Instrumental Music Memory and the Cerebellum

Scientific advancements and functional viewpoints regarding music memory, performance, cognition and creativity

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Cerebellum Function

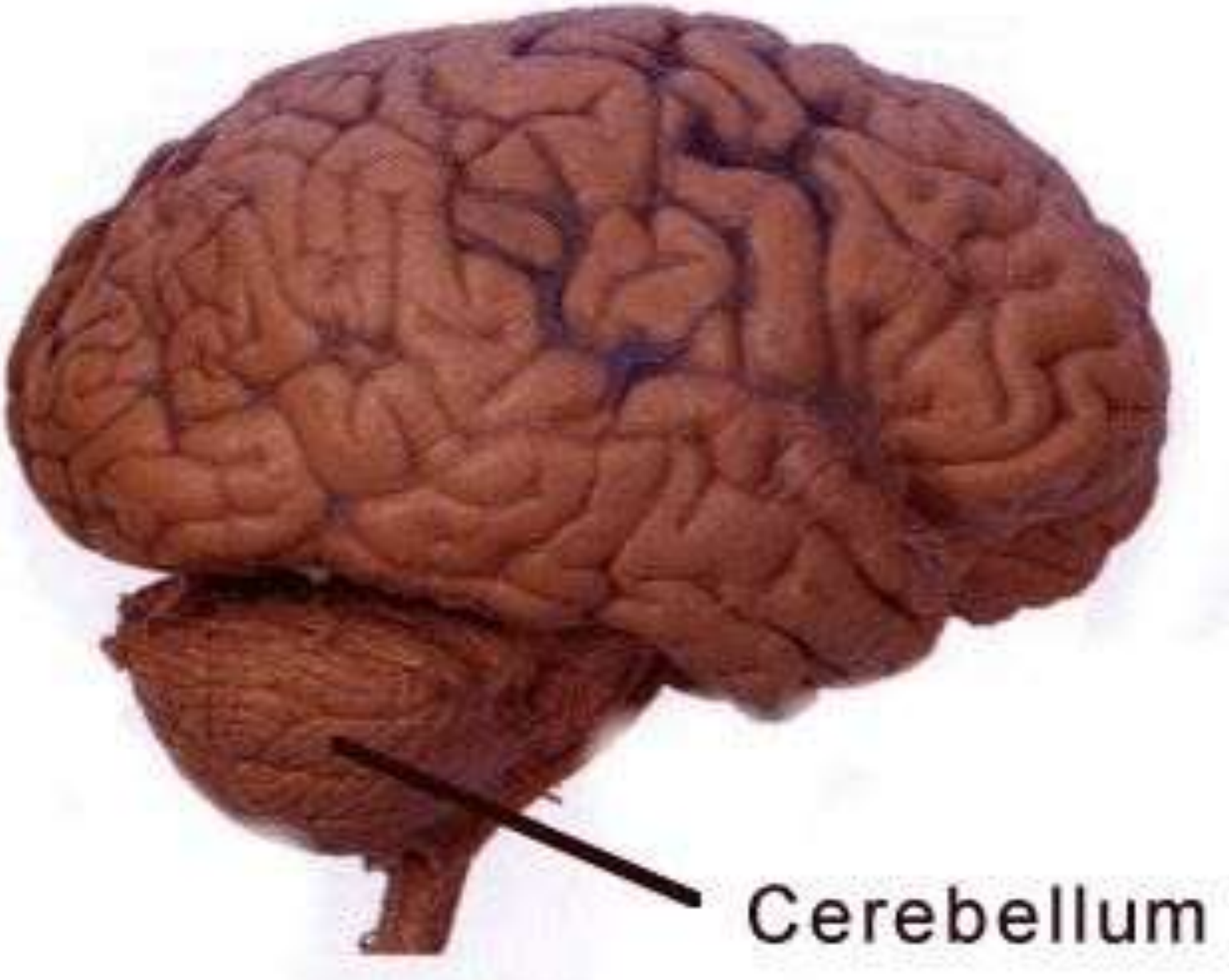
- Turns motor intent into action
- Acquisition, consolidation, motor memory storage
- Determines quality of a performance
- Nonconscious proprioception

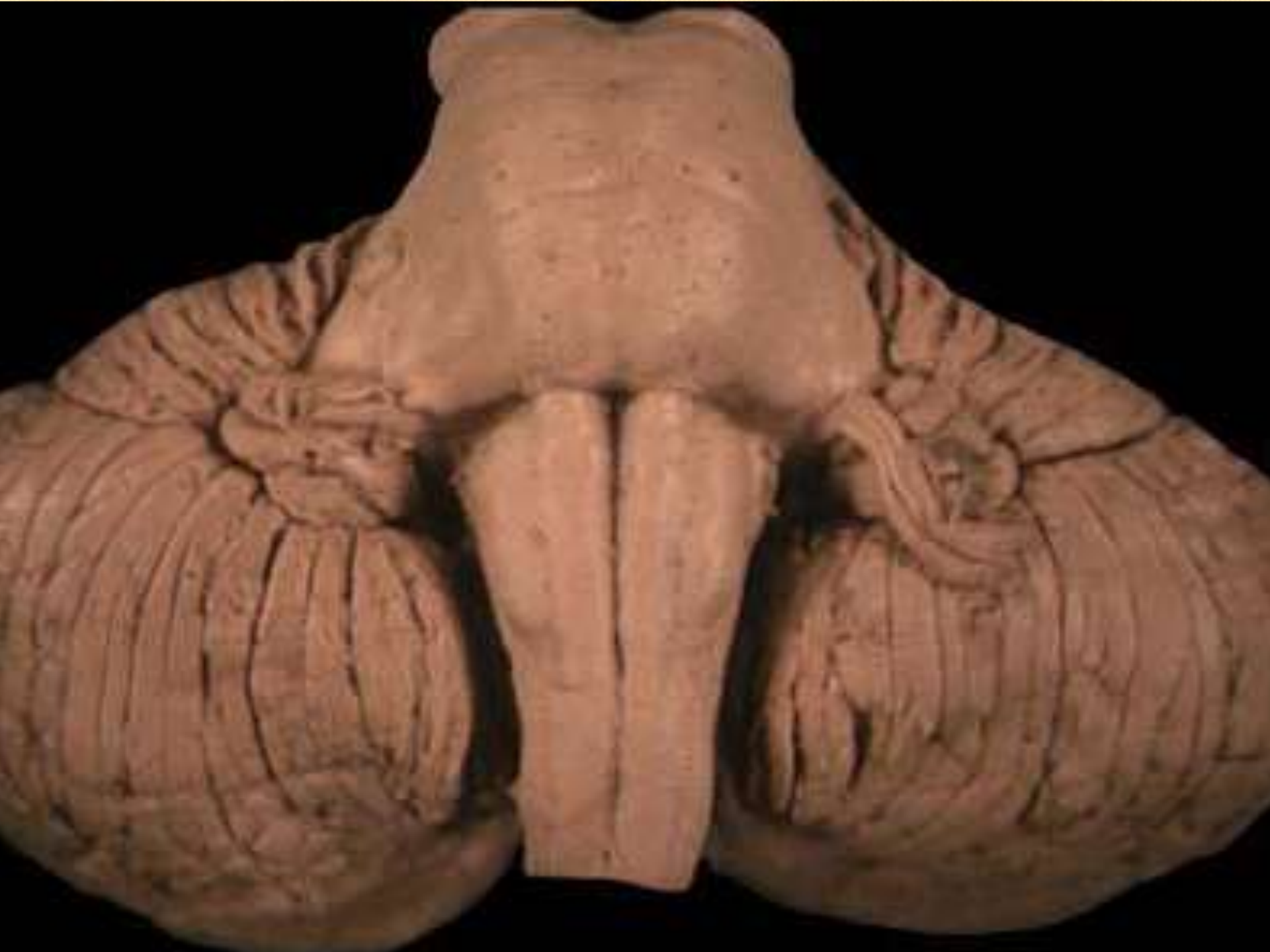
Cerebellar Evolution

- Fossil endocasts - functionally ambiguous
- Posterior cranial fossa (cerebellum housing) - ontologically discrete
- Neo-Cortex was larger until Holocene pd. 10-12tya, current neuronal mix 50/50
- However, CB only 10% of total brain weight – neuronal / functional reorganization
- Volume vs Mass
- CB evolved to facilitate human ability to cope w/ increasingly complex cultural and conceptual environment – use of tools, harvesting, rituals, ++ stimulation, language, music, stylized life

Cerebellum
Reciprocal Connections

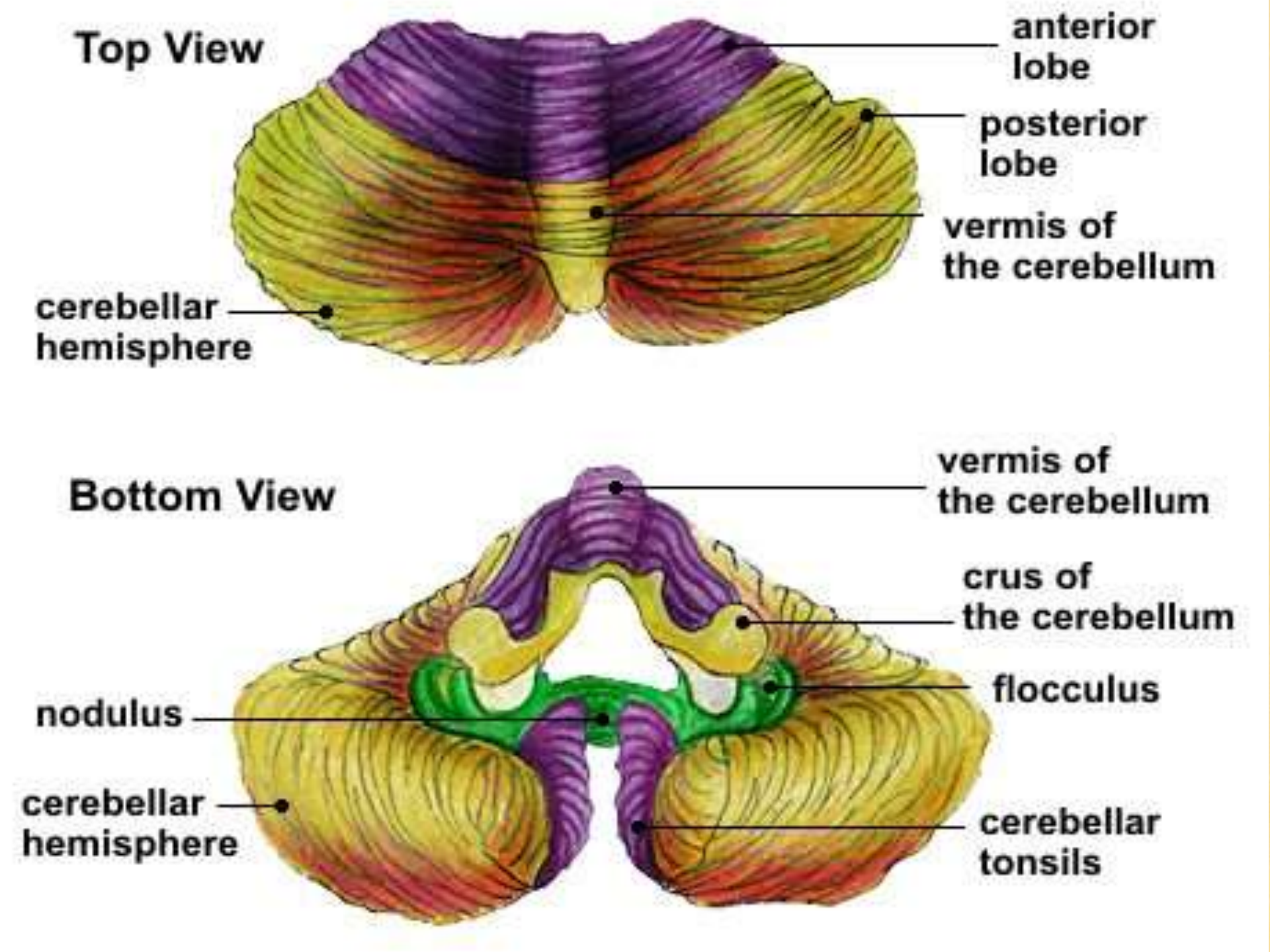
- Reciprocally connected to 14 neocortical regions (through thalmus)
- Parietal cortex - Areas 5.7.39.40 (hand movements, motor planning; verbal processing; spatial navagation)
- Temporal cortex – Areas 22.37 (cognitive / articulation of language)
- Frontal/ prefrontal – Areas 8.9.10.44.45 (language functions, working memory, directed attention, cognitive planning)
- Occipital cortex – Areas 17.18.19 (visual processing)
- Ipsilateral Motor System of body

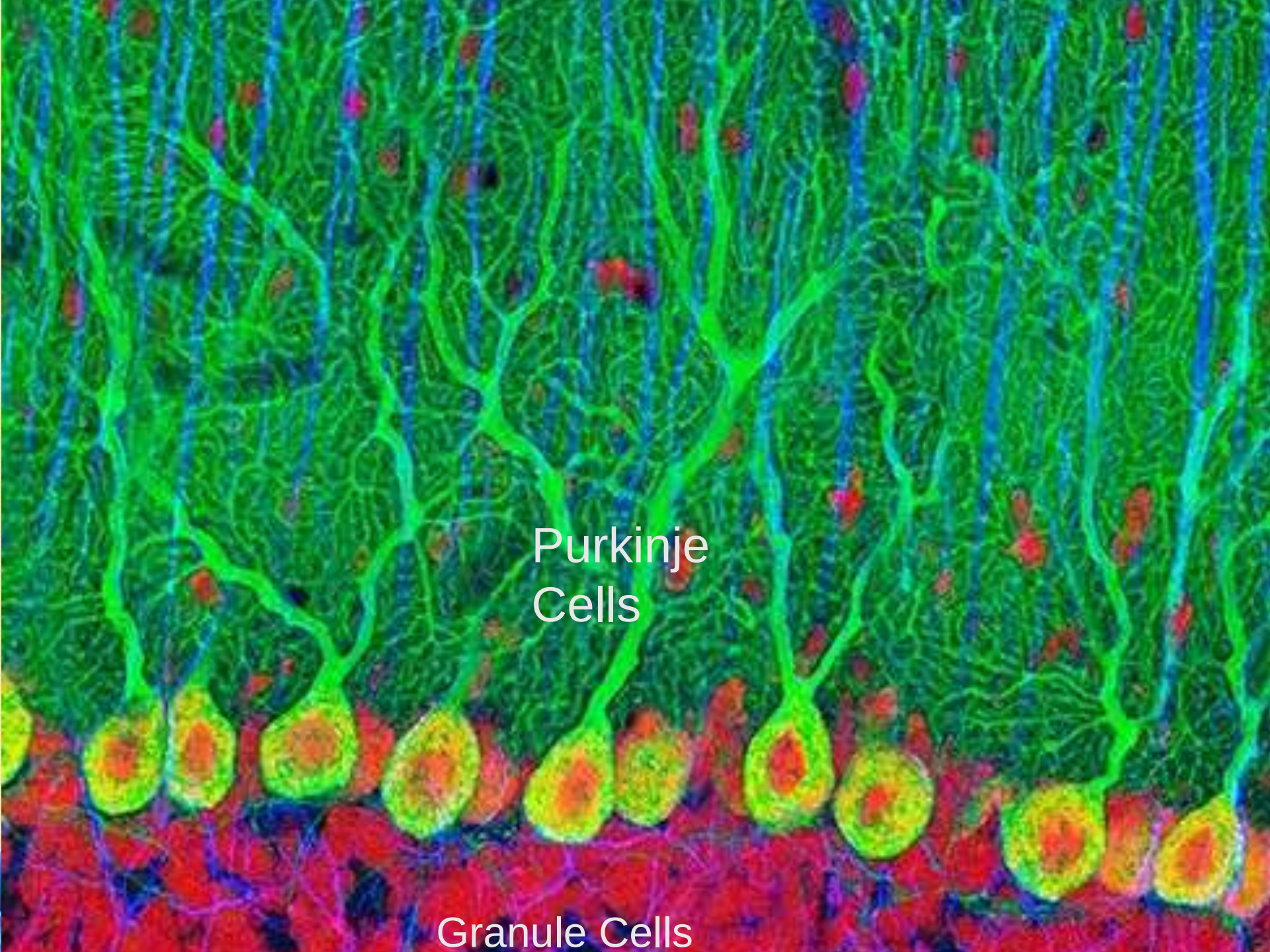

Cerebellum



3 Lobes – (10 Lobules)

- Anterior lobe – control of trunk and limbs (lobules I-V)
- Posterior lobe – Mov't and planning, non-motor functions (lobules VI-IX)
- Flocculonodular lobe – balance, controlling eye mov't (lobule X)


Top View
anterior lobe
posterior lobe
vermis of the cerebellum
cerebellar hemisphere
Bottom View
vermis of the cerebellum
crus of the cerebellum
flocculus
nodulus
cerebellar hemisphere
cerebellar tonsils


Purkinje
Cells
Granule Cells

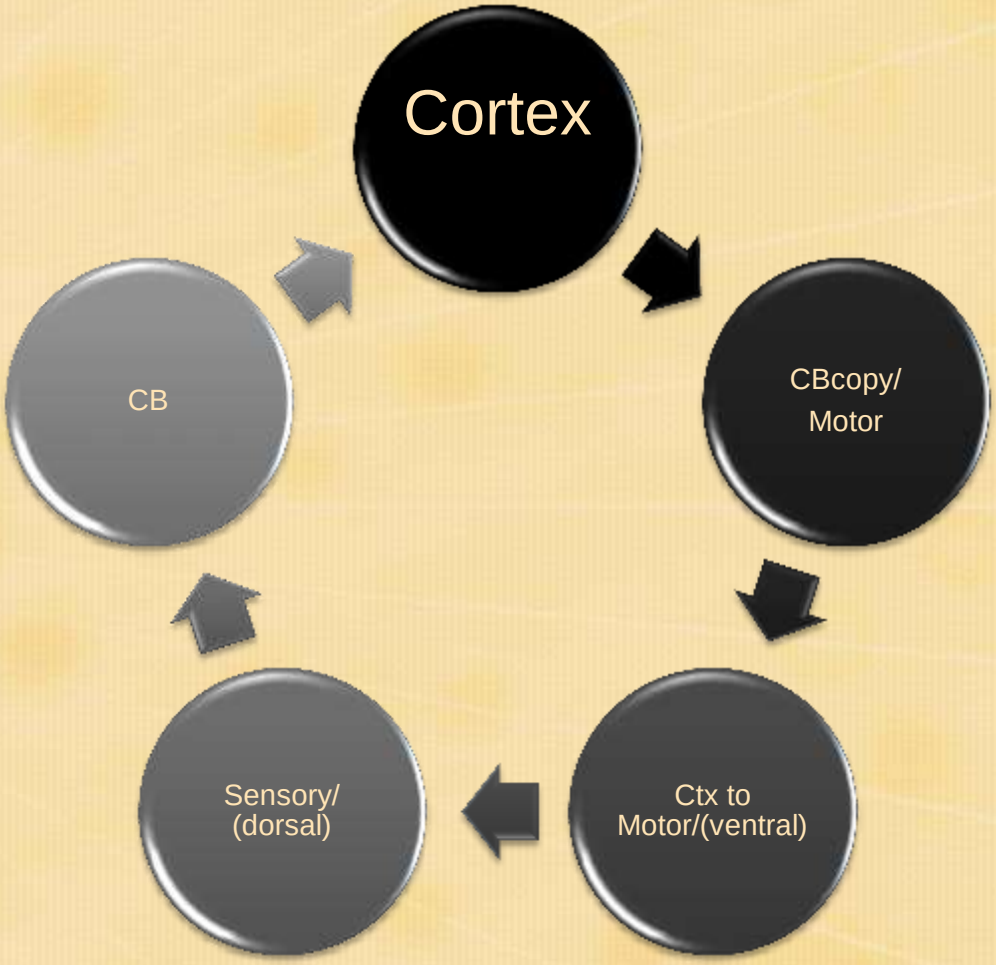
Cerebellum Motor Components

- Scientifically established
- GABAergic = mostly inhibition
- Leads to optimal evolutionary function via implicit events/ storage
- Enhance / sharpen precise timings
- Smooth control of rapid, stereotyped responses (motor, cognitive, visual)
- Implicit, algorithmic, “rule-based”
- Frequency and intensity of music practice correlate with increased cerebellar volume

Cerebellar (loop) Circuitry

- Gets motor instructions (copy) from neocortex, (waits) and then
- Receives sensory input from spinal cord dorsal column
- Analyzes movement – instructs for correction
- Neocortex then adjusts and loop continues
- Loop = Neocortex – spinal cord (ventral) – muscles – sensory / vestibular receptors – spinal cord (dorsal) – CB cortex - NCtx

Cerebellar loop



Cerebellum Summary 1

- Evolving declarative multiplicity taxed neocortex to limit
- Reciprocal connections dev't in response to environmental (and cultural demands)
- Increased foraging, ++ cultural objects, behaviorally complex routines (self adornment, burial of dead, music/dance)
- CB evolved for complexity management
- Secondary CB evolutionary expansion led to ++ efficiency w/o brain volume increase

Cerebellum
Music and Brain plasticity

- 10,000h “rule” – but what kind of hours?
- Much time spent with “unwanted practice effects” – getting out of CB’s way
- Use dependent brain plasticity
- Tendency to still use neocortex to control = “primitive” use of brain
- “Omega sign”/ plasticity pianists v violinists
- 6 yr olds – 16 mos training CC & Au Ctx
- Adults 3+ yrs for results incl transferability
- Q. Why does it look so easy? A. It is easy.

Pianists (who actually practice)

- Higher integrity of white fiber system, esp CC (via Fractional Anisotropy/ FA reading)
- Increased volume in Heschl's gyrus
- 100% + neurophysiological activity in primary auditory cortex (PAC)
- Chord analysis (music) = ++ PAC and rh Heschl's for fundamental/ spectral pitches
- No age related volume loss in Broca's
- Mental rotation activation in Broca's area for musicians only

What Musicians Say (and what scientists say) on Music and Memorizing…..

- Play music immediately before sleep (Consolidation) and replay in morning
- Slow playing (i.e. one note per second) for brain to process between notes (CB inhibition)
- Take frequent breaks (Oxygenation)
- Memorize hands separately then together (Bilateral consolidation process)
- Withdraw to muscle memory (CB Loop)
- Exercise, happiness, overall well-being (Oxygenation, Multiplicity of Brain Usage)

Music and Memory (cont.)

- Watch your hands as you play (striatal visual cue based learning)
- Always memorize the dynamics and articulations as you play (spatial-acoustic perception/ processing)
- Use consistent fingering (motor recall)
- Memorize in small sections (Hippocampal)
- Analyze the music (Prefrontal Cortex)
- Designate various, random restart points (working memory - PFC)
- Practice mentally - no piano (Temporal)

Cerebellar Lesions

Motor issues : limbs: prone/ supination, vestibular/balance, visual/ nystagmus

Cognitive affect syndrome

- Executive function (planning behaviors)
- Abstract reasoning
- Visuospatial
- Personality changes (blunting of affect)

(Motor = anterior lobe. Cognitive = mainly posterior lobe and vermis lesions)

Ergo… activated CB in musicians may activate engagement of above behaviors

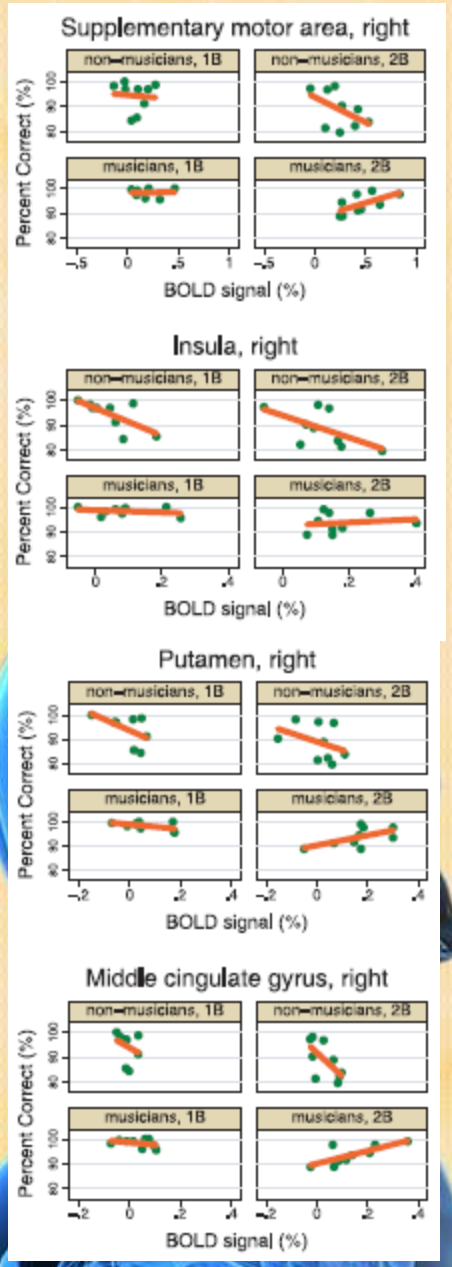
Learning sound sequences and motor sequence consolidation

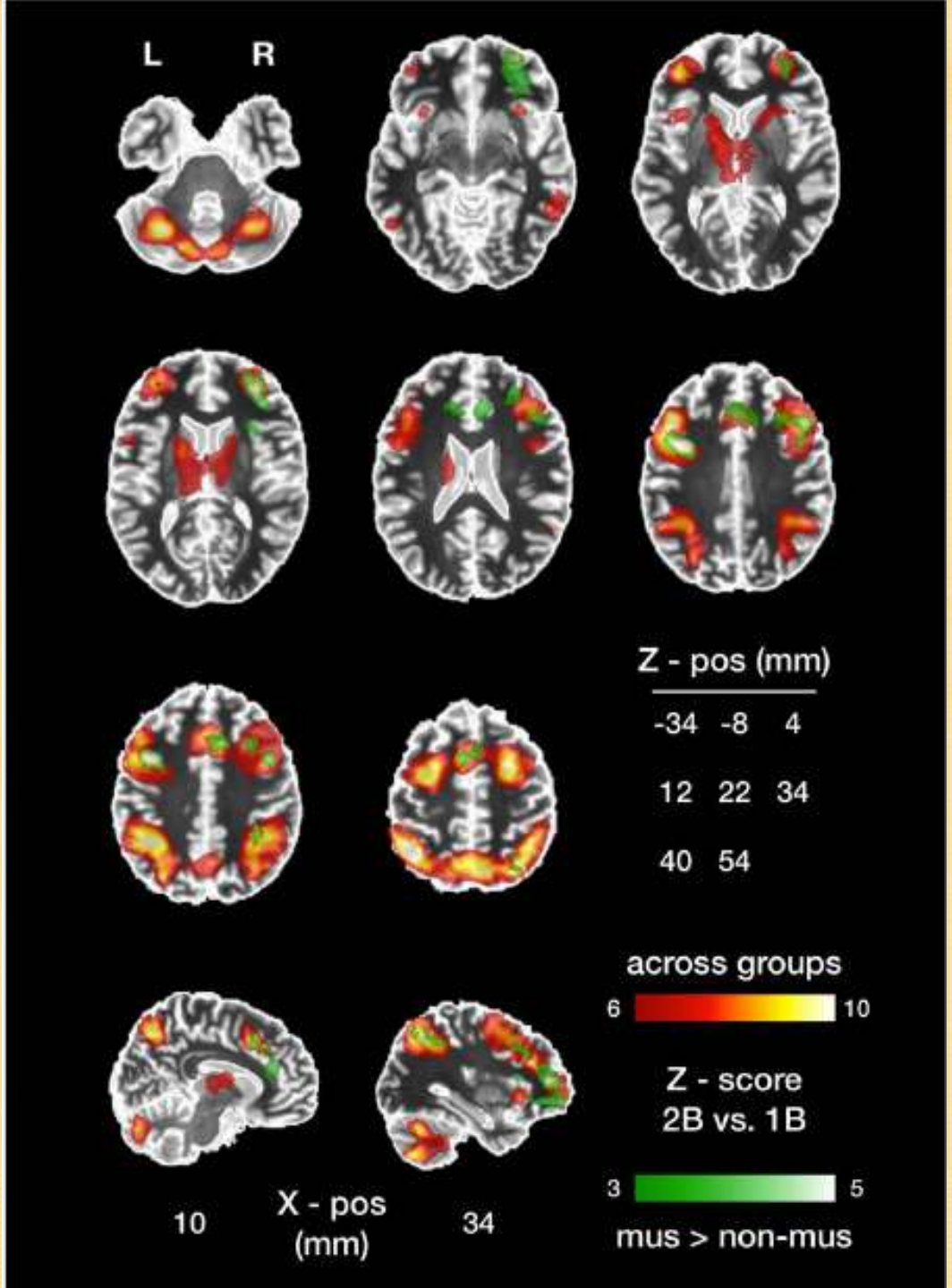
Perception and delivery of familiar music (in patients with Cerebellar lesions) use the following brain areas:

- Parahippocampal gyrus (PHG)
- Posterior cingulate cortex (PCC)
- Inferior parietal lobule (IPL)
- Medial temporal lobe (MTL)

(*Priming test used tonic or non-tonic end ‘di or du’ point of familiar musical phrases – not complex)

Tillman et al, 2007


Supplementary motor area, right
non−musicians, 1B
non−musicians, 2B
musicians, 1B
musicians, 2B
Percent Correct (%)
BOLD signal (%)
Insula, right
non−musicians, 1B
non−musicians, 2B
musicians, 1B
musicians, 2B
Percent Correct (%)
BOLD signal (%)
Putamen, right
non−musicians, 1B
non−musicians, 2B
musicians, 1B
musicians, 2B
Percent Correct (%)
BOLD signal (%)
Middle cingulate gyrus, right
non−musicians, 1B
non−musicians, 2B
musicians, 1B
musicians, 2B
Percent Correct (%)
BOLD signal (%)


L
R
Z - pos (mm)
-34 -8 4
12 22 34
40 54
across groups
6
10
Z - score
2B vs. 1B
3
5
mus > non-mus
10
X - pos
(mm)
34

CB lesion results

- Interesting – 97% CB pts vs 88% controls
- 2 controls (%64 & %67) found task difficult
- FL trying to control understanding of music (First year of music studies – could not hear sections/ architecture of music– trying to control – conflicts with CB doing job)
- Conflicts with CBs job at assisting process
- Ergo, if you delete CB position, FL works solo again (CB pts ++ scores)
- Back to square one (Cro Magnon) = no CB and limited FL abilities (pass simple test)

Cerebellum Summary 2

Musicians and + CB use = potential for ++ enhanced cognitive arenas in:

- Attention
- Planning
- Memory
- Self-discipline
- Overall executive functions
- Parallel (and Mastermind) imprinting
- Parallel task/disposition acquisition/ enhancement – “transference plasticity”

Music and the Cerebellum ~ Anticipating (familiar) sound

- Importance of fronto-striatal connections, consistent with a role of the basal ganglia in “training” frontal cortex
- Anticipatory imagery (in silence) for highly familiar music - accompanied by ++ activity in rostral prefrontal cortex (PFC) and premotor areas
- Training occurs in caudal to rostral
- Once in rostral, recall not necessarily dependent on CB
- Implicit stored AFTER CB processing

Leaver et al, 2009

Beyond Motor ~ Cerebellum Cognitive Control

Areas involved (Right Hemisphere)

- Lateral prefrontal cortex
- Lateral parietal cortex,
- Insula
- Putamen in the right hemisphere,

Bilaterally:

- Posterior dorsal prefrontal cortex
- Anterior cingulate gyrus

Pallesen et al, 2010

Vocal - Cognitive / Cerebellum

- Heavy Conceptualizing/ Imagery
- Internalizing of rhythm
- Muscular identifying with resonance
- Different muscle groups than instrumental
- Respiratory-based
- Brain stimulation via resonance
- Specific cognitive journey vs piano/ more architectural
- May use CB to ultimate extent – core muscles – is “universal language”

Instrumental / Keyboard
Q.Why it looks easy? A.It is easy.

- Commit to process
- Do not rush initial “beats” in motor acqusition
- Allow CB inhibition to occur
- Stay oxygenated
- Relax, minimal FL control
- Music/ instrument eventually “plays itself”
- Difficult to reprogram tense habits from initial FL over-control/ micromanagement
- 45 minutes 3x per week

Music Memory and the Cerebellum ~ Conclusion

- PFC needed to initiate process
- CB then teaches PFC via BG
- Implicit motor actions via CB lessen Ctx burden
- Caudal to Rostal (PCC to ACC) of frontal involvement – CB to frontal
- Latter then stores product - enabling CB independence of musical memory
- ACC (final destination) - relieves apathy
- Exact temporal progression and continuing reciprocity to be revealed

Leaver et al, 2009

Spontaneous Improvisation (and all that Jazz)

- Neural substrates of spontaneous performance
- Dissociated pattern of activity in the prefrontal cortex
- Deactivation of dorsolateral prefrontal and lateral orbital regions
- Activation of the medial prefrontal cortex

Limb and Braun, 2009

Music Improvisation (continued)

- stimulus-independent behaviors
- absence of central processes mediating self-monitoring and conscious control
- = widespread activation of neocortical sensorimotor areas mediating performance “organization” and execution
- deactivation of limbic structures regulating motivation and emotional tone
- system primed to let implicit motor sequences surface and CB works freely

Limb and Braun, 2009

My inspiration for this presentation….

(PiP ~ HAM_MMLayering)

Bach-Reger-Jacobs

Paul Jacobs (26), organist, Chair Juilliard Organ Dept. playing : **Max Reger - Phantasie über B-A-C-H, op.46**

- http://www.youtube.com/watch?v=-aR4YEDcXBI
- http://www.youtube.com/watch?v=_E7f00J0hDw
- http://www.youtube.com/watch?v=d-Sosw9UGis

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Brain Activation during Anticipation of Sound Sequences Amber M. Leaver,[1] Jennifer Van Lare,[1] Brandon Zielinski,[1] Andrea R. Halpern,[2] and Josef P. Rauschecker[1] (2009) [1]Laboratory of Integrative Neuroscience and Cognition, Department of Physiology and Biophysics, Georgetown University Medical Center, Washington, DC 20057, and [2]Psychology Department, Bucknell University, Lewisburg, Pennsylvania 17837 The Journal of Neuroscience, February 25, **2009**, 29(8):2477-2485; doi:10.1523/JNEUROSCI.4921-08

- **Music drives brain plasticity** Jäncke L. (2009) F1000 Biology Reports, 1:78 Division of Neuropsychology, Psychological Institute, University of Zurich, Binzmühlestrasse 14, 8050 Zürich, Switzerland F1000 Biology Reports, 1:78 (doi:10.3410/B1-78)

Neural Substrates of Spontaneous Musical Performance: An fMRI Study of Jazz Improvisation Limb CJ, Braun AR (2008) Neural Substrates of Spontaneous Musical Performance: An fMRI Study of Jazz Improvisation. PLoS ONE 3(2): e1679. doi:10.1371/journal.pone.0001679

Cognitive Control in Auditory Working Memory Is Enhanced in Musicians Karen Johanne Pallesen,1,2,3*¤ Elvira Brattico,4,5 Christopher J. Bailey,2,3 Antti Korvenoja,6 Juha Koivisto,1 Albert Gjedde,2,3¤ and Synnöve Carlson1,7,8 PLoS One. 2010; 5(6): e11120. Published online 2010 June 15. doi: 10.1371/journal.pone.0011120.PMCID: PMC2886055 1. Neuroscience Unit, Institute of Biomedicine/Physiology, University of Helsinki, Helsinki, Finland,

Cerebellar patients demonstrate preserved implicit knowledge of association strengths in musical sequences Barbara Tillmann,* Timothy Justus,** and Emmanuel Bigand*** Brain Cogn. 2008 March; 66(2): 161–167. Université Claude Bernard-Lyon, France

Reciprocal evolution of the cerebellum and neocortex in fossil humans Anne H. Weaver* (Santa Fe) Proc Natl Acad Sci U S A. 2005 March 8; 102(10): 3576–3580. Published online 2005 February 24. doi: 10.1073/pnas.0500692102.PMCID: PMC553338 The National Academy of Sciences Anthropology

Brain Cogn. 2008 March; 66(2): 161–167.
Published online 2007 September 18. doi: 10.1016/j.bandc.2007.07.005.PMCID: PMC2271057
NIHMSID: NIHMS41268

Cerebellar patients demonstrate preserved implicit knowledge of association strengths in musical sequences

Barbara Tillmann,* Timothy Justus,** and Emmanuel Bigand***

- Abstract
- Recent findings suggest the involvement of the cerebellum in perceptual and cognitive tasks. Our study investigated whether cerebellar patients show musical priming based on implicit knowledge of tonal-harmonic music. Participants performed speeded phoneme identification on sung target chords, which were either related or less-related to prime contexts in terms of the tonal-harmonic system. As groups, both cerebellar patients and age-matched controls showed facilitated processing for related targets, as previously observed for healthy young adults. The outcome suggests that an intact cerebellum is not mandatory for accessing implicit knowledge stored in long-term memory and for its influence on perception. One patient showed facilitated processing for less-related targets (suggesting sensory priming). The findings suggest directions for future research on auditory perception in cerebellar patients to further our understanding of cerebellar functions.
- Keywords: nonverbal auditory

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Cerebellar patients demonstrate preserved implicit knowledge of association strengths in musical sequences

Barbara Tillmann,* Timothy Justus,** and Emmanuel Bigand***

- Abstract
- Music consists of sound sequences that require integration over time. As we become familiar with music, associations between notes, melodies, and entire symphonic movements become stronger and more complex. These associations can become so tight that, for example, hearing the end of one album track can elicit a robust image of the upcoming track while anticipating it in total silence. Here we study this predictive “anticipatory imagery” at various stages throughout learning and investigate activity changes in corresponding neural structures using functional magnetic resonance imaging (fMRI). Anticipatory imagery (in silence) for highly familiar naturalistic music was accompanied by pronounced activity in rostral prefrontal cortex (PFC) and premotor areas. Examining changes in the neural bases of anticipatory imagery during two stages of learning conditional associations between simple melodies, however, demonstrates the importance of fronto-striatal connections, consistent with a role of the basal ganglia in “training” frontal cortex (Pasupathy and Miller, 2005). Another striking change in neural resources during learning was a shift between caudal PFC earlier to rostral PFC later in learning. Our findings regarding musical anticipation and sound sequence learning are highly compatible with studies of motor sequence learning, suggesting common predictive mechanisms in both domains.

PLoS One. 2010; 5(6): e11120.
Published online 2010 June 15. doi: 10.1371/journal.pone.0011120.PMCID: PMC2886055

Cognitive Control in Auditory Working Memory Is Enhanced in Musicians

Karen Johanne Pallesen,1,2,3*¤ Elvira Brattico,4,5 Christopher J. Bailey,2,3 Antti Korvenoja,6 Juha Koivisto,1 Albert Gjedde,2,3¤ and Synnöve Carlson1,7,8

- Musical competence may confer cognitive advantages that extend beyond processing of familiar musical sounds. Behavioural evidence indicates a general enhancement of both working memory and attention in musicians. It is possible that musicians, due to their training, are better able to maintain focus on task-relevant stimuli, a skill which is crucial to working memory. We measured the blood oxygenation-level dependent (BOLD) activation signal in musicians and non-musicians during working memory of musical sounds to determine the relation among performance, musical competence and generally enhanced cognition. All participants easily distinguished the stimuli. We tested the hypothesis that musicians nonetheless would perform better, and that differential brain activity would mainly be present in cortical areas involved in cognitive control such as the lateral prefrontal cortex. The musicians performed better as reflected in reaction times and error rates. Musicians also had larger BOLD responses than non-musicians in neuronal networks that sustain attention and cognitive control, including regions of the lateral prefrontal cortex, lateral parietal cortex, insula, and putamen in the right hemisphere, and bilaterally in the posterior dorsal prefrontal cortex and anterior cingulate gyrus. The relationship between the task performance and the magnitude of the BOLD response was more positive in musicians than in non-musicians, particularly during the most difficult working memory task. The results confirm previous findings that neural activity increases during enhanced working memory performance. The results also suggest that superior working memory task performance in musicians rely on an enhanced ability to exert sustained cognitive control. This cognitive benefit in musicians may be a consequence of focused musical training.
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Proc Natl Acad Sci U S A. 2005 March 8; 102(10): 3576–3580.
Published online 2005 February 24. doi: 10.1073/pnas.0500692102.PMCID: PMC553338 The National Academy of Sciences
Anthropology

Reciprocal evolution of the cerebellum and neocortex in fossil humans

Anne H. Weaver* (Santa Fe)

- Abstract
- Human brain evolution involved both neurological reorganization and an increase in overall brain volume relative to body mass. It is generally difficult to draw functional inferences about the timing and nature of brain reorganization, given that superficial brain morphology recorded on fossil endocasts is functionally ambiguous. However, the cerebellum, housed in the clearly delineated posterior cranial fossa, is functionally and ontologically discrete. The cerebellum is reciprocally connected to each of 14 neocortical regions important to human cognitive evolution. Cerebellar volume varies significantly relative to overall brain volume among mammalian orders, as well as within the primate order. There is also significant diachronic variation among fossil human taxa. In the australopithecines and early members of the genus Homo, the cerebral hemispheres were large in proportion to the cerebellum, compared with other hominoids. This trend continued in Middle and Late Pleistocene humans, including Neandertals and Cro-Magnon 1, who have the largest cerebral hemispheres relative to cerebellum volume of any primates, including earlier and Holocene humans. In recent humans, however, the pattern is reversed; the cerebellum is larger with respect to the rest of the brain (and, conversely, the cerebral hemispheres are smaller with respect to the cerebellum) than in Late Pleistocene humans. The cerebellum and cerebral hemispheres appear to have evolved reciprocally. Cerebellar development in Holocene humans may have provided greater computational efficiency for coping with an increasingly complex cultural and conceptual environment.

Published online 2008 February 27. doi: 10.1371/journal.pone.0001679.PMCID: PMC2244806

Neural Substrates of Spontaneous Musical Performance: An fMRI Study of Jazz Improvisation

Charles J. Limb1,2* and Allen R. Braun1

- Abstract
- To investigate the neural substrates that underlie spontaneous musical performance, we examined improvisation in professional jazz pianists using functional MRI. By employing two paradigms that differed widely in musical complexity, we found that improvisation (compared to production of over-learned musical sequences) was consistently characterized by a dissociated pattern of activity in the prefrontal cortex: extensive deactivation of dorsolateral prefrontal and lateral orbital regions with focal activation of the medial prefrontal (frontal polar) cortex. Such a pattern may reflect a combination of psychological processes required for spontaneous improvisation, in which internally motivated, stimulus-independent behaviors unfold in the absence of central processes that typically mediate self-monitoring and conscious volitional control of ongoing performance. Changes in prefrontal activity during improvisation were accompanied by widespread activation of neocortical sensorimotor areas (that mediate the organization and execution of musical performance) as well as deactivation of limbic structures (that regulate motivation and emotional tone). This distributed neural pattern may provide a cognitive context that enables the emergence of spontaneous creative activity.
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Estimated (Haines pg 57)

- Every 5th nerve cell and one of 6 synaptic contacts is GABAergic/ inhibitory

- Exercising minimal overall control in the rehearsal room lends to “giving it over” in performance.
- What is minimal control – cognitive, technical, musical, sensory/dynamic
- Keep it simple but always have something to do – leads to zero nervousness
- Following predetermined actions without controlling the moment
- Leading up to moment (difficulties) critical
- Practicing slow, clean, exact execution

- Cerebellum – motor tasks that are time dependent - RESEARCH

Acupuncture

- Pain element w needles – treats ipsilateral side of body
- Whereas muscle/ massage treats contralateral side
- Cordo et al (1997)
- LTD and CB functioning – look up

- Cannot control inhibition

- Mastering higher and higher tasks
- Automating simpler ones

- Music primes the environment to move in it. Rather than command arm (as most people do) sense the environment and then employ the command (let’s the CB run the show(
- Music vibrates and primes the environment so that the CB works first by default – double inhibition is enabled and “flow” is established
- Leads to optimal task acquisition and delivery

CB point in music

- To engage CB you must let brain sense the sounds and order of experiences
- Trying to control experience disengages CB
- Back to caveman status with CB still active and trying to function
- = double dumb (as in 1st year music studies)
- Oberlin exercised CB but still too much FL
- Perfect pitch, et al may demand CB invlmt