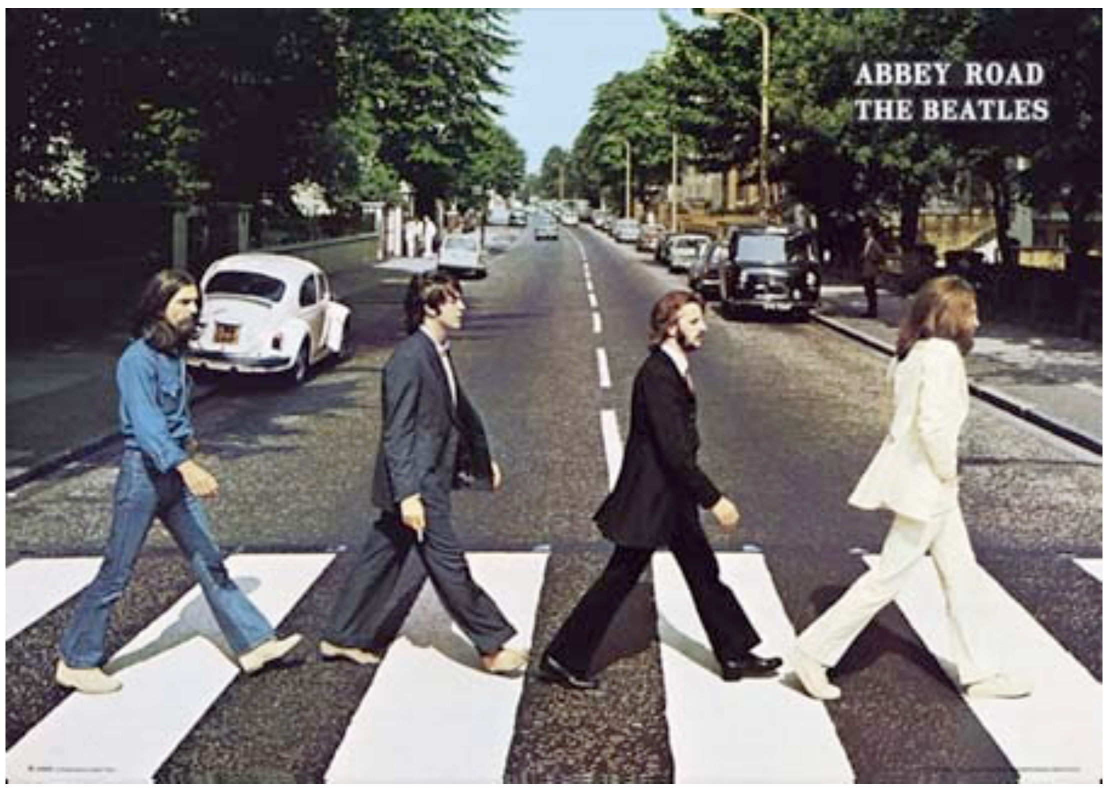
8.4. The Neurochemistry of Music

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

62

9.2. Alluri et al. (2013): PROCEDURE
- similar to Alluri et al. (2012)

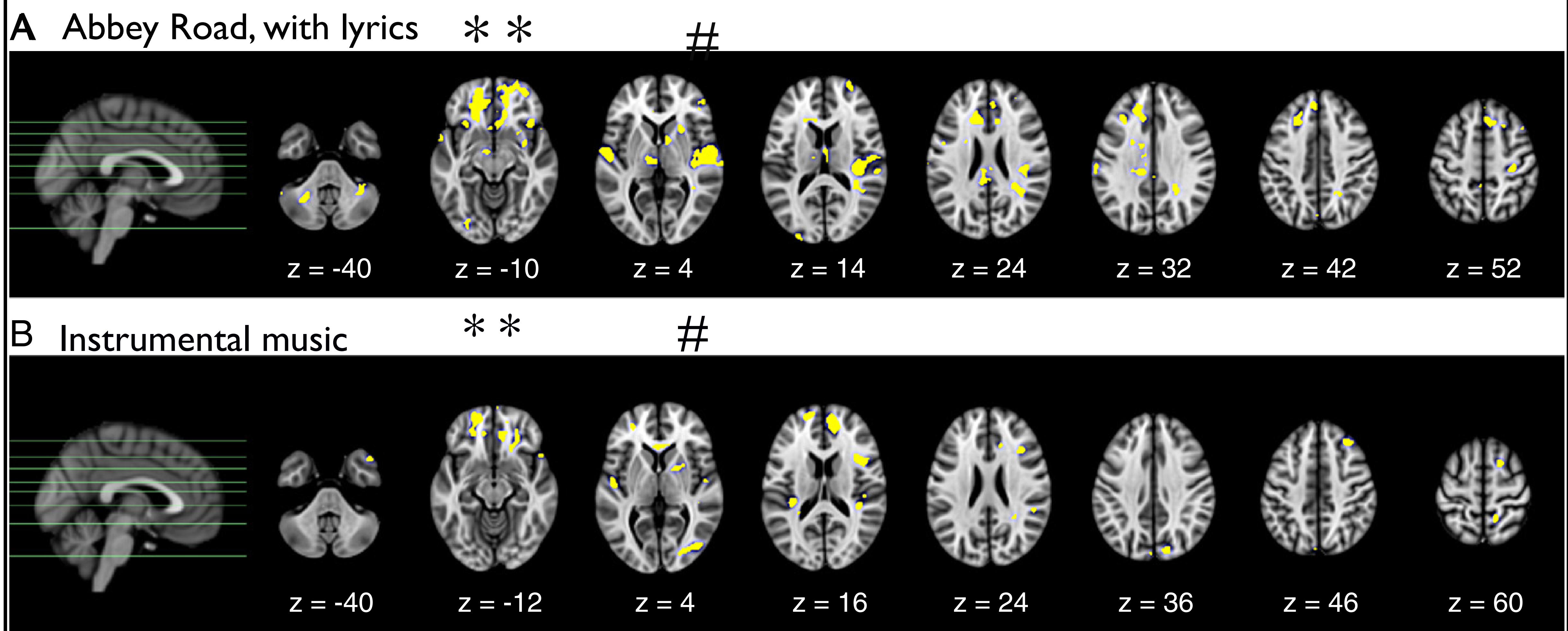
1. Extraction of principal acoustic musical components by means of computer analysis (Music Information Retrieval)

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

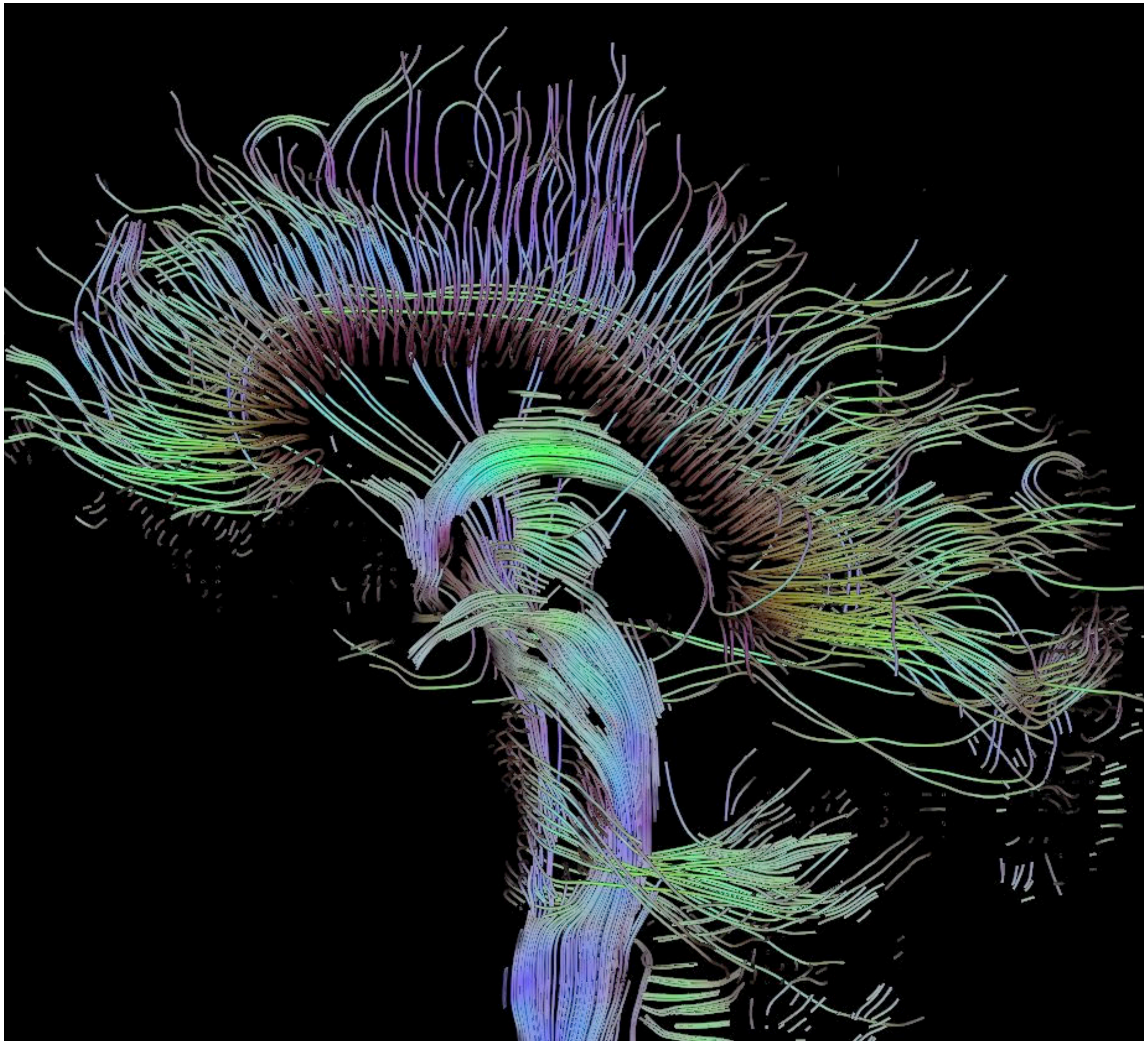


Two of the results:

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

Christensen, E. (2012). *Music Listening, Music Therapy, Phenomenology and Neuroscience*. PhD Thesis, Aalborg University. Available at http://www.mt-phd.aau.dk/phd-theses/
Damasio, A. (1999). *The Feeling of What Happens*.
Damasio, A. (2010). *Self Comes to Mind. Constructing the Conscious Brain.*
Daniels Beck, B. (2012). *Guided Imagery and Music (GIM) with adults on sick leave suffering from work-related stress*. PhD Thesis, Aalborg University. Available at http://www.mt-phd.aau.dk/phd-theses/
Edelman, G.M. & Tononi, G. (2000). *A Universe of Consciousnss.*
Gazzaniga, M. (Ed. 1995). *The Cognitive Neurosciences*. First edition.
Hald, S. (2012) *Music Therapy, Acquired Brain Injury and Interpersonal Communication Competencies*. PhD Thesis, Aalborg University. Available at http://www.mt-phd.aau.dk/phd-theses/
Koelsch, S. (2012). *Brain and Music*.
Kringelbach, M.L. & Berridge, K.C. (2010). *Pleasures of the Brain.*
Levitin, D. (2006). *This is your Brain on Music*.
MacDonald, R.A.R. et al. (Eds. 2012). *Music, Health, and Wellbeing.*
Malloch, S. & Trevarthen, C. (Eds. 2009). *Communicative Musicality.*
Panksepp, J. (1998). *Affective Neuroscience*.
Pfaff, D.W. (2006). *Brain Arousal and Information Theory. Neural and Genetic Mechanisms*.

References: Articles and book chapters

Alluri, V., Toiviainen, P., Jääskeläinen, I.P., Glerean, E., Sams, M. & Brattico, E. (2012). Large-scale brain networks emerge from dynamic processing of musical timbre, key and rhythm. *NeuroImage* 59, 3677– 3689.

Alluri, V. et al. (2013). From Vivaldi to Beatles and back: Predicting lateralized brain responses to music. *NeuroImage* 83, 627-636.

Altenmüller, E. & Schlaug, G. (2012). Music, Brain, and Health: Biological Foundations of Music's Health Effects. In MacDonald, R.A.R. et al. (Eds.) *Music, Health, and Wellbeing,* 12-24.

Blood, A.J. & Zatorre, R.J. (2001). Intensely pleasurable responses to music correlate with activity in brain regions implicated in reward and emotion. *PNAS* 98 (20), 118118-11923.

Chanda, M.L. & Levitin, D.J. (2013). The neurochemistry of music. *Trends in Cognitive Sciences* 17(4), 179-193.

Christensen, E. (2000): Music Precedes Language. *Nordic Journal of Music Therapy* 9 (2), 32-35.

Grahn, J.A. & Brett, M. (2007). Rhythm and Beat Perception in Motor Areas of the Brain. *Journal of Cognitive Neuroscience* 19 (5), 893–906.

Grahn, J.A. & Rowe, J.B. (2009). Feeling the Beat: Premotor and Striatal Interactions in Musicians and Nonmusicians during Beat Perception. *The Journal of Neuroscience* 29 (23), 7540 –7548.

Grewe, O., Kopiez, R., & Altenmüller, E. (2009). The Chill Parameter: Goose Bumps and Shivers as Promising Measures in Emotion Research. *Music Perception* 27 (1), 61-74.

Huang, C. et al. (1982). Projections from the Cochlear Nucleus to the Cerebellum. *Brain Research* 244, 1-8.

Janata, P. & Grafton, S.T. (2003). Swinging in the Brain: shared neural substrates for behaviors related to sequencing and music. *Nature Neuroscience* 6 (7), 682-687.

Koelsch, S. (2009). A Neuroscientific Perspective on Music Therapy. *Annals of the New York Academy of Sciences* 1169: 374–384.

Koelsch, S. (2010). Towards a neural basis of music-evoked emotions. *Trends in Cognitive Sciences* 14 (3),131-137.

Koelsch, S. (2011). Toward a neural basis of music peception - a review and updated model. *Frontiers in Psychology* Vol. 2, Article 110, 1-20.

Koelsch, S. & Stegemann, T. (2012). The Brain and Positive Biological Effects in Healthy and Clinical Populations. In MacDonald, R.A.R., Kreutz, G. & Mitchell, L. (Eds.) *Music, Health, and Wellbeing*. Oxford: Oxford University Press, 436-456.

Kraus et al. (2009). Experience-induced Malleability in Neural encoding of Pitch, Timbre, and Timing. *Annals of the New York Academy of Sciences* 1169, 543-557.

Kringelbach, M.L. et al. (2012). The functional neuroanatomy of food pleasure cycles. *Physiology and Behavior* 106, 307-316.

Menon, V. & Levitin, D.J. (2005). The rewards of music listening: Response and physiological connectivity of the mesolimbic system. *NeuroImage* 28,175-184.

Panksepp, J. (1995) The Emotional Sources of "Chills" Induced by Music. *Music Perception* 13 (2),171-207.

Panksepp, J. & Trevarthen, C. (2009). The neuroscience of emotion in music. In Malloch, S. & Trevarthen, C. (Eds.) *Communicative Musicality,* 105-126.

Petacchi, A. et al. (2005). Cerebellum and Auditory Function: An ALE Meta-Analysis of Functional Neuroimaging Studies. *Human Brain Mapping* 25:118 –128

Salimpoor. V.N. et al. (2009). The Rewarding Aspects of Music Listening Are Related to Degree of Emotional Arousal. *PLoS ONE* 4(10). e7487. doi:10.1371/journal.pone.0007487

Salimpoor, V.N. et al. (2011). Anatomically distinct dopamine release during anticipation and experience of peak emotion to music. *Nature Neuroscience* 14 (2), 257-264.

Schmahmann, J.D. (2010). The Role of the Cerebellum in Cognition and Emotion. *Neuropsychology Review* 20:236–260.

Sens, P.M. & Ribeira de Almeida, C.I. (2007). Participation of the Cerebellum in Auditory Processing. *Revista Brasileira de Otorrinolaringologia* 73 (2), 266-270.

Stein, B.E. et al. (1995). Neural Mechanisms Mediating Attention and Orientation to Multisensory Cues. In Gazzaniga, M. (Ed. 1995). *The Cognitive Neurosciences*. First edition, 683-702.

Särkämö, T. et al. (2008). Music listening enhances cognitive recovery and mood after middle cerebral artery stroke. *Brain* 131, 866-876.

Thaut, M. H. (2010). Neurologic Music Therapy in Cognitive Rehabilitation. *Music Perception* 27 (4), 281-285.

Thaut, M.H. & Abiru, M. (2010). Rhythmic Auditory Stimulation in Rehabilitation of Movement Disorders. *Music Perception* 27 (4), 263-269.

Witek, M. (2009). Groove Experience: Emotional and Physiological Responses to Groove-Based Music. *Proceedings of ESCOM 2009*, University of Jyväskylä, Finland, 573-582.
Retrieved 29 July 2012 from https://jyx.jyu.fi/dspace/handle/123456789/20138

Zatorre. R.J. (2005). Music, the food of neuroscience? *Nature* 434, 312-315.

Zatorre, R.J., & Halpern, A. (2005). Mental Concerts: Musical Imagery and Auditory Cortex. *Neuron* 47, 9-12.

Zatorre, R.J. et al. (2007). When the brain plays music: auditory-motor interactions in music perception and production. *Nature Reviews Neuroscience* 8 (4), 494-521.