Perception of Music

Augusto Sarti

Computer Music Representations and Models

M.Sci. Music and Acoustic Engineering

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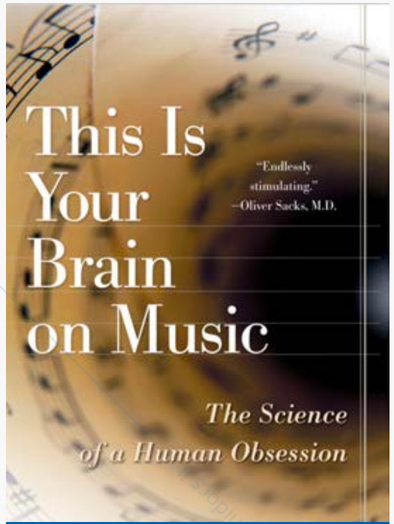

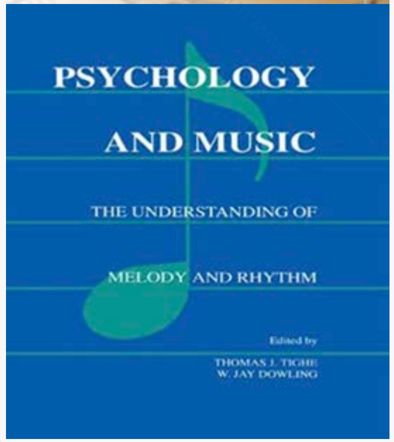

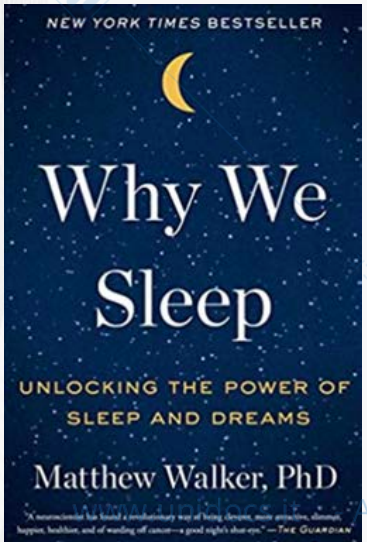

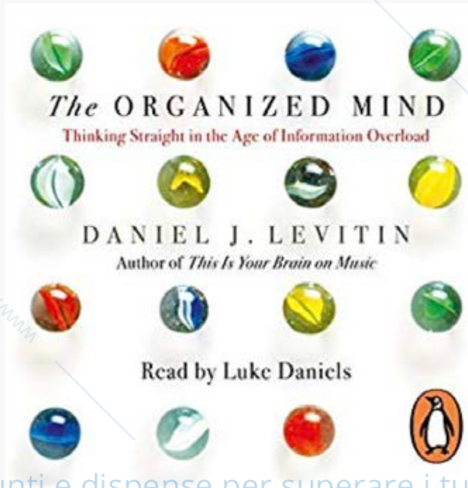

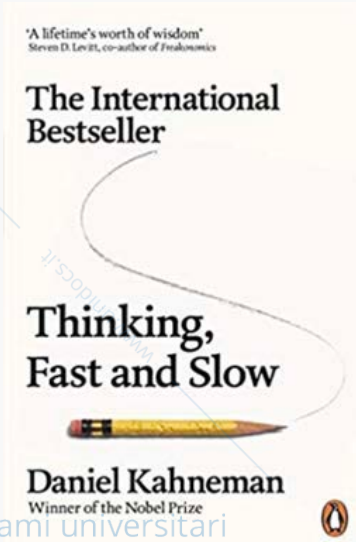

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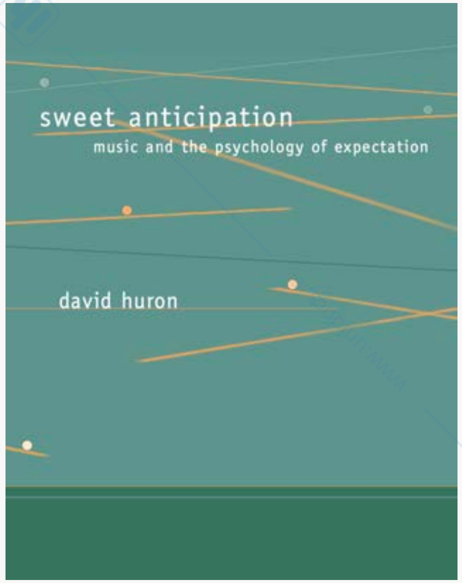

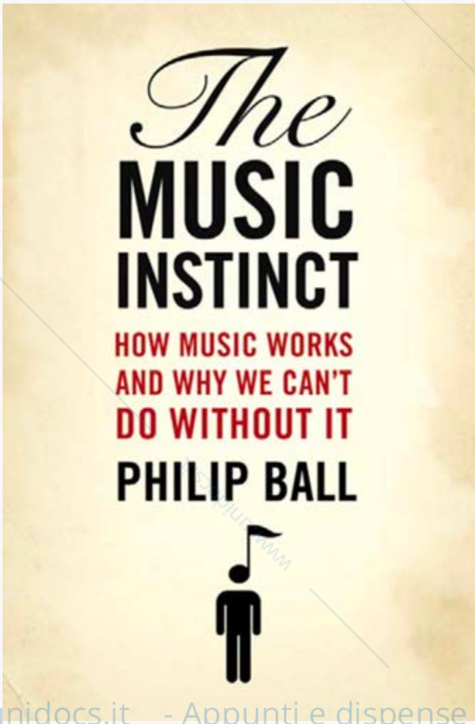

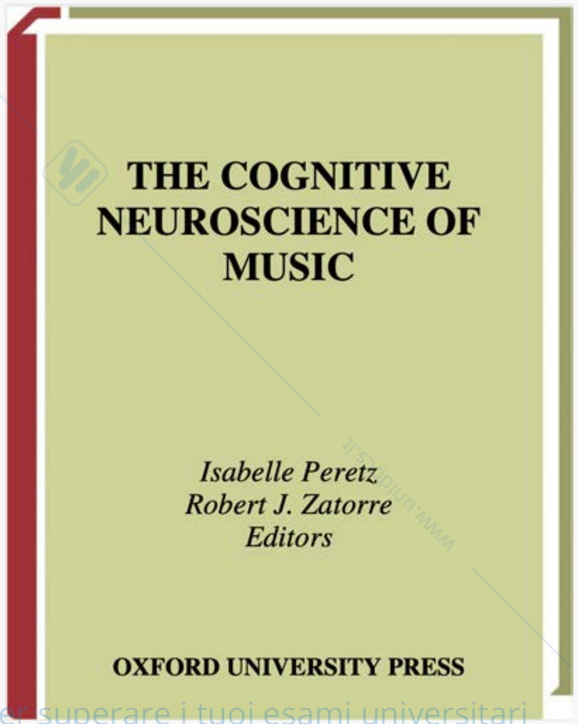

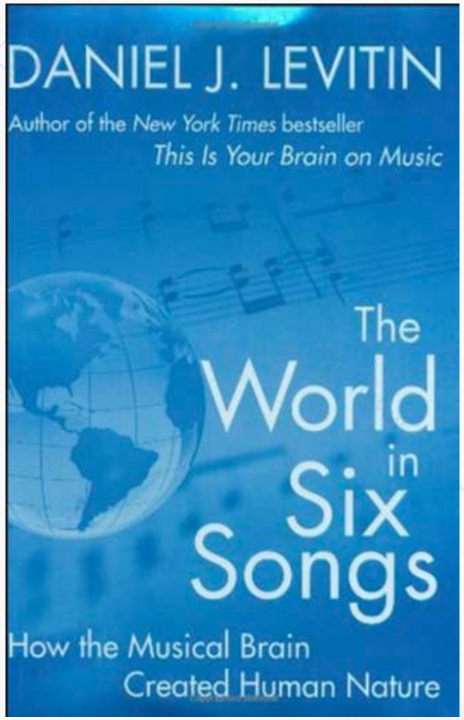

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Is a Definition of Music possible?

music

[ˈmjuːzɪk] noun

vocal or instrumental sounds (or both) combined in such a way as to produce beauty of form, harmony, and expression of emotion.

without music, life would be a mistake.

music

[myü-zik] noun

the science or art of ordering tones or sounds in succession, combined with rhythm, melody and harmony

a composition having unity and continuity, resulting in an expression of emotions, ideas and / or memories

mu•sic \ˈmyü-zik\ *n* **1:** the art of combining tones so that they are pleasing, expressive, or intelligible **2:** sounds that have rhythm, harmony, and melody; *also* : an agreeable sound

music \ˈmyü-zik\
noun
1 the poetry of human expression through sound in time.

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Is a Definition of Music possible?

Merriam-Webster
- the science or art of ordering tones or sounds in succession, in combination, and in temporal relationships to produce a composition having unity and continuity
- vocal, instrumental, or mechanical sounds having rhythm, melody, or harmony

Cambridge dictionary
- a pattern of sounds made by musical instruments, voices, or computers, or a combination of these, intended to give pleasure to people listening to it

Oxford dictionary
- Vocal or instrumental sounds (or both) combined in such a way as to produce beauty of form, harmony, and expression of emotion.

Dictionary.com
- an art of sound in time that expresses ideas and emotions in significant forms through the elements of rhythm, melody, harmony, and color
- the tones or sounds employed, occurring in single line (melody) or multiple lines (harmony), and sounded or to be sounded by one or more voices or instruments, or both

Etymology

1200–50; Middle English musike, Latin mūsica, Greek mousikḗ (téchnē), meaning (the art) of the Muse

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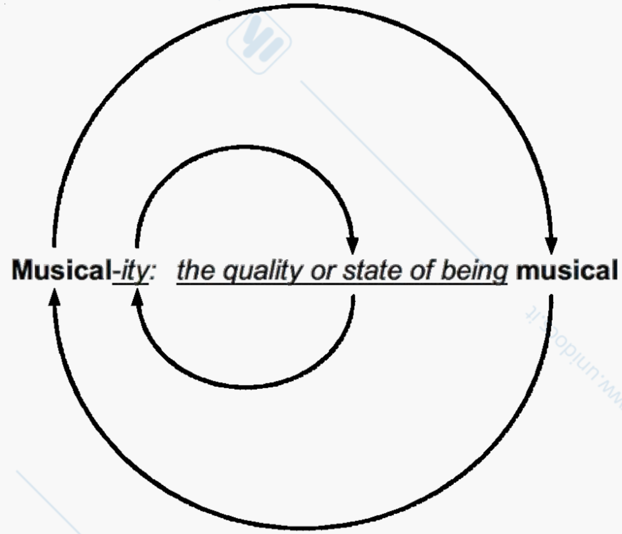
Is a Definition of Music possible?

Wikipedia:

"... Many authorities have suggested definitions, but defining music turns out to be more difficult than might first be imagined"

Music is an art form and cultural activity whose medium is sound organized in time



The common elements of music are

- pitch (which governs melody and harmony)
- rhythm (and its associated concepts tempo, meter, and articulation)
- dynamics (loudness and softness)
- the sonic qualities of timbre and texture (which are sometimes termed the "color" of a musical sound)

Different styles or types of music may emphasize, de-emphasize or omit some of these elements

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Attributes of music

- **Tone**
  - A discrete musical sound. Tone and note refer to the same entity in the abstract, where the word tone refers to what you hear, and the word note refers to what you see written on a musical score
- **Pitch**
  - a purely psychological construct, describing the perception of frequency of a particular tone (and its relative position in the musical scale)
- **Rhythm**
  - Rhythm refers to the durations of a series of notes, and to the way that they group together into temporal units. It is made of repeating patterns over time
- **Tempo**
  - refers to the overall speed or pace of the piece

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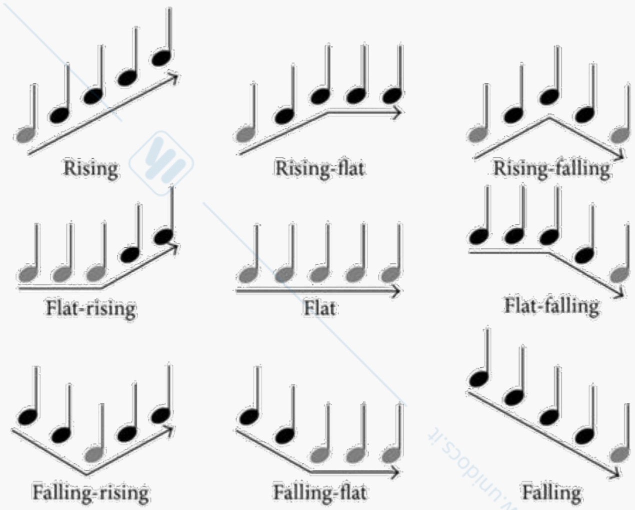
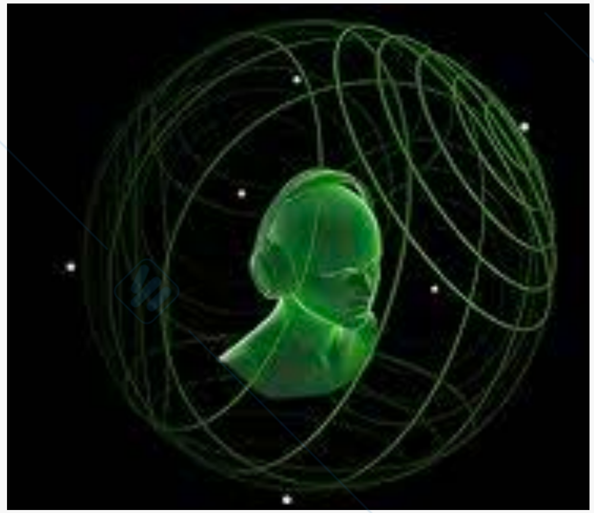
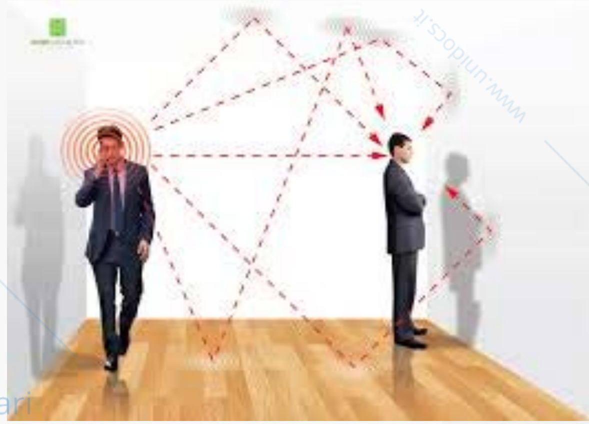
Attributes of music

- **Contour**
  - describes the overall shape of a melody, taking into account only the pattern of “up” and “down”
- **Timbre**
  - Timbre is that which distinguishes one instrument from another when both are playing the same written note
- **Loudness**
  - A purely psychological construct that describes the perceived amplitude of a tone
- **Spatial location**
  - where sound is coming from
- **Reverberation**
  - environment’s acoustic response. Refers to the perception of how distant the source is from us in combination with how large a room or hall the music is.







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Attributes of music

- These attributes are separable. Each can be varied independently of the others, allowing the scientific study of one at a time, which is why we can think of them as dimensions
- In music these fundamental attributes combine according to meaningful relations that give rise to higher-order concepts such as
  - **Meter**
  - **Key**
  - **Harmony**
  - **Melody**

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Music attributes

- **Meter**
  - Describes how tones are grouped with one another across time
  - Our brains infer it by extracting information from rhythm and loudness cues

  - *Example 1: Waltz for Debby (Bill Evans)*
    regular waltz (3/8) https://youtu.be/qqnj-pQ9dDc
  - *Example 2: Estate (Bruno Martino, performed by Michel Petrucciani)*
    regular complete meter (4/4) https://youtu.be/yPuiDrXp2XA
  - *Example 3: Take Five (Paul Desmond, Dave Brubeck)*
    5/4 (3+2) https://youtu.be/vmDDOFXSgAs
  - *Example 4: Dark matter (Porcupine Tree)*
    polyrhythm (7 against 2) https://youtu.be/TMc-75oLgU8
  - *Example 5: Dawn (Dario Marianelli)*
    polyrythm (3 against 2 - hemiola) https://youtu.be/2wGzDFbjFko
  - *Example 6: Sound of muzak (Porcupine tree)*
    polyrhythm 7 against 4 - https://youtu.be/MPm-oPy87R0
  - *Example 7: Three Years Older (Steven Wilson)*
    uneven subdivision of a 4/4 https://youtu.be/dTyHsIQqDa8
  - *Example 8: Blue Rondo à la Turk (Dave Brubeck quartet)*
    uneven subdivision of 9/8 https://youtu.be/vKNZqM0d-xo
  - *Example 9: Etude No. 1 (Tigran Hamasyan, An ancient observer)*
    polymetric structure (multiple layers) https://youtu.be/xmScqhDSJrI

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Music attributes

- **Key**
  - Tonal reference of a musical piece - group of pitches, or scale, that forms the basis of a music composition in classical, Western art, and Western pop music (Wikipedia)
    - The group features a tonic note and its corresponding chords, also called a tonic or tonic chord, which provides a subjective sense of arrival and rest, and also has a unique relationship to the other pitches of the same group, their corresponding chords, and pitches and chords outside the group. Notes and chords other than the tonic in a piece create varying degrees of tension, resolved when the tonic note or chord returns.
  - Key has to do with a hierarchy of importance that exists between tones in a musical piece; this hierarchy exists only in our minds, as a function of our experiences with a musical style and musical idioms, and mental schemas that all of us develop for understanding music
  - Example 1: Theme from MASH TV series (Johnny Mendel)
    tonal piece (fixed tonal reference) https://youtu.be/4gO7uemm6Yo
  - Example 2: Theme from MASH (Bill Evans)
    modal piece (drifting tonal reference) https://youtu.be/ECtNyyLEW7E
  - Example 3: Kefel (Avishai Cohen)
    off-tonal piece https://youtu.be/3pO5tf0Vcx4
  - Example 4: Polytonal blues (Dave Brubeck)
    polytonal piece https://youtu.be/HBWGj5myvS4
  - Example 5: Les sons impalpables du rêve
    [Huit Préludes pour piano] (Olivier Messiaen)
    no reference https://youtu.be/5Pc6kE8udE4

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Music attributes

Harmony

- Harmony has to do with relationships between the pitches of different tones, and with tonal contexts that these pitches set up; which ultimately lead to expectations for what will come next in a musical piece
- a skillful composer that can either meet or violate expectations for artistic and expressive purposes
- harmony can mean simply a parallel melody to the primary one (as when two singers harmonize) or it can refer to a chord progression—the clusters of notes that form a context and background on which the melody rests
  - Example 1: "Danny Boy" - arr. Flummerfelt for choir https://youtu.be/CKl8zXz4BeE
    - King's Singers https://youtu.be/SfGTq71VXfo
    - Bill Evans https://youtu.be/X5Sg0WGy9YA
    - Keith Jarrett https://youtu.be/C6tIzxmPCQE
  - Example 2: "That's Amore" – a straightforward arrangement https://youtu.be/3auE7zq9H7w
    - Stefano Bollani https://youtu.be/2ZL_spxppH0
  - Example 3: "Hark! The herald angels sing",
    - Mormon tabernacle choir https://youtu.be/SFjMPaOBzXc
    - Take 6s https://youtu.be/Uby81SEOBFA

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Music attributes: harmony

Wikipedia

"In music, harmony considers the process by which the composition of individual sounds, or superpositions of sounds, is analysed by hearing. Usually, this means simultaneously occurring frequencies, pitches (tones, notes), or chords.

The study of harmony involves chords and their construction and chord progressions and the principles of connection that govern them.

Harmony is often said to refer to the "vertical" aspect of music, as distinguished from melodic line, or the "horizontal" aspect.

Counterpoint, which refers to the relationship between melodic lines, and polyphony, which refers to the simultaneous sounding of separate independent voices, are thus sometimes distinguished from harmony."

Schoenberg's early definition of harmony in "Theory of Harmony" (p.13)

"...the study of simultaneous sounds (chords) and of how they may be joined with respect to their architectonic, melodic, and rhythmic values and their significance, their weight relative to one another."

In a later book entitled "Structural functions of harmony", he re-defines HARMONY by explaining what teaches:

1. *The constitution of chords, that is, which tones and how many of them can be sounded simultaneously in order to produce consonances and the traditional dissonances: triads, seventh chords, ninth chords, etc., and their inversions.*
2. *The manner in which chords should be used in succession: to accompany melodies and themes; to control the relation between main and subordinate voices; to establish a tonality at the beginning and at the end (cadence); or, on the other hand, to abandon a tonality (modulation and remodulation)*

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Music attributes

- **Melody**

  Melody is the main theme of a musical piece, the part you sing along with, the succession of tones that are most salient in your mind

  – Example 1: Over the rainbow (Keith Jarrett) https://youtu.be/AyLQGDIrGcI

  – Example 2: Allegretto of Beethoven's 7th Symphony https://youtu.be/J12zprD7V1k
  which theme represents the melody?

  – Example 3: Kefel (Avishai Cohen)
  floating melody https://youtu.be/3pO5tf0Vcx4

  Points of discussion

  – Unpredictable (beyond modeling) aspect of a musical piece: ends up being retained and memorized as is
    - **Good melody = memorable melody?**
    - Example: "Twinkle twinke little star" challenge launched by Jacob collier https://www.youtube.com/results?search_query=twinkletwinklelittlestarchallenge

  – Melody is "architecture devoid of function", as it can be thought of as fairly independent of structural aspects (harmony and rhythm)
    - Example: Tico tico no fubà (Stefano Bollani)

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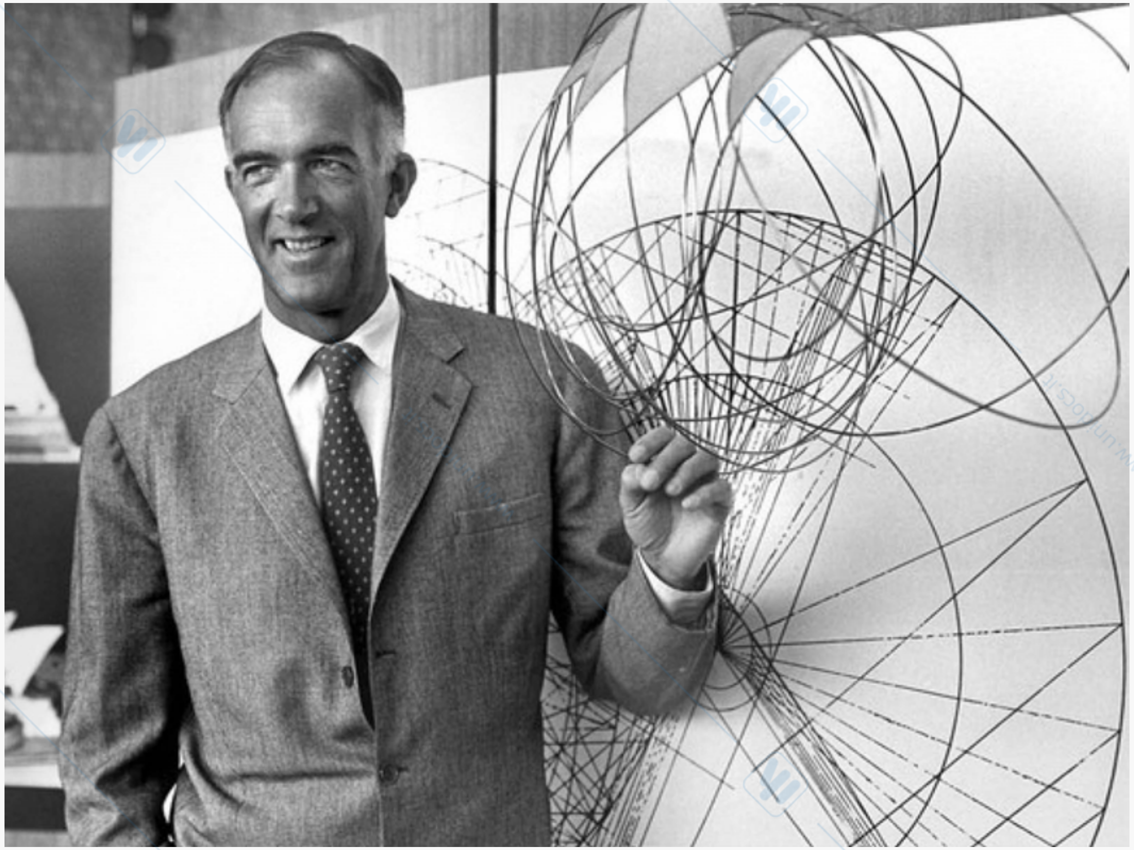
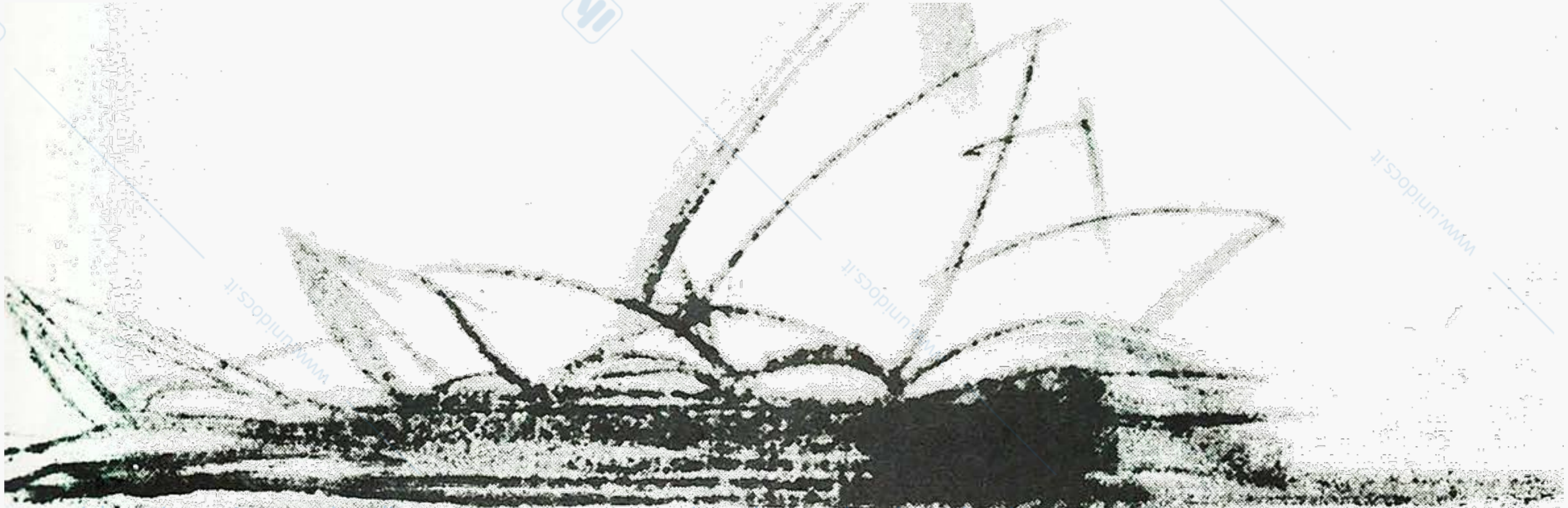
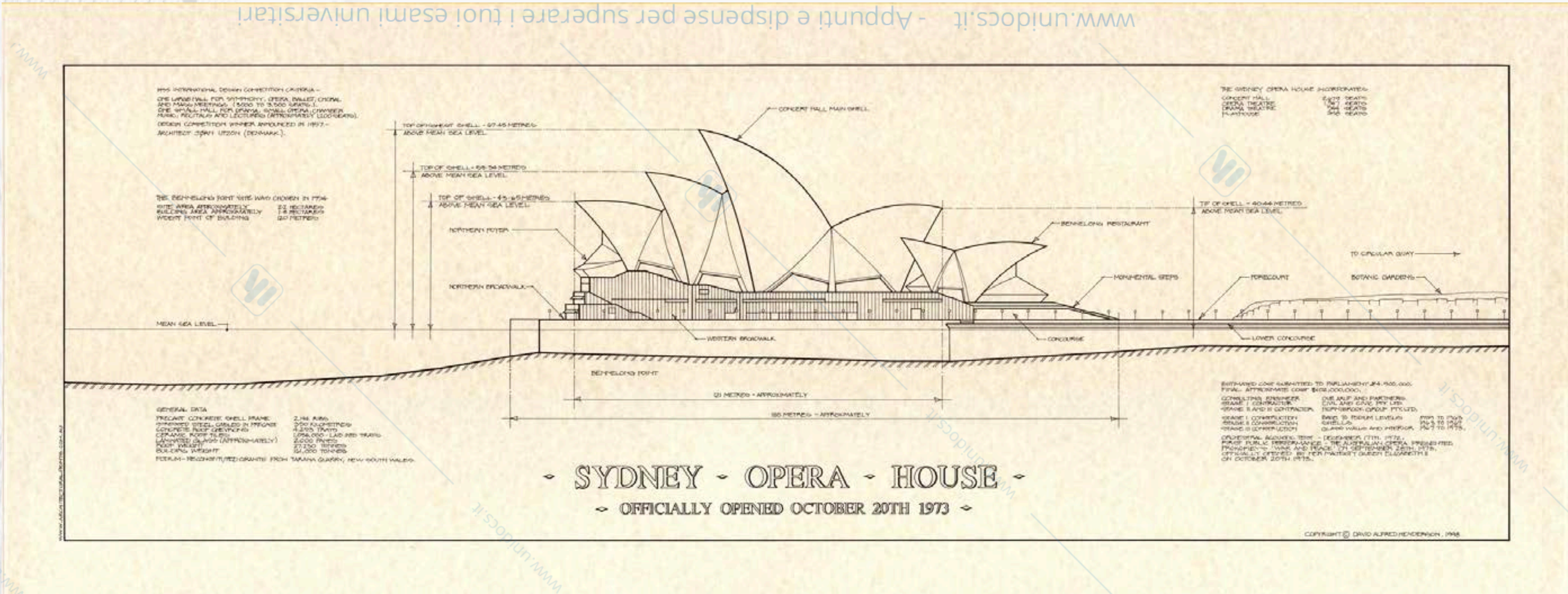
Melody = architecture devoid of function...



Danish architect
Jørn Utzon





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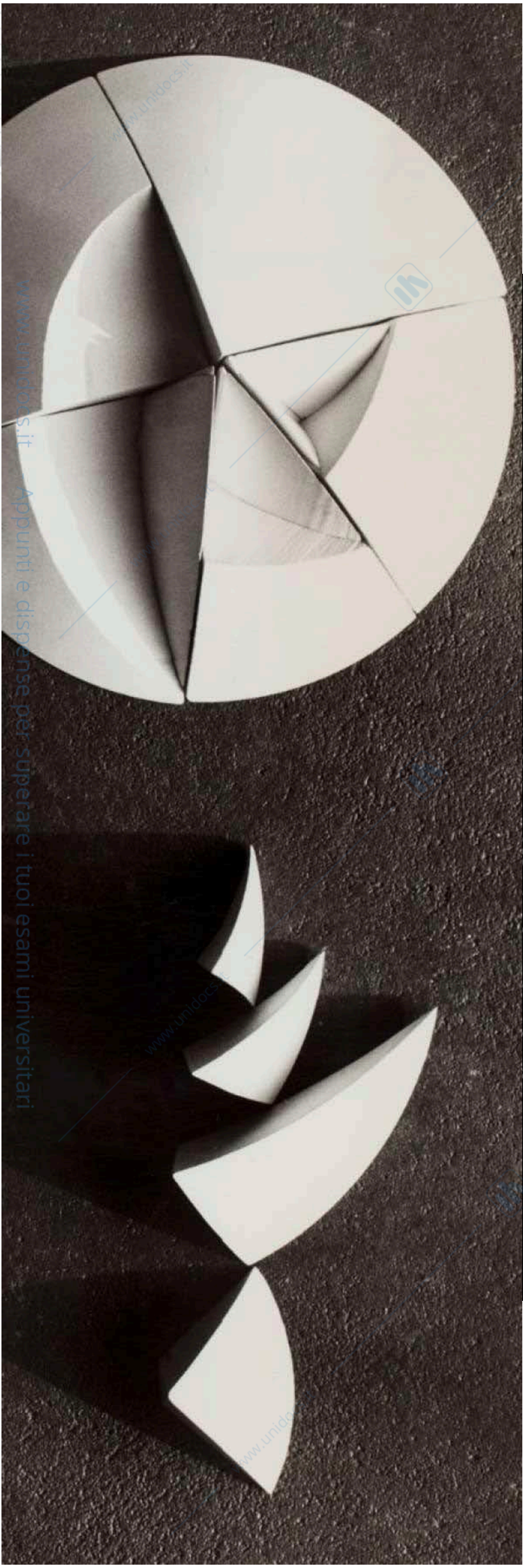

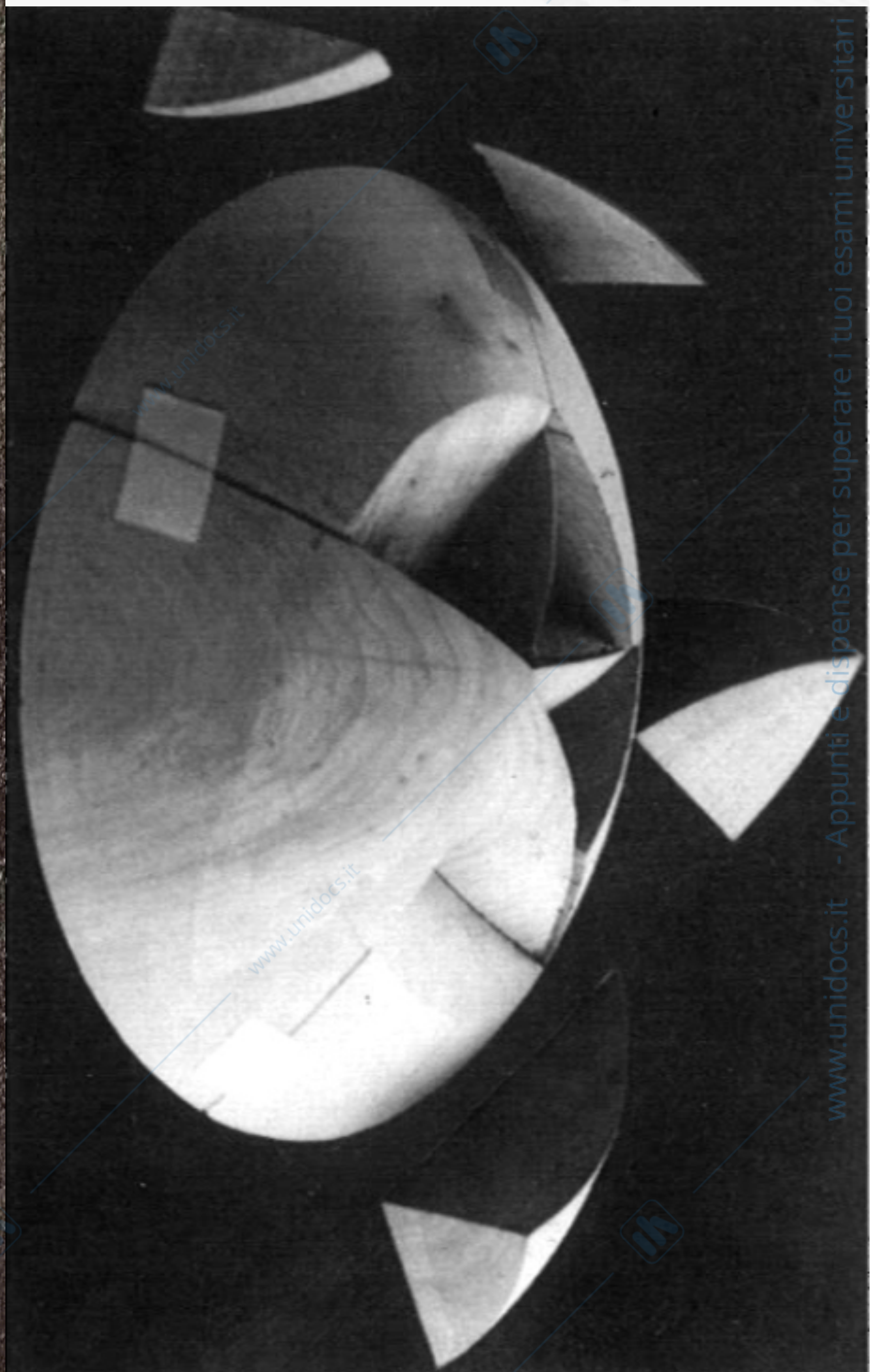

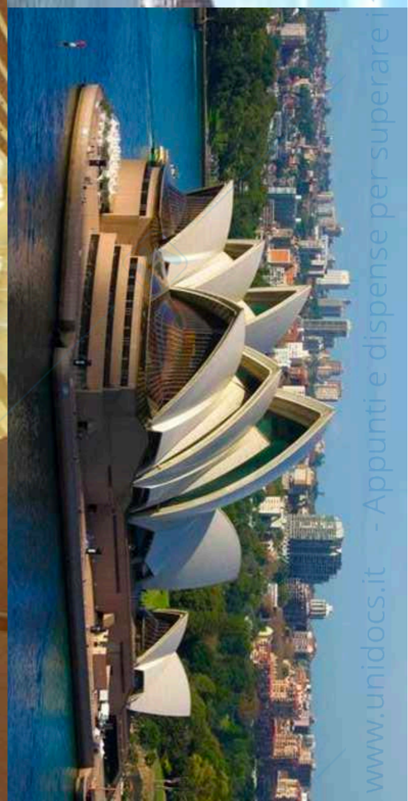

Melody

Melody adapts to the structure of the musical piece (harmony, rhythm) with surprising flexibility

- Human nature (Steve Porcaro & John Bettis, popularized by M. Jackson)
  - Trijntje Oosterhuis w/ Leo Amuedo: (4/4)
    - https://youtu.be/jT0DfTxB4DY

  - Vijay Iyer Trio (13/8)
    - https://youtu.be/NEVJRdo-eHc

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Music and the mind machine

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A perspective from cognitive science and neuroscience

- According Cognitive scientists
  - “mind” that part that embodies our thoughts, hopes, desires, memories, beliefs, and experiences;
  - “brain” the organ that resides in the skull. Activity in the brain gives rise to the contents of the mind
- This dualism is inherited from René Descartes, who argued that mind and brain are two entirely separate things. Dualists assert that the mind preexisted, before you were born, and that the brain is not the seat of thought — rather, it is merely an instrument of the mind, helping to implement the mind’s will, move muscles, and maintain homeostasis in the body
- Our perception tells us that our mind is separate from the neurochemical processes that reside in the brain but this could be an illusion
- Most scientists and contemporary philosophers believe that brain and mind are two parts of the same thing, and some believe that the distinction itself is flawed
- The dominant view today is that that the sum total of your thoughts, beliefs, and experiences is represented in patterns of firings —electrochemical activity — in the brain
- Evidence comes from neuropsychological findings of regional specificity of function. Damage to a specific brain region leads to a loss of a particular mental or bodily function, suggesting that this brain region is responsible for that function
- We have known since 1848 (and the medical case of Phineas Gage) that the frontal lobes are intimately related to aspects of self and personality. Yet even one hundred and fifty years later, most of what can be said about personality and neural structures is vague and quite general
- The brain has regional differentiation of structure and function, but complex personality attributes are no doubt distributed widely throughout the brain

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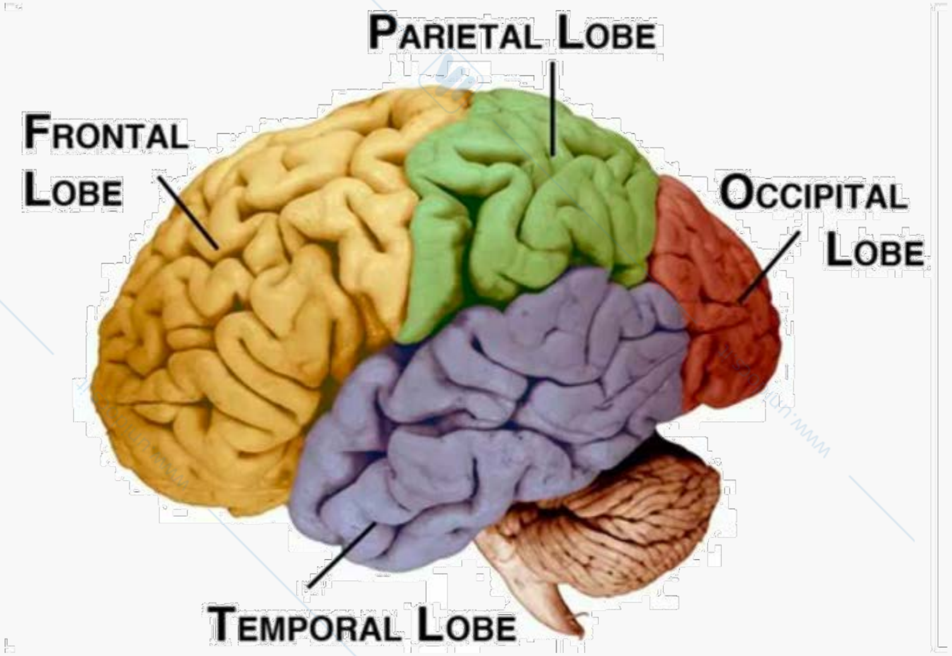
The Mind Machine

- The human brain is divided up into four lobes (+ cerebellum)
  - Frontal
  - Temporal
  - Parietal
  - Occipital



- We can make some gross generalizations about function, but in fact behavior is complex and not readily reducible to simple mappings
  - frontal lobe – associated with planning, and with self-control, and with making sense out of the dense and jumbled signals that our senses receive—the so-called “perceptual organization” that the Gestalt psychologists studied
  - temporal lobe – associated with hearing and memory
  - parietal lobe – associated with motor movements and spatial skill
  - occipital lobe – associated with vision
  - cerebellum – involved in emotions and the planning of movements (oldest part of our brain)

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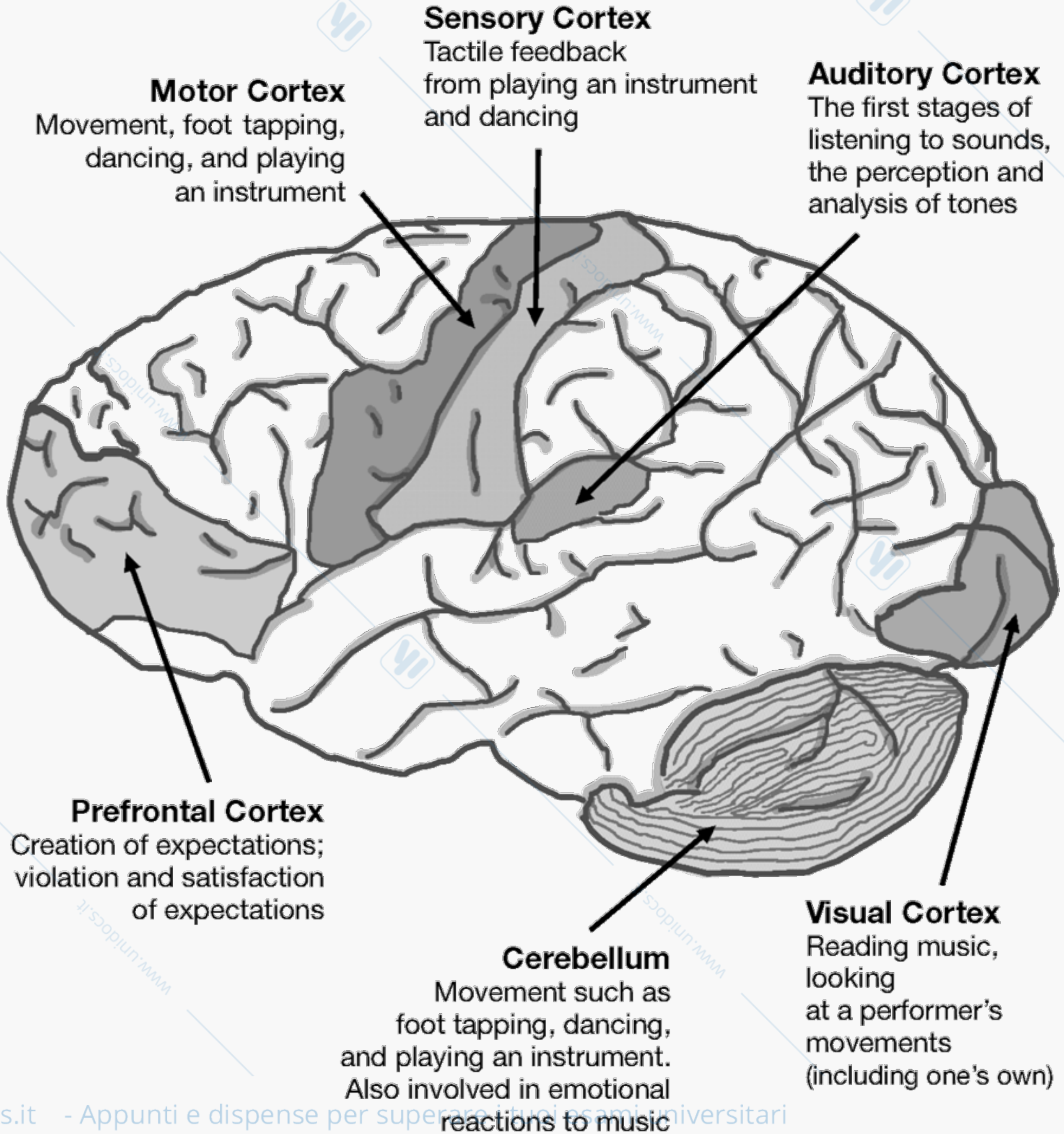
Music and the Mind Machine



Music and the Mind Machine

- Musical activity involves nearly every region of the brain and nearly every neural subsystem
- Different aspects of the music are handled by different neural regions
  - the brain uses **functional segregation** for music processing, and employs a system of feature detectors whose job it is to analyze specific aspects of the musical signal, such as pitch, tempo, timbre, and so on
  - Some of the music processing has points in common with the operations required to analyze other sounds; understanding speech, for example, requires that we segment a flurry of sounds into words, sentences, and phrases, and that we be able to understand aspects beyond the words (e.g. as sarcasm, irony, ...)
  - Several different dimensions of a musical sound need to be analyzed—usually involving several quasi-independent neural processes—and they then need to be brought together to form a coherent representation of what we're listening to

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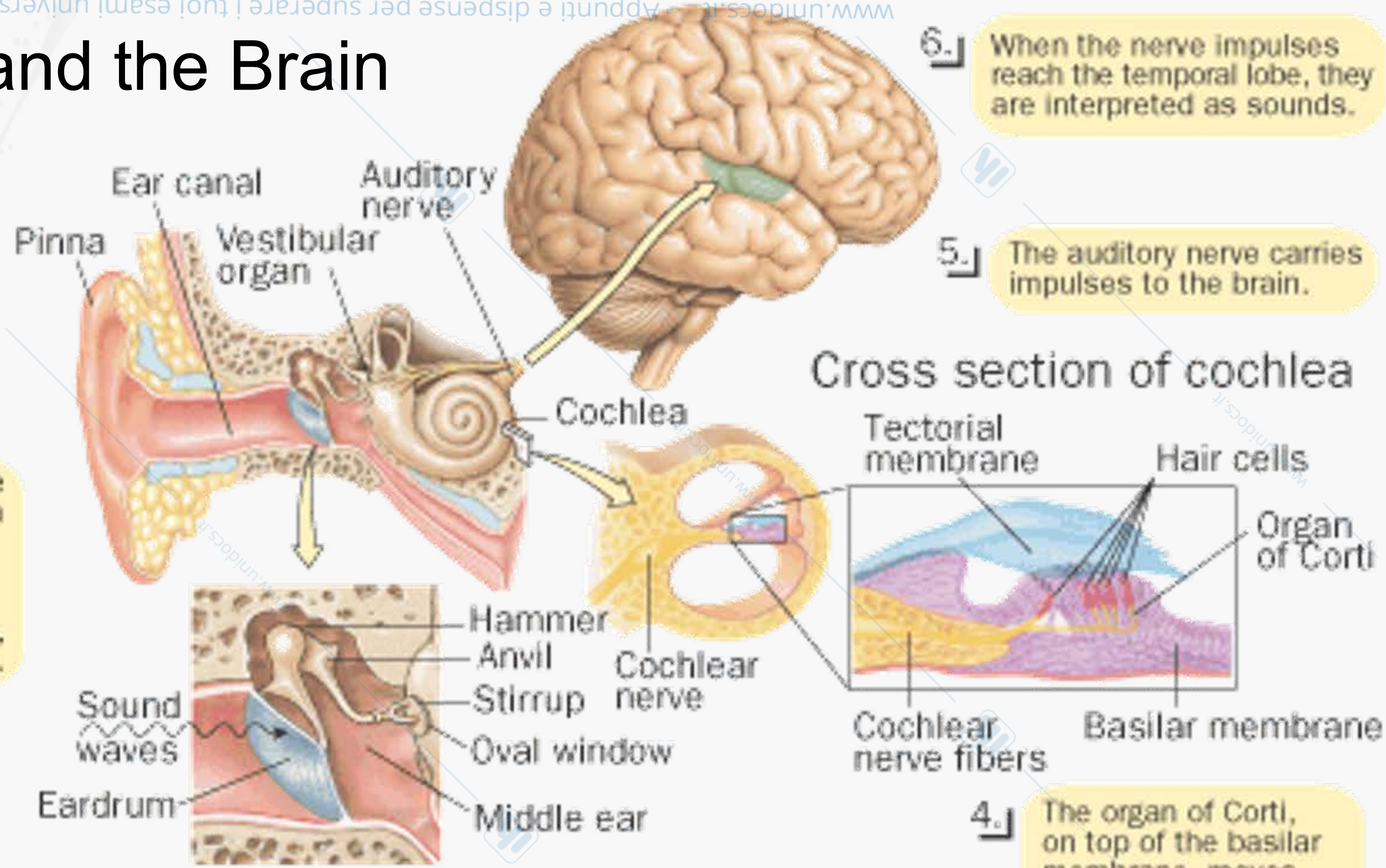
The Ear and the Brain



1. The first stage of the hearing process is a series of vibrations. Sound waves enter the outer ear and travel to the eardrum, causing it to vibrate.

2. The vibrating eardrum causes the bones of the middle ear (the hammer, anvil, and stirrup) to strike each other, amplifying and carrying the vibrations to the oval window and on to the fluid in the coiled cochlea of the inner ear.

3. Now, the moving fluid sets the basilar membrane, inside the cochlea, moving.

4. The organ of Corti, on top of the basilar membrane, moves too. Inside the organ of Corti, thousands of tiny receptor cells are topped by a bundle of hair-like fibers. As the basilar membrane vibrates, the fibers bend, stimulating the receptor cells to send a signal through afferent nerve endings, which join to form the auditory nerve.

5. The auditory nerve carries impulses to the brain.

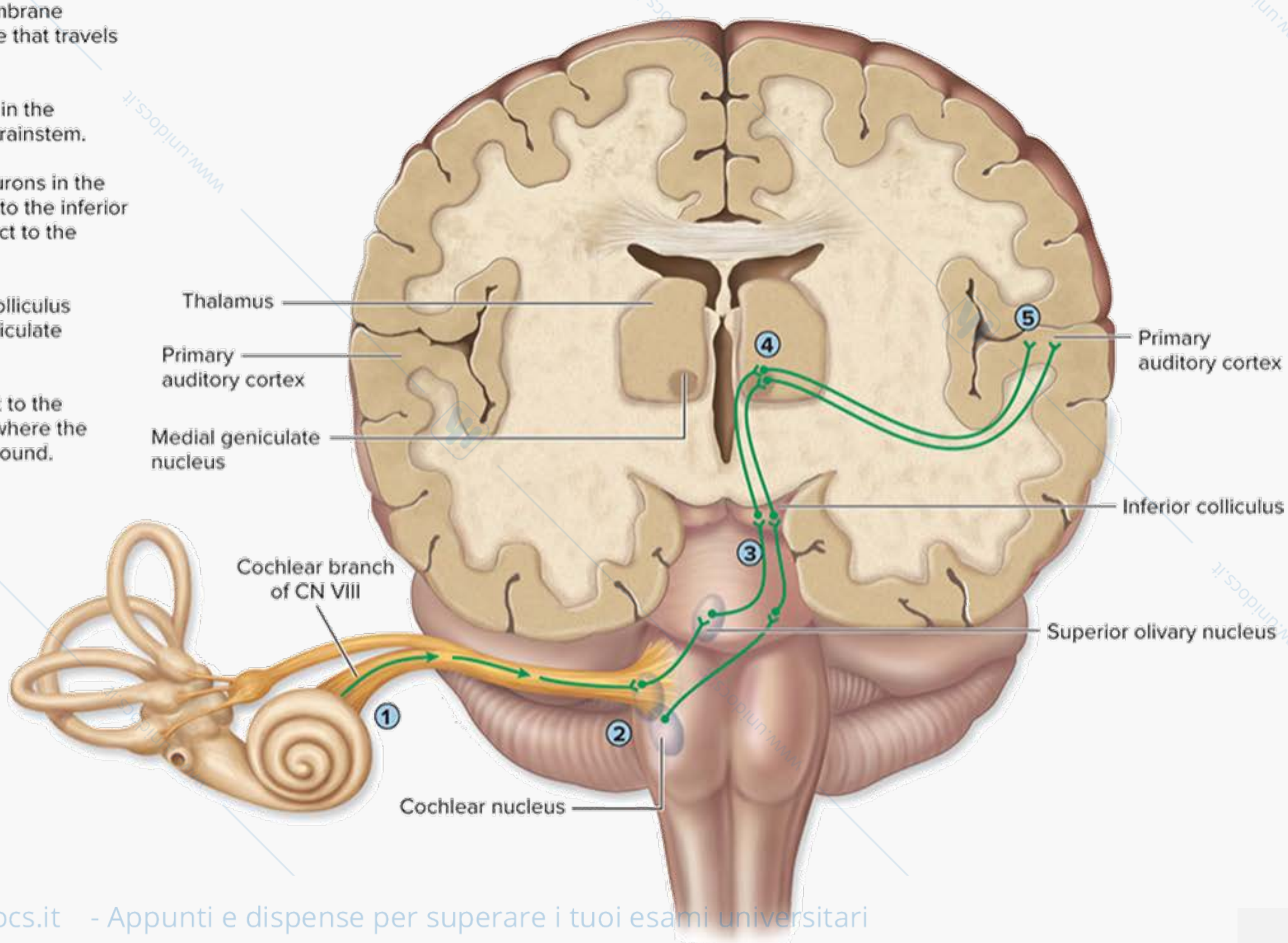
6. When the nerve impulses reach the temporal lobe, they are interpreted as sounds.

Music and the Mind Machine

- Listening to music starts with subcortical structures
  - the cochlear nuclei
  - the brain stem
  - the cerebellum

  and then moves up to auditory cortices on both sides of the brain

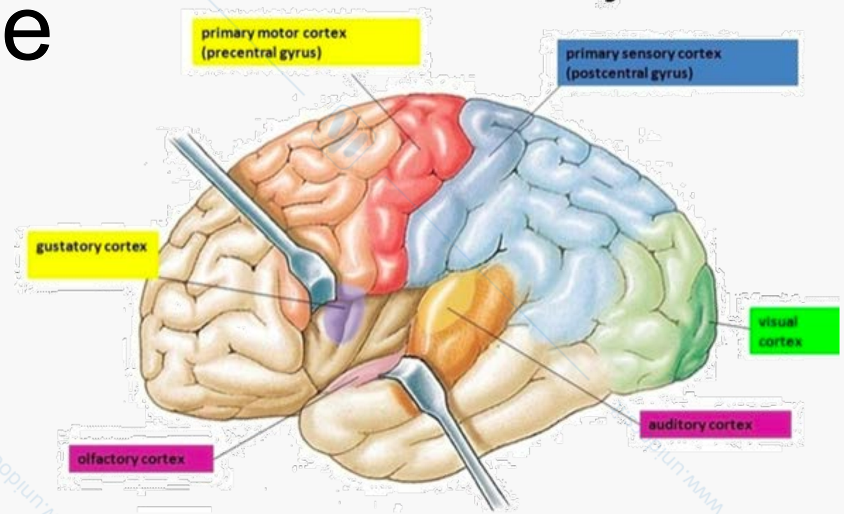
1. Movement of basilar membrane produces a nerve impulse that travels in cochlear nerve axons.
2. Sensory axons terminate in the cochlear nucleus in the brainstem.
3. Some axons from the neurons in the cochlear nucleus project to the inferior colliculi, and others project to the superior olivary nucleus.
4. Axons from the inferior colliculus project to the medial geniculate nucleus of the thalamus.
5. Thalamic neurons project to the primary auditory cortex, where the impulse is perceived as sound.

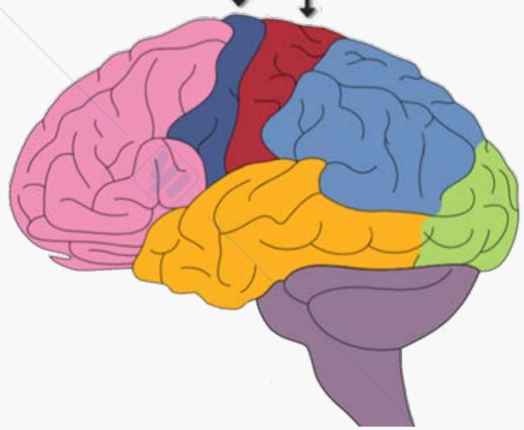


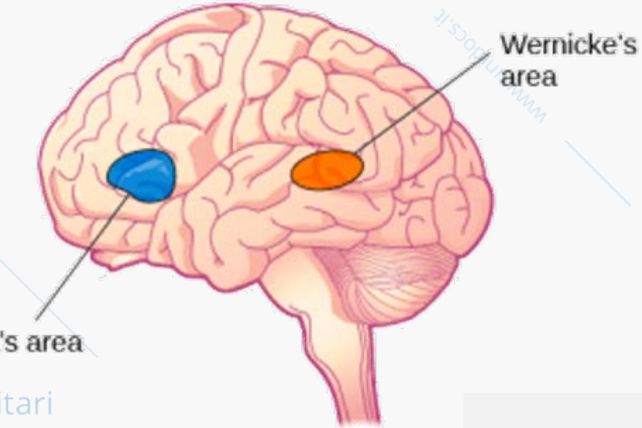
Music and the Mind Machine

- Trying to follow along with music that is familiar to you recruits additional regions of the brain
  - hippocampus (memory center): involved in anticipating music from past experience
  - subsections of the frontal lobe, particularly a region called inferior frontal cortex.
  - cerebellum (timing circuits, normally used for controlling body motion): involved in beat following
  - frontal lobes (behavioral planning): heavily involved when performing music (play, sing, or conduct)
  - motor cortex in the parietal lobe (just underneath the top of your head): involved during musical performance or when moving in sync with the music
  - sensory cortex: provides tactile feedback
  - visual cortex (back of your head, in the occipetal lobe): used when reading music
  - auditory cortex: for obvious reasons...
  - language centers (temporal and frontal lobes + Broca's and Wernicke's areas), when listening to or recalling lyrics

Motor & Sensory







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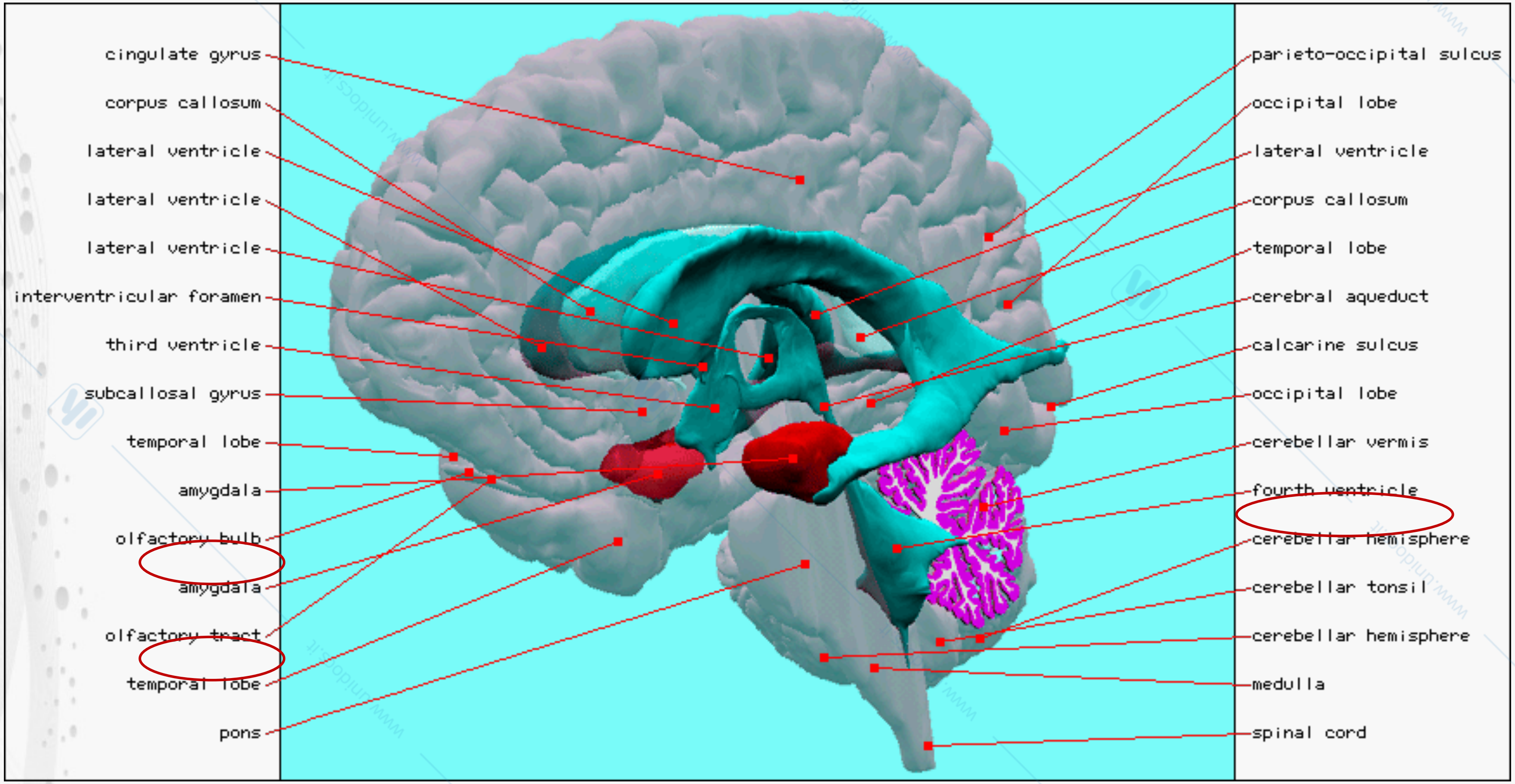
Music and the Mind Machine

- At a deeper level, the emotions we experience in response to music involve structures deep in the primitive, reptilian regions of the **cerebellar vermis**, responsible for bodily posture and locomotion; and the **amygdala**, the heart of emotional processing in the cortex



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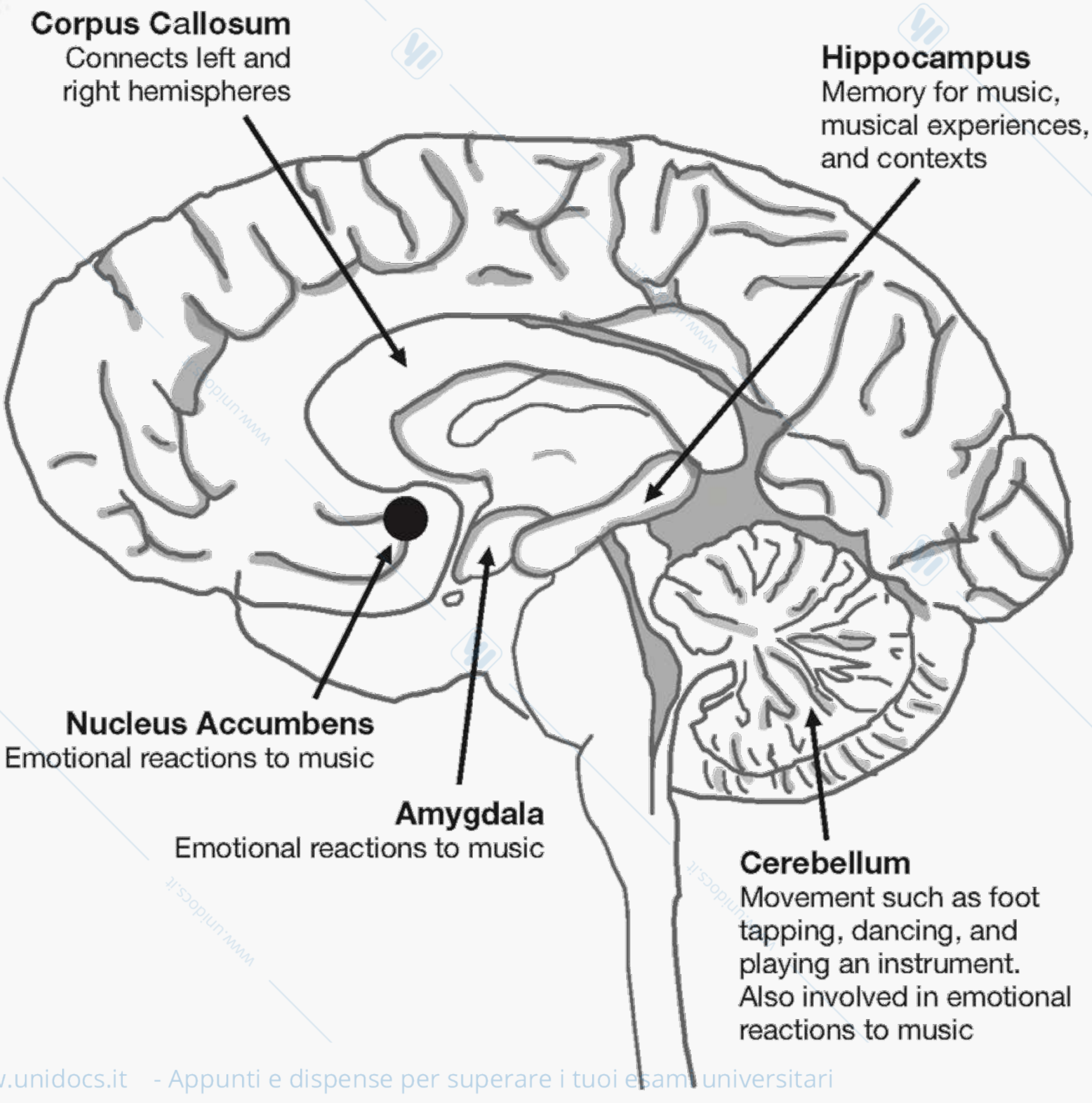
Music and the Mind Machine



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Music and the Mind Machine

- regional specificity at low level is complemented by distribution of function at higher level
  - The brain is a massively parallel device, with operations distributed widely throughout
  - There is no single language center, nor is there a single music center. Rather, there are regions that perform component operations, and other regions that coordinate the bringing together of this information
- Neuroplasticity: a capacity for reorganization that suggests that regional specificity may be temporary
  - the processing centers for important mental functions actually move to other regions after trauma or brain damage

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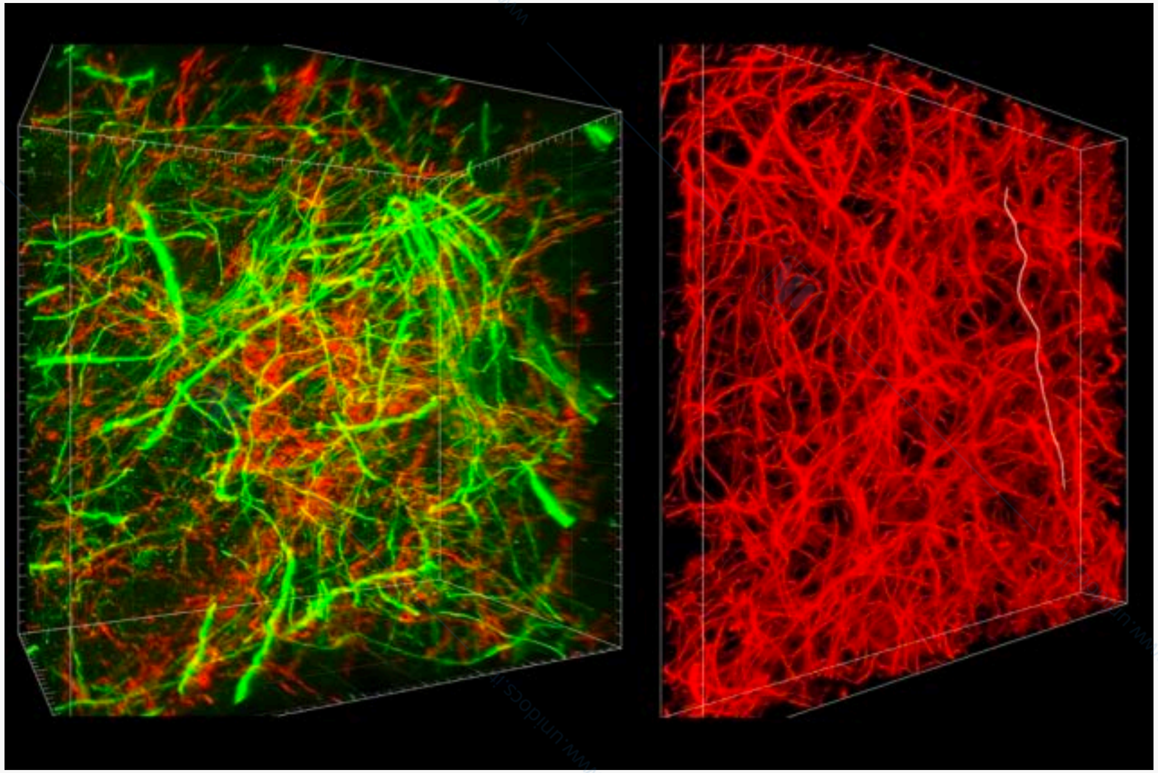
Complexity of the brain

- The average brain consists of one hundred billion (10^{11}) neurons, but this does not explain its complexity. What matters are the possible connections btw neurons

Imaging the brain at multiple size scales: a new technique called Magnified Analysis of Proteome (MAP) allows researchers to peer at molecules within cells or take a wider view of the long-range connections between neurons (MIT)



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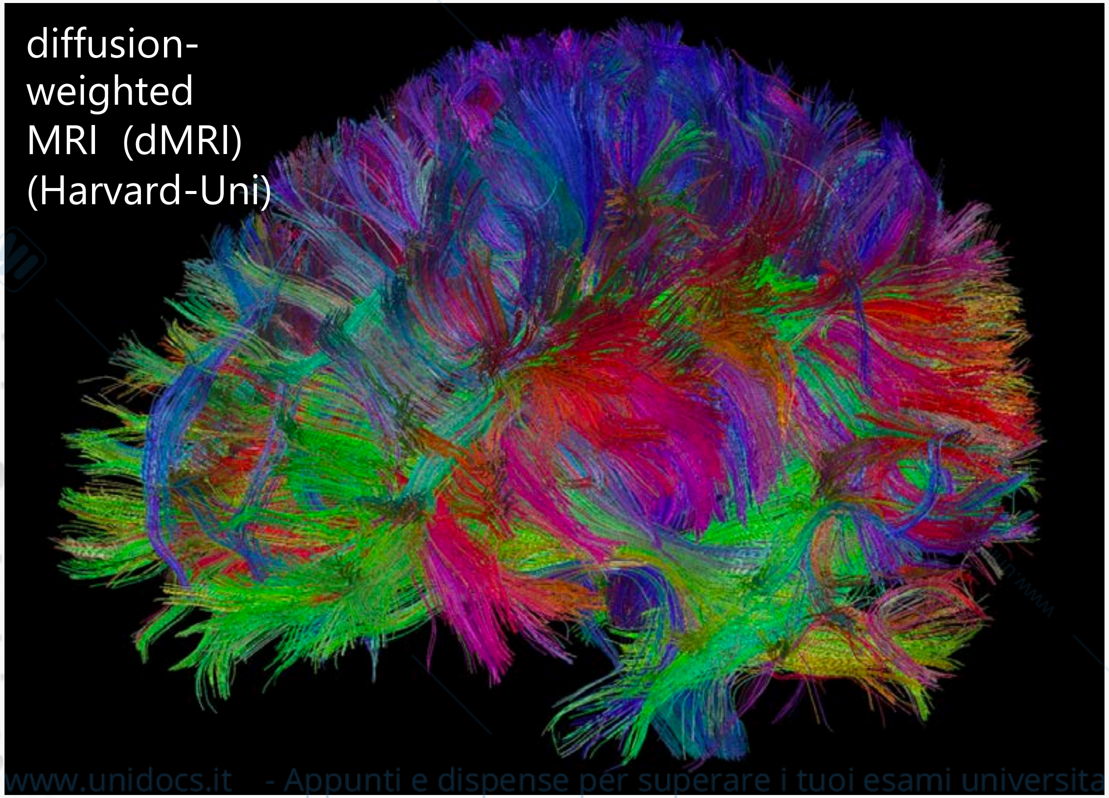
Complexity of the brain

it is estimated that the there are between 10^{78} to 10^{82} atoms in the known, observable **universe**

- The average brain consists of one hundred billion (10^{11}) neurons, but this does not explain its complexity. What matters are the possible connections btw neurons
  - Each neuron is connected to other neurons, usually one thousand to ten thousand others.
  - The number of possible connections between *n* neurons grows exponentially with n^2



n	$2^{\frac{n(n-1)}{2}}$
3	8
4	64
5	1024
6	32768
7	2097152
8	268435456
9	68719476736
10	3,51844E+13
11	3,60288E+16
12	7,3787E+19
13	3,02231E+23
14	2,47588E+27
15	4,05648E+31
16	1,32923E+36
17	8,71123E+40
18	1,1418E+46
19	2,99316E+51
20	1,56928E+57
21	1,6455E+63
22	3,45087E+69
23	1,4474E+76
24	1,21417E+83
25	2,03704E+90
26	6,83516E+97
27	4,587E+105
28	6,1566E+113
29	1,6526E+122
30	8,8725E+130

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Mind vs. Brain

- **Functionalism**: a theory of cognitive science that studies how our mental and behavioral process function in response to the real world
  - similar minds can arise from quite different brains
  - brains are the collection of “wires and processing modules” that instantiate thought
  - there are limits to how much we can know about thought from just studying brains

Structuralism is known to be a part of experimental psychology	Functionalism was introduced as a counter argument to structuralism
Focuses on different brain elements and their capacities	Focuses on the adaptations of human mind to different environments

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Mind vs. Brain – Common Illusions

- There is a widespread belief (even among scientists, particularly gestalt psychologists) that *inside the brain there is a strictly isomorphic representation of the world around us*
  - This intuition is flawed because If an isomorphic representation of an object is stored somewhere, there has to be a part of our brain that is «looking at» or «listening to» that representation. What would that «spectator» do with that it views/hears? Form another isomorphic representation of it? (self-referencing reasoning)
- We are also under the illusion that what we sense is immediately mapped onto an isomorphic representation of what we sense
  - This is also an illusion: our perceptions are the end product of a long chain of neural events that give us the illusion of an instantaneous sensory image.
  - There are many domains in which our strongest intuitions mislead us (e.g. flat earth)

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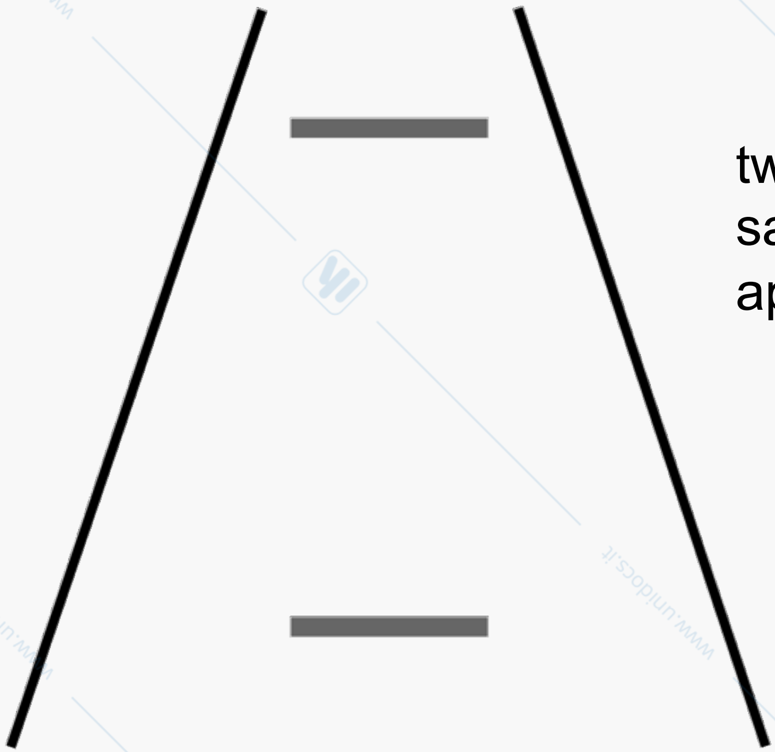
Mind vs. Brain – Common Illusions

- when functioning properly, our perceptual system is supposed to distort the world we see and hear in order to make sense of it
- We interact with the world around us through our senses, therefore what we see must come to an agreement with our understanding of the world around us
- Visual illusions are perhaps the most compelling proof of sensory distortion

Ponzo illusion:

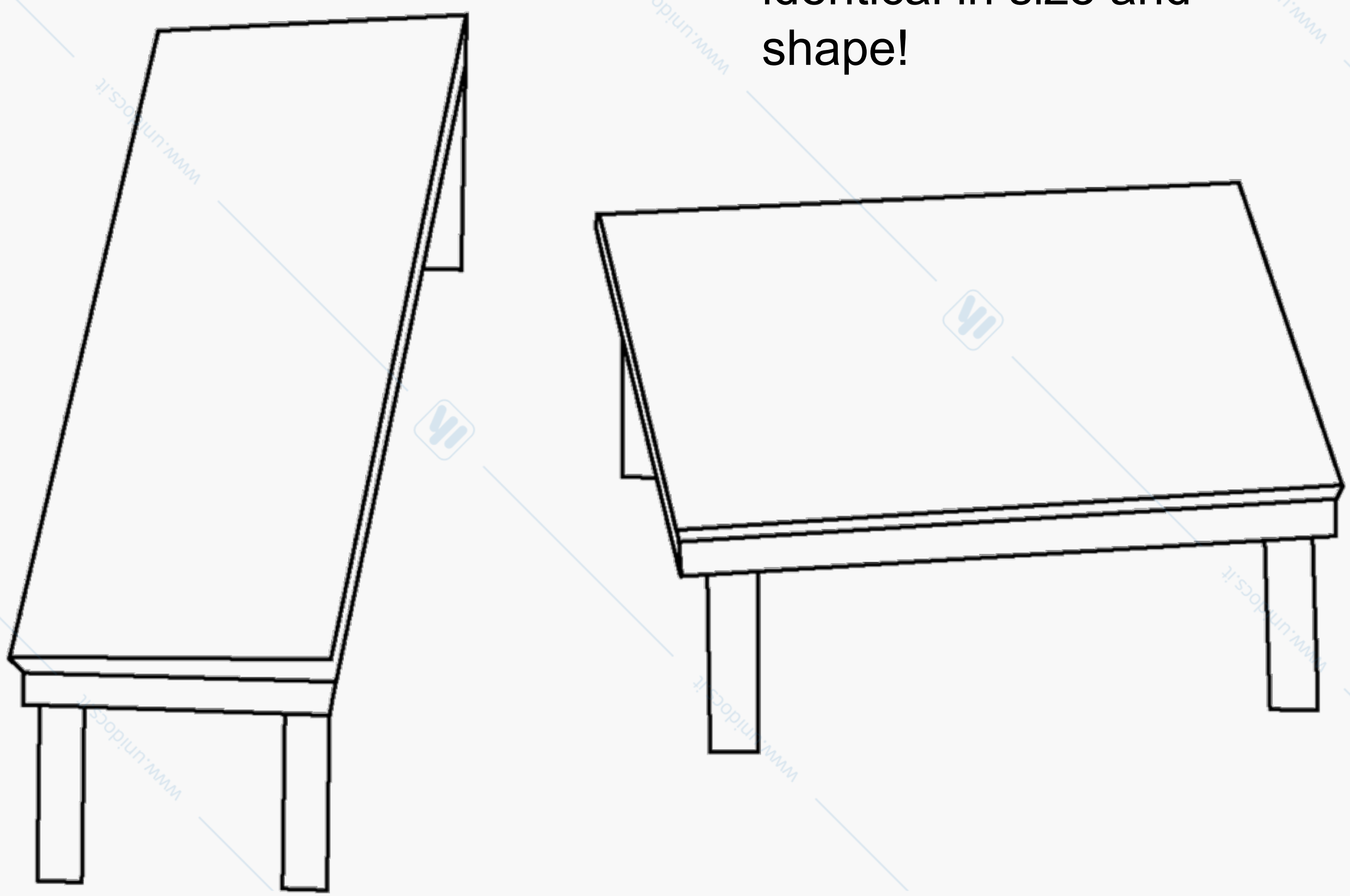


two lines of the same length appear different

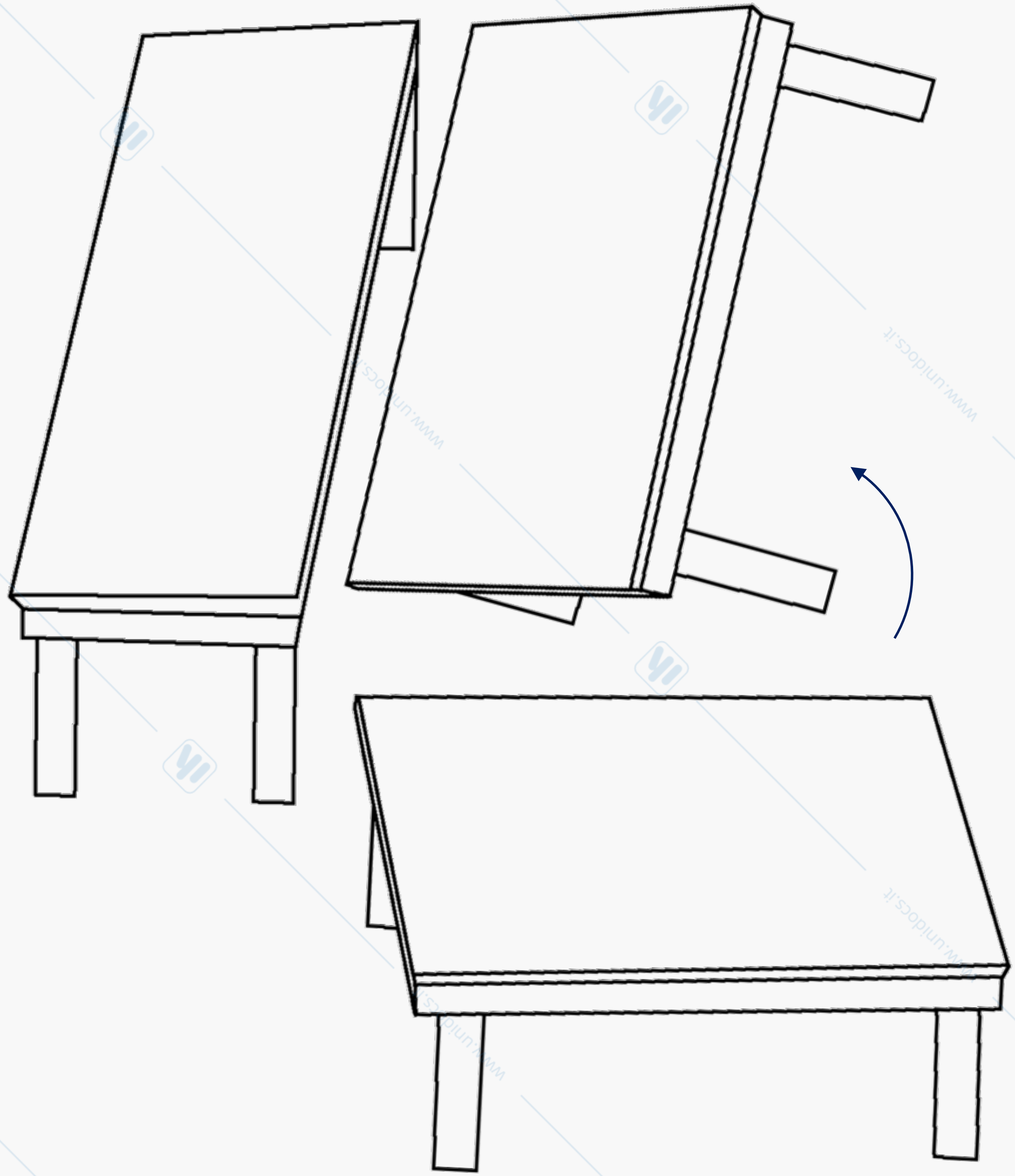
Mind vs. Brain – Common Illusions

- Visual illusions as proof of sensory distortion

these tabletops are identical in size and shape!

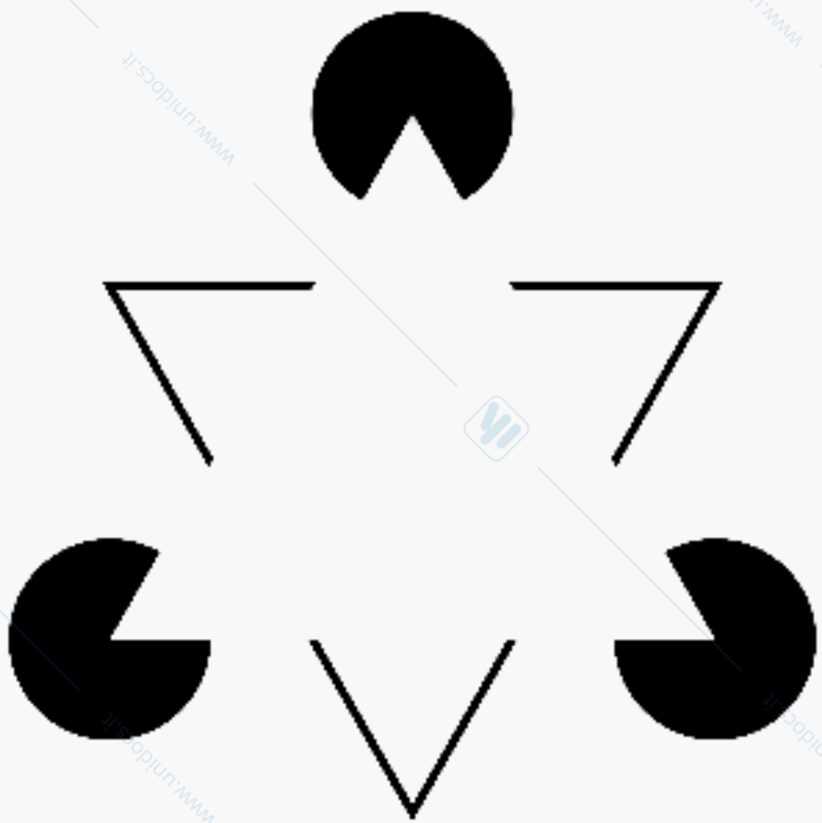


Check it...



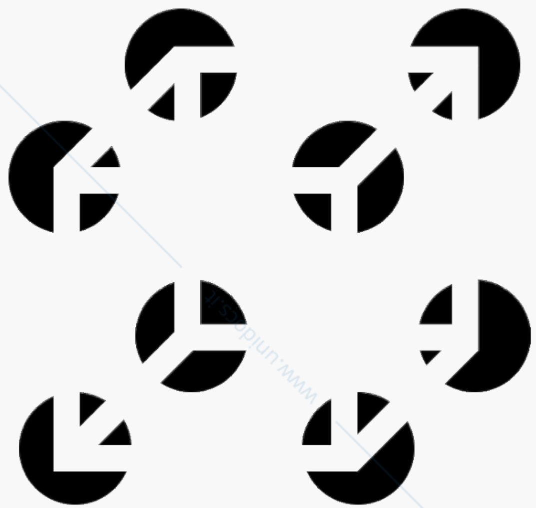
Mind vs. Brain – Common Illusions

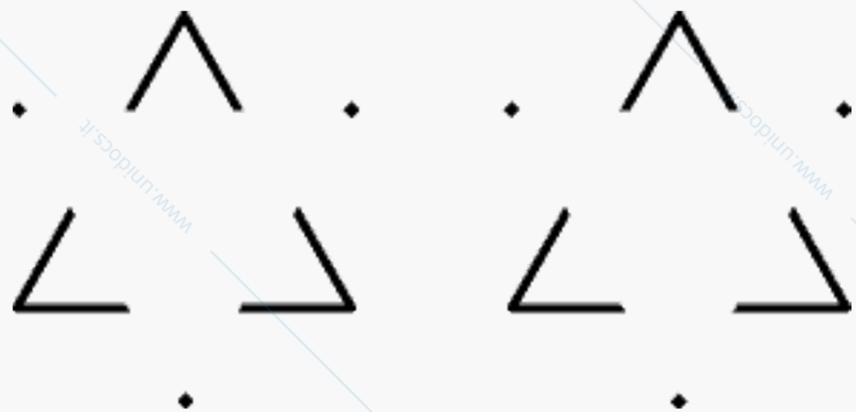
- Kaniza illusion

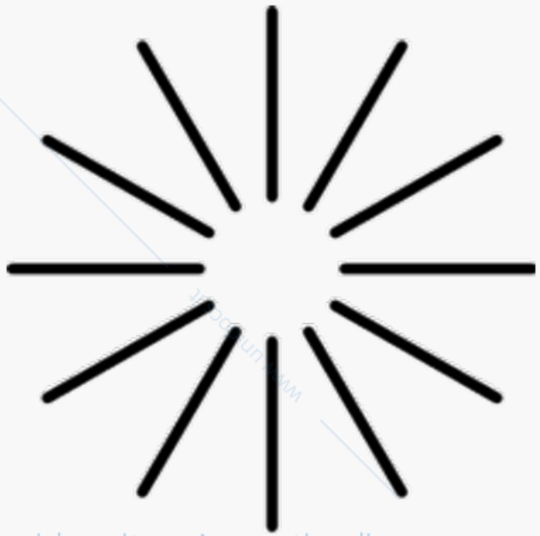


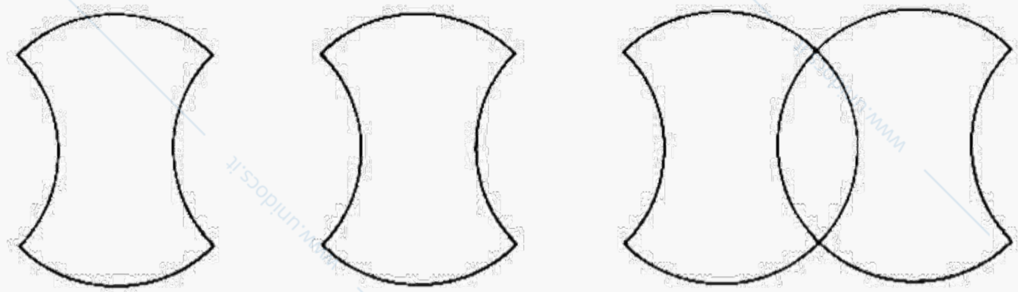
there appears to be a white triangle lying on top of a black-outlined one, but there are no triangles in the figure...

Mind vs. Brain – Common Illusions









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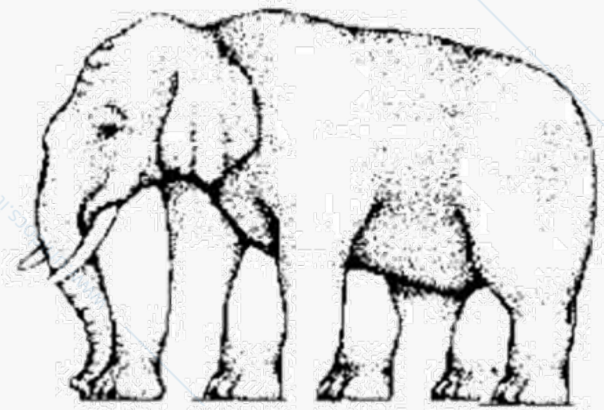

Mind vs. Brain – Common Illusions

Perceptual completion in audio

- The cognitive psychologist Richard Warren demonstrated this particularly well:
  - He recorded a sentence, “The bill was passed by both houses of the legislature”
  - He then cut out a piece of the sentence , and replaced it with a burst of white noise
  - Nearly everyone who heard the altered recording could report that they heard both a sentence and static. But a large proportion of people couldn’t tell *where* the static was!

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Mind vs. Brain – Common Illusions

Perceptual completion in audio

- Most of the time the information we receive at our sensory receptors is incomplete or ambiguous. Voices are mixed in with other voices and noise souces
- Our brain's ability to make these identifications is nothing short of remarkable, considering that it starts out with whatever sensory receptors pass up to it
- Grouping principles — by timbre, spatial location, loudness, and so on — help segregate them, but how this is done is still unclear
- Even more complex to address is how this works with music...

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Perceptual completion

A bottom-up approach

- A two-stage process based on
  - Feature extraction
  - Feature integration
- The brain extracts basic, low-level features from music, using specialized neural networks that decompose the signal into information about
  - Pitch
  - Timbre
  - Spatial location
  - Loudness
  - Reverberant environment
  - Tone durations
  - Onset times for different notes (and for different components of tones)
  - ...

These operations are carried out in parallel by neural circuits that compute these values and that can operate somewhat independently of one another

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Bottom-up vs. Top-down processing

Low-level, bottom-up processing of basic elements occurs in the peripheral and phylogenetically older parts of our brain

- Low-level refers to the perception of elemental or building-block attributes of a sensory stimulus
- High-level processing occurs in more sophisticated parts of our brains that take neural projections from the sensory receptors and from a number of low-level processing units; this refers to the combining of low-level elements into an integrated representation

High-level processing is where it all comes together, where our minds come to an understanding of form and content

Low-level processing allows a reader to see blobs of ink on a written page, put them together and perhaps recognize a basic form in the visual vocabulary

High-level processing puts together multiple basic forms (e.g. letters) into a word or a phrase and generate a mental image of its meaning

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Bottom-up vs. Top-down processing

As feature extraction is taking place in the cochlea, auditory cortex, brain stem, and cerebellum, the higher-level centers of our brain are receiving a constant flow of information about what has been extracted so far; this information is continually updated, and typically rewrites the older information.

As our centers for higher thought (mostly in the frontal cortex) receive these updates, they are working hard to predict what will come next in the music, based on several factors:

- what has already come before in the piece of music we are hearing (model-based prediction)
- what we remember will come next if the music is familiar
- what we expect will come next if the genre or style is familiar, based on previous exposure to this style of music
- any additional information we are given

These frontal-lobe calculations are called top-down processing and **they can exert influence on the lower-level modules while they are performing their bottom-up computations**. The top-down expectations can cause us to misperceive things by resetting some of the circuitry in the bottom-up processors. This is partly the **neural basis for perceptual completion and other illusions**

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High-level processing

The ultimate illusion in music is the illusion of structure and form

- There is nothing in a sequence of notes themselves that creates the rich emotional associations we have with music, nothing about a scale, a chord, or a chord sequence that intrinsically causes us to expect a resolution
- Our ability to make sense of music depends on experience, and on neural structures that can learn and modify themselves with each new song we hear, and with each new listening to an old song
- Our brains learn a kind of musical grammar that is specific to the music of our culture, just as we learn to speak the language of our culture
- According to Noam Chomsky we are all born with an innate capacity to understand any of the world's languages, and that experience with a particular language shapes, builds, and then ultimately prunes a complicated and interconnected network of neural circuits
- Our brains and natural languages coevolved so that all of the world's languages share certain fundamental principles, and our brains have the capacity to incorporate **any** of them through mere exposure

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High-level processing

Similarly, it seems that we all have an innate capacity to learn any of the world's musics, although they, too, differ in substantial ways from one another

- The brain undergoes a period of rapid neural development after birth, continuing for the first years of life. During this time, new neural connections are forming more rapidly than at any other time in our lives, and during our midchildhood years, the brain starts to prune these connections, retaining only the most important and most often used ones
- This becomes the basis for our understanding of music, and ultimately the basis for what we like in music, what music moves us, and how it moves us. This is not to say that we can't learn to appreciate new music as adults, but basic structural elements are incorporated into the very wiring of our brains when we listen to music early in our lives

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Music and emotions: anticipation and expectation

- Music is organized sound, but the organization has to involve some element of the unexpected or it is emotionally flat
- The appreciation we have for music is intimately related to our ability to learn the underlying structure of the music we like and to be able to make predictions about what will come next
- Composers imbue music with emotion by knowing what our expectations are and then very deliberately controlling when those expectations will be met, and when they won't
- A typical example in western classical music is the deceptive cadence. A cadence is a chord sequence that sets up a clear expectation and then closes, typically with a satisfying resolution. In the deceptive cadence, the composer repeats the chord sequence again and again until he has finally convinced the listeners that we're going to get what we expect, but then at the last minute, he gives us an unexpected chord, a chord that tells us that it's not over, a chord that doesn't completely resolve.
  - Haydn's use of the deceptive cadence is so frequent, it borders on an obsession
  - The Beatles' "For No One" ends on the V chord and we wait for a resolution that never comes, at least not in that song. But the very next song on the album Revolver starts with the very chord we were waiting to hear https://youtu.be/ELILIwhvknk

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Anticipation and expectation

Examples of violated expectations

- Steely Dan: his songs are essentially blues but include unusual harmonies that make them sound very unblues. E.g. “Chain Lightning” https://youtu.be/K-zhjJatmpA
- In “Yesterday,” the main melodic phrase is seven measures long; the Beatles surprise us by violating one of the most basic assumptions of popular music, the four- or eight-measure phrase unit https://youtu.be/jo505ZyaCbA
- In “I Want You (She’s So Heavy),” the Beatles first set up a hypnotic, repetitive ending that sounds like it will go on forever. We expect a fade out, instead the song ends abruptly in the middle of a random note https://youtu.be/tAe2Q_LhY8g

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Neural basis for musical expectations and emotion

If we acknowledge that the brain is constructing a version of reality, we must reject that the brain has an accurate and strictly isomorphic representation of the world. So...

what is the brain holding in its neurons that represents the world around us?

The brain represents music in terms of mental or neural codes

- Neuroscientists try to decipher this code and understand its structure, and how it translates into experience
- Cognitive psychologists try to understand these codes at a somewhat higher level

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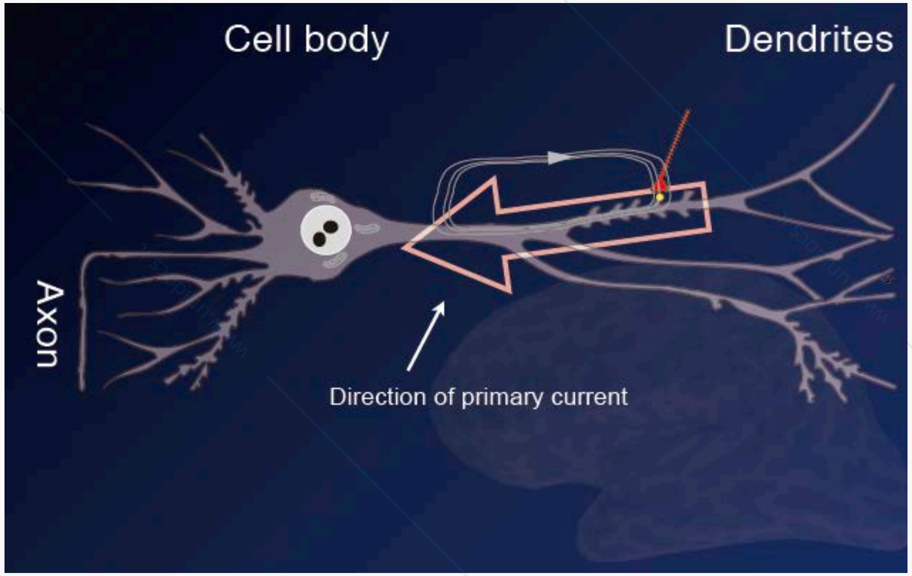
Neural basis for musical expectations and emotion

- Neurons are the primary cells of the brain; they are also found in the spinal cord and the peripheral nervous system
- Activity from outside the brain can cause a neuron to fire
- The neurons in the brain aren't actually touching; there's a space between them called the synapse
- When a neuron is firing, it sends an electrical signal that causes the release of a neurotransmitter



- Neurotransmitters are chemicals that travel throughout the brain and bind to receptors attached to other neurons. Receptors and neurotransmitters can be thought of as locks and keys respectively. After a neuron fires, a neurotransmitter swims across that synapse to a nearby neuron, and when it finds the lock and binds with it, then the new neuron starts to fire. Not all keys fit all locks; there are certain locks (receptors) that are designed to accept only certain neurotransmitters
- Generally, neurotransmitters cause the receiving neuron to fire or prevent it from firing. The neurotransmitters are then absorbed through a process called **reuptake**; without reuptake, the neurotransmitters would continue to stimulate or inhibit the firing of a neuron

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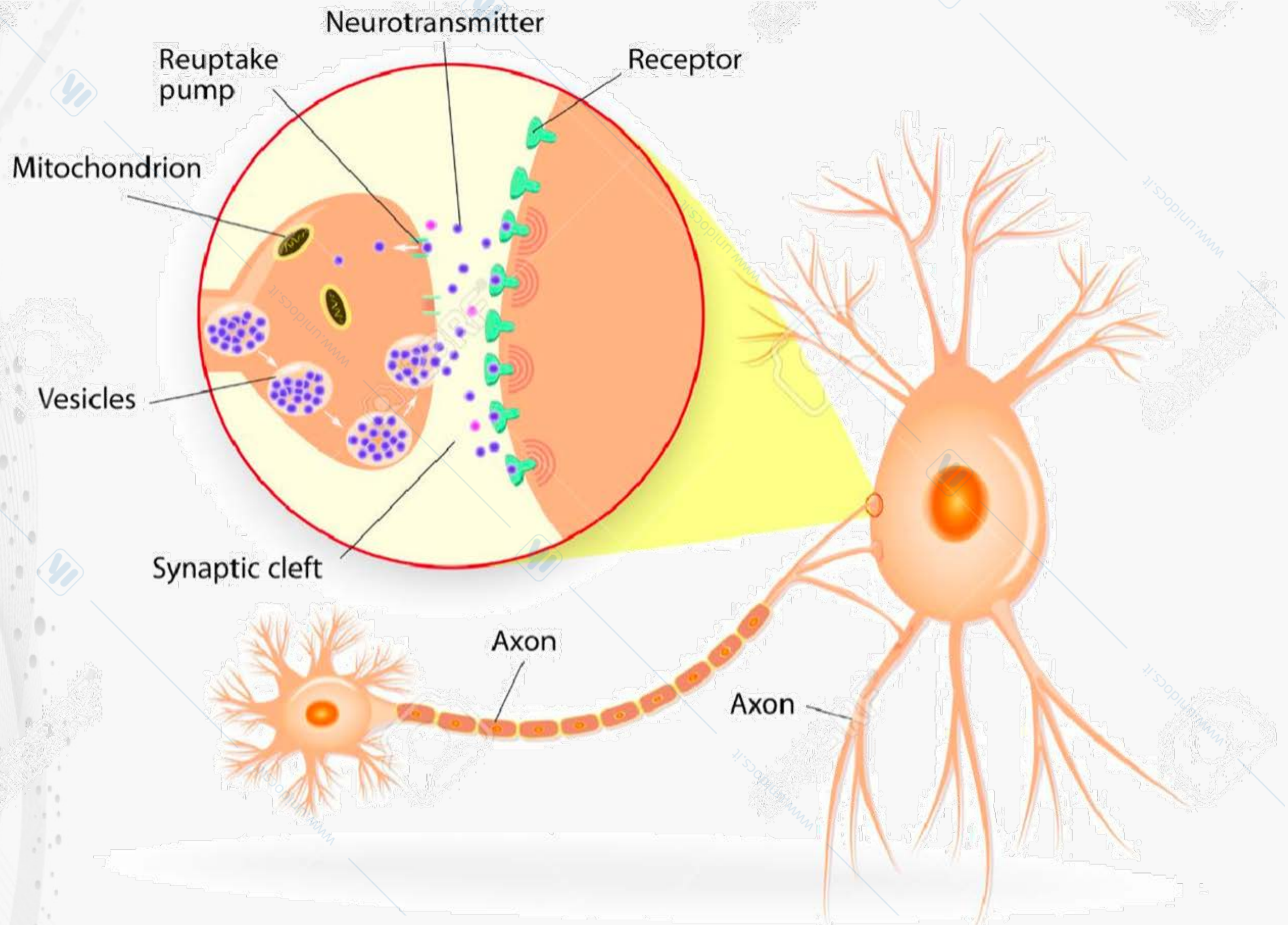
https://youtu.be/WhowH0kb7n0

Neural basis for musical expectations and emotion



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Neural basis for musical expectations and emotion

Some neurotransmitters are used throughout the nervous system, and some only in certain brain regions and by certain kinds of neurons

- **Serotonin is produced in the brain stem and is associated with the regulation of mood and sleep**.
  Antidepressants (e.g. Prozac and Zoloft) are known as selective serotonin reuptake inhibitors (SSRIs), allowing serotonin to act for a longer period of time. The precise mechanism by which this alleviates depression, obsessive-compulsive disorder, and mood and sleep disorders is not known
- **Dopamine is released by the nucleus accumbens and is involved in mood regulation and the coordination of movement**
  Most famous for being part of the brain's *pleasure and reward system*. When drug addicts get drug, or when compulsive gamblers win a bet, this is the neurotransmitter that is released. Its role and the important role played by the nucleus accumbens in music was unknown until 2005

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Neural basis for musical expectations and emotion

- Hemispheric specialization (the popular conception that the left brain is analytical and the right brain is artistic) has some merit, but is overly simplistic
  - Both sides of the brain engage in analysis and both sides in abstract thinking
  - All of these activities require coordination of the two hemispheres, although some of the particular functions involved are clearly lateralized
  - Speech processing is primarily left-hemisphere localized, although certain global aspects of spoken language, such as intonation, emphasis, and the pitch pattern, are more often disrupted following right-hemisphere damage
  - The ability to distinguish a question from a statement, or sarcasm from sincerity, often rests on these right-hemisphere lateralized, nonlinguistic cues, known collectively as prosody
- It is natural to wonder whether music shows the opposite asymmetry, with processing located primarily on the right
  - There are many cases of individuals with brain damage to the left hemisphere who lost the power of speech, but retained their musical function, and vice versa
  - Cases like these suggest that music and speech, although they may share some neural circuits, cannot use completely overlapping neural structures

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Neural basis for musical expectations and emotion

Just as local features of spoken language (early processing) appear to be left-hemisphere lateralized, local features of in the brain basis of music are also lateralized

- Right hemisphere
  - melodic shape
  - fine discriminations of tones that are close together in pitch
- Left hemisphere
  - naming aspects of music (a song, a performer, an instrument, or a musical interval)
- Lateralization based on which half of the body is being used
  - musicians using their right hands or reading music from their right eye also use the left brain because the left half of the brain controls the right half of the body
- Left frontal lobe
  - tracking the ongoing development of a musical theme
  - thinking about key and scales and whether a piece of music makes sense or not
- Musical training appears to have the effect of shifting some music processing from the right (imagistic) hemisphere to the left (logical) hemisphere, as musicians learn to talk/think about music using linguistic terms
- The normal course of development seems to cause greater hemispheric specialization: children show less lateralization of musical operations than do adults, regardless of whether they are musicians or not

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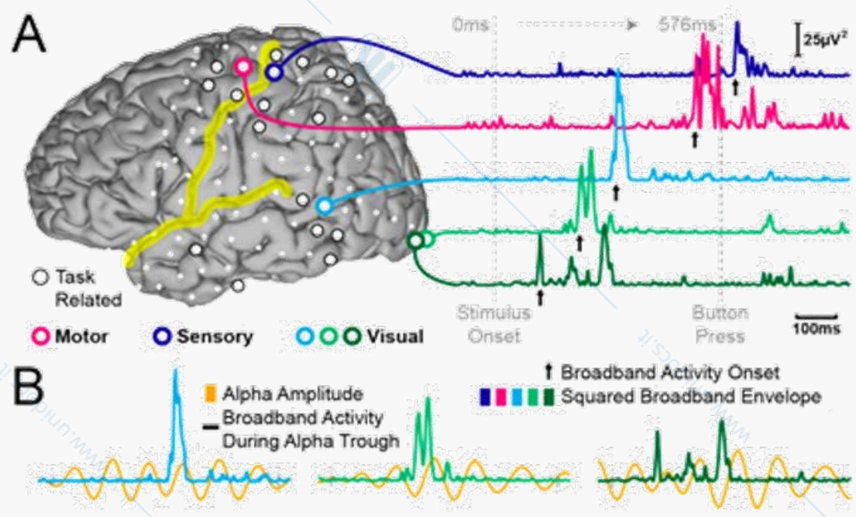
Studying brain response: EEG



Neural firings produce a small electric current

We can measure when and how often neurons are firing through EEG (electro-encephalogram), whose electrodes are placed on the scalp

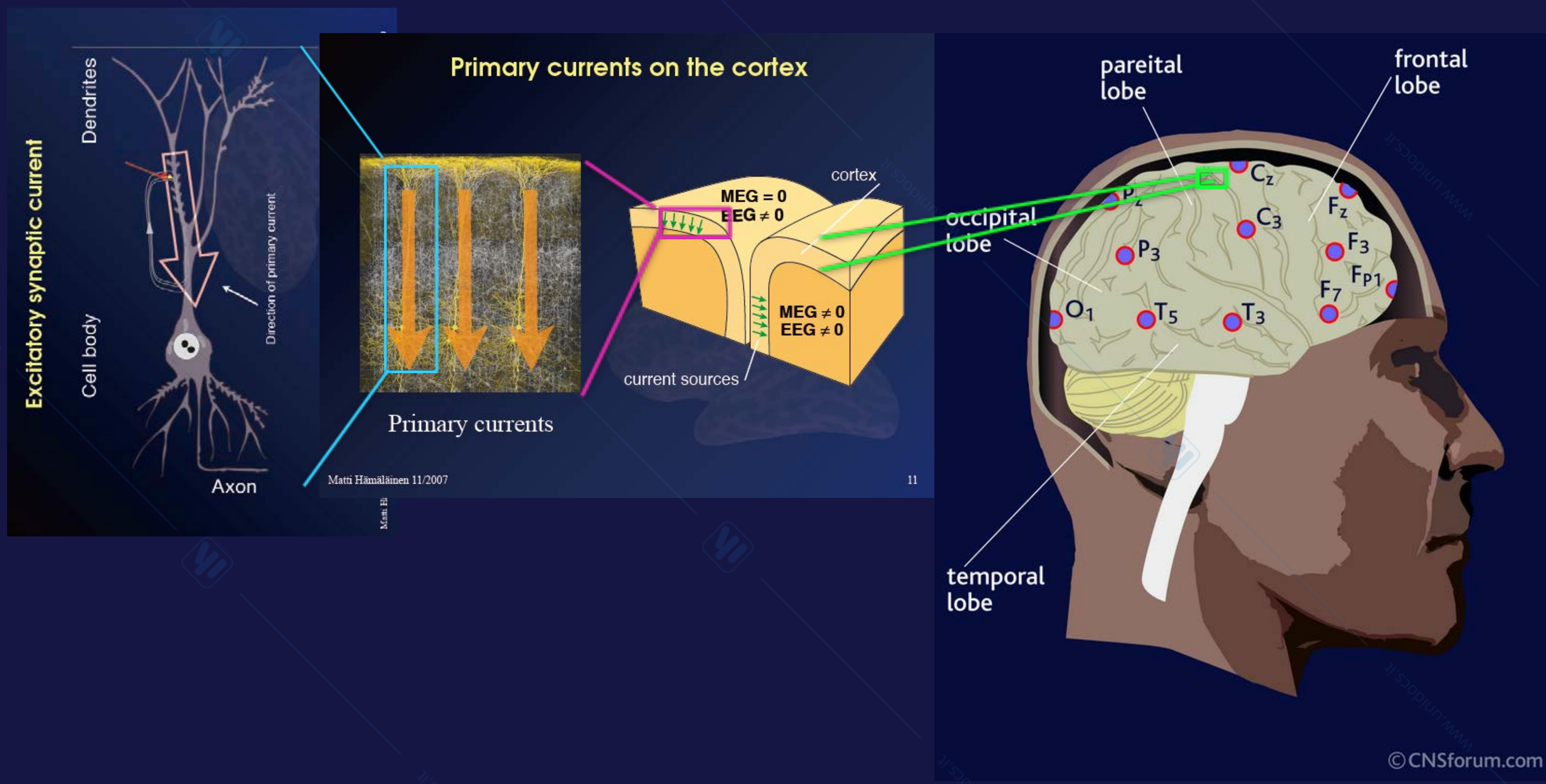
The EEG is particularly sensitive to the timing of neural firings, and can detect activity with excellent temporal resolution (about 1 ms)

EEG, however, has limits:

- **cannot classify neural activity**, i.e. distinguish whether the neuron is releasing excitatory, inhibitory, or modulatory neurotransmitters (which refers to the chemicals such as serotonin and dopamine that influence the behavior of other neurons)
- **limited sensitivity**: because the electrical signature generated by a single neuron firing is relatively weak, the EEG only picks up the synchronous firing of large groups of neurons, rather than individual neurons
- **limited spatial resolution**: it cannot tell us the exact location of the neural firings due to scattered propagation. Spatial resolution gets worse when the firing occurs at greater depth

Despite such limitations, EEG is helpful in understanding musical behavior because music is time based, and EEG has much better temporal resolution than other imaging/analysis tools (e.g. MRI)

Neural basis for musical expectations and emotion



Studying brain response: MEG

- Magnetoencephalography (MEG) is a functional neuroimaging technique for mapping brain activity by recording magnetic fields produced by electrical currents occurring naturally in the brain, using very sensitive magnetometers
- Arrays of SQUIDs (Superconducting QUantum Interference Devices) are currently the most common magnetometer, while the SERF (Spin Exchange Relaxation-Free) magnetometer is being investigated for future machines

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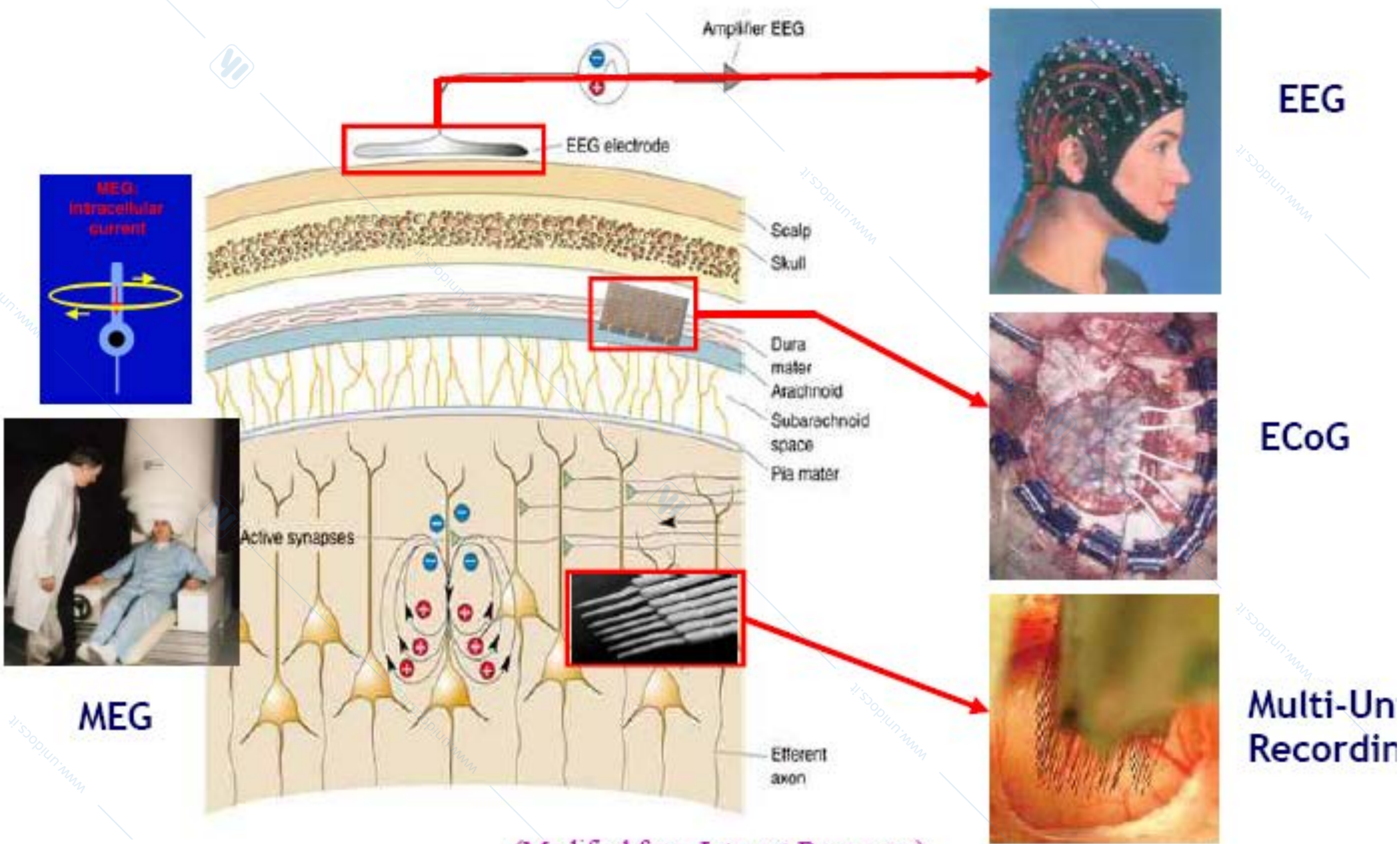
Neural Electrical Signal Measurements

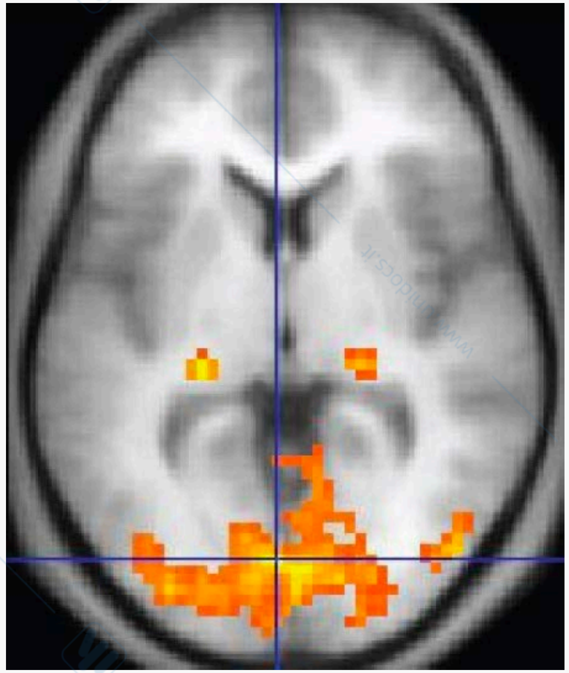


(Modified from Internet Resources)

Studying brain response: fMRI

Functional Magnetic Resonance Imaging or **functional MRI** (**fMRI**) measures brain activity by detecting changes associated with blood flow. This technique relies on the fact that cerebral blood flow and neuronal activation are coupled. When an area of the brain is in use, blood flow to that region also increases

- The primary form of fMRI uses the blood-oxygen-level dependent (BOLD) contrast. This is a type of specialized brain and body scan used to map neural activity in the brain by imaging the change in blood flow (hemodynamic response) related to energy use by brain cells
- As the measure is frequently corrupted by noise from various sources signal processing is needed to perform statistical extraction of the underlying signal
- The resulting brain activation can be graphically represented by color-coding the strength of activation across the brain or the specific region studied
- **The technique can localize activity to within millimeters** but, using standard techniques, no better than within a window of a few seconds.
- Other methods of obtaining contrast are arterial spin labeling and diffusion MRI (the latter procedure is similar to BOLD fMRI but provides contrast based on the magnitude of diffusion of water molecules in the brain



An fMRI image with yellow areas showing increased activity compared with a control condition

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Neural basis for musical expectations and emotion

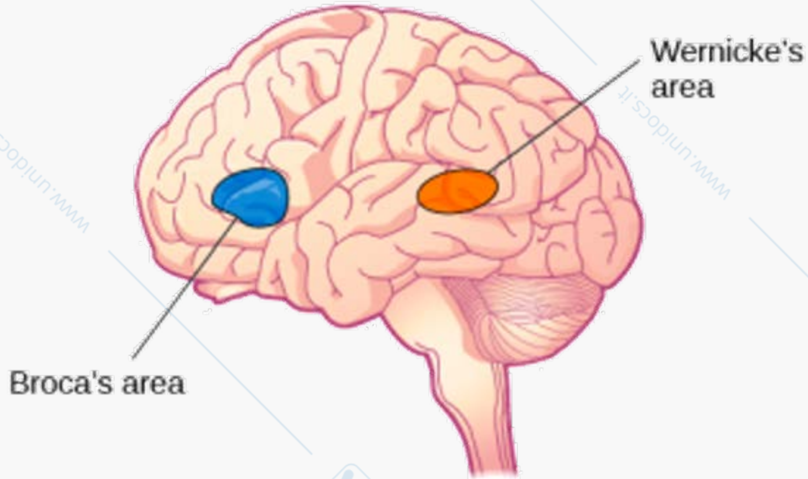
Back to the question: how do we study brain response?

EEG can be used for studying expectation in harmonic progressions:

The experimenters play chord sequences that either resolve in the standard, schematic way, or that end on unexpected chords

After the onset of the chord:

- electrical activity in the brain associated with musical structure is observed within 150–400 ms
- activity associated with musical meaning about 100–150 ms later



The structural processing (musical syntax) has been localized to the frontal lobes of both hemispheres in areas adjacent to and overlapping with those regions that process speech syntax, such as Broca's area, and shows up regardless of whether listeners have musical training

The regions involved in musical semantics (associating a tonal sequence with meaning) appear to be in the back portions of the temporal lobe on both sides, near Wernicke's area

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Neural basis for musical expectations and emotion

The brain's music system appears to operate with functional independence from the language system

The evidence comes from many case studies of patients who, postinjury, lose one or the other faculty but not both

- Clive Wearing, a musician and conductor, whose brain was damaged as a result of herpes encephalitis (he lost all memory except for musical memories, and the memory of his wife)
- When portions of his left cortex deteriorated, the composer Ravel selectively lost his sense of pitch while retaining his sense of timbre, a deficit that inspired his writing of Bolero, a piece that emphasizes variations in timbre

The most parsimonious explanation is that music and language do, in fact, share some common neural resources, and yet have independent pathways as well

The close proximity of music and speech processing in the frontal and temporal lobes, and their partial overlap, suggests that those neural circuits that become recruited for music and language may start out life undifferentiated. Experience and normal development then differentiate the functions of what began as very similar neuronal populations

- Consider that at a very early age, babies are thought to be synesthetic, to be unable to differentiate the input from the different senses

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Neural basis for musical expectations and emotion

- The process of maturation creates distinctions in the neural pathways as connections are cut or pruned
- What may have started out as a neuron cluster that responded equally to sights, sound, taste, touch, and smell becomes a specialized network
- So, too, may music and speech have started in us all with the same neurobiological origins, in the same regions, and using the same specific neural networks. With increasing experience and exposure, the developing infant eventually creates dedicated music pathways and dedicated language pathways

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Studying brain response: fMRI

- **Spatial resolution of EEG is not fine enough to really pinpoint the neural locus of musical syntax**
- Because the hemoglobin of the blood is slightly magnetic, changes in the flow of blood can be traced with a magnetic resonance imaging machine (MRI) is, which in turn can tell us where, at any given point in time, the blood is flowing in the body.
- As neurons need oxygen, and the blood carries oxygenated hemoglobin, we can trace the flow of blood in the brain too.
- Neurons that are actively firing need more oxygen than neurons that are at rest, and so those regions of the brain that are involved in a particular cognitive task will be just those regions with the most blood flow at a given point in time. When we use the MRI machine to study the function of brain regions in this way, the technology is called functional MRI, or fMRI.
- **fMRI images let us see a human brain while it is thinking**
- With the high spatial resolution of fMRI, one can tell within just a couple of millimeters where something is occurring in the brain. The problem, however, is that the temporal resolution of fMRI isn't particularly good because of the amount of time it takes for blood to become redistributed in the brain (hemodynamic lag)

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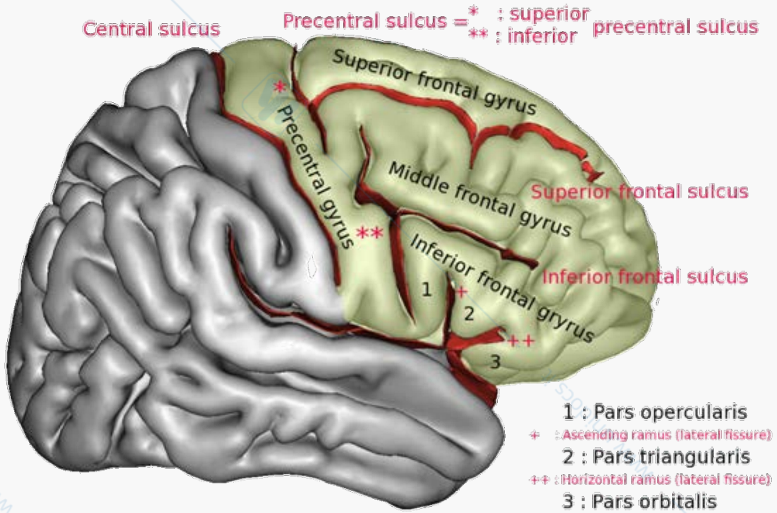
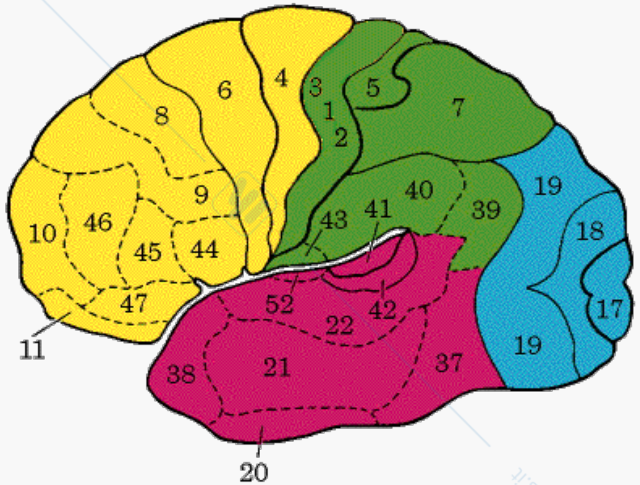
Studying brain response: fMRI

- When the goal is to localize activities (where) rather than onsets (when) fMRI is a better option
- In particular, it is interesting to learn about if there are areas of speech that are involved in music
- Listening to music and attending to its syntactic features (structure) turns out to activate a particular region of the frontal cortex on the left side called **pars orbitalis** — a subsection of the region known as Brodmann Area 47.
- The region found to be activated had some overlap with those related to language + new ones
- In addition to this left hemisphere activation, there is an analogous area of the right hemisphere, which suggests that attending to structure in music requires both halves of the brain, while attending to structure in language only requires the left half





- the left-hemisphere regions that are found to be active in tracking musical structure are same ones that are active when deaf people are communicating by sign language
- this a region that responds to sight as well, which suggests that it processes structure in general, which is conveyed over time

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...to summarize

All sound begins at the eardrum where sounds get segregated by "pitch".

Speech and music diverge into separate processing circuits

Speech circuits decompose the signals in order to identify individual phonemes

Music circuits decompose the signals and separately analyze pitch, timbre, contour and rhythm

The output of the neurons performing these tasks connect to regions in the frontal lobe that put all of it together and try to figure out if there is any structure or order to the "temporal" patterning of it all

The frontal lobes access our hippocampus and regions in the interior of the temporal lobe and ask if there is anything in our memory banks that can help to understand this signal

Have I heard this "pattern" before?

If so when?

Is it part of a larger sequence whose meaning is unfolding right now in front of me?

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How we Categorize Music

HOW ARE MEMORIES OF MUSIC DIFFERENT FROM OTHER MEMORIES? WHY CAN MUSIC TRIGGER MEMORIES IN US THAT OTHERWISE SEEMED BURIED OR LOST? AND HOW DOES EXPECTATION LEAD TO THE EXPERIENCE OF EMOTION IN MUSIC? HOW DO WE RECOGNIZE SONGS WE HAVE HEARD BEFORE?

TUNE RECOGNITION INVOLVES A NUMBER OF COMPLEX NEURAL COMPUTATIONS INTERACTING WITH MEMORY. IT REQUIRES THAT OUR BRAINS IGNORE CERTAIN FEATURES WHILE WE FOCUS ONLY ON FEATURES THAT ARE INVARIANT FROM ONE LISTENING TO THE NEXT (INVARIANT PROPERTIES OF A SONG)

THE BRAIN MUST BE ABLE TO SEPARATE THE ASPECTS OF A SONG THAT REMAIN THE SAME EACH TIME WE HEAR IT FROM THOSE THAT ARE ONE-TIME-ONLY VARIATIONS, OR FROM THOSE THAT ARE PECULIAR TO A PARTICULAR PRESENTATION (VOLUME, PITCH, INSTRUMENTATION, TEMPO, ...)

TUNE RECOGNITION DRAMATICALLY INCREASES THE COMPLEXITY OF THE NEURAL SYSTEM NECESSARY FOR PROCESSING MUSIC. SEPARATING THE INVARIANT PROPERTIES FROM THE MOMENTARY ONES IS A HUGE COMPUTATIONAL PROBLEM

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How we Categorize Music

Debate about the 'nature' and function of memory in humans

- Two theories: the Relational School (also called the Constructivist view) AND the Record-keeping theory
- Constructivist Theory
  - our memory system stores information about the relations between objects and ideas, but not necessarily details about the objects themselves
  - Known as the constructivist view because it implies that, lacking sensory specifics, we construct a memory representation of reality out of these relations (with many details filled in or reconstructed on the spot)
  - the function of memory is to ignore irrelevant details, while preserving the gist
- Record Keeping Theory
  - memory is like a tape recorder or digital video camera, preserving all or most of our experiences accurately, and with near perfect fidelity

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How we Categorize Music

- Evidence in support of constructivists
  - studies in which people listen to speech (auditory memory) or are asked to read text (visual memory) and then report what they've heard or read
  - In study after study, people are not very good at recreating a word-for-word account. They remember general content, but not specific wording
  - Several studies also point to the malleability of memory. Seemingly minor interventions can powerfully affect the accuracy of memory retrieval
    - Elizabeth Loftus (Uni-Washington) was interested in the accuracy of witnesses' courtroom testimonies. Subjects were shown videotapes and asked leading questions about the content.
    - If shown two cars that barely scraped each other, one group of subjects might be asked, "How fast were the cars going when they scraped each other?" and another group would be asked, "How fast were the cars going when they smashed each other?" Such one-word substitutions caused dramatic differences in the eyewitnesses' estimates of the speeds of the two vehicles.
    - Then Loftus brought the subjects back, sometimes up to a week later, and asked, "How much broken glass did you see?" (There really was no broken glass.) The subjects who were asked the question with the word smashed in it were more likely to report "remembering" broken glass in the video
- Evidence in support of record-keeping theory
  - According to this theory, every experience leaves a trace or residue in the brain. Experiences are stored as traces, they said, that are reactivated when we retrieve the episodes from memory.
    - Roger Shepard showed people hundreds of photographs for a few seconds each. A week later, he brought the subjects back into the laboratory and showed them pairs of photographs that they had seen before, along with some new ones that they hadn't. In many cases, the "new" photos had only subtle differences from the old, such as the angle of the sail on a sailboat, or the size of a tree in the background. Subjects were able to remember which ones they had seen a week earlier with astonishing accuracy
    - Our ability to recognize hundreds of voices also support record-keeping theory

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How we Categorize Music

How can a song is able to retain its identity in spite of transposition in pitch and time?

- In a number of experiments run at MIT in the early 1960s, Benjamin White systematically altered well-known songs by transpose all the pitches or altering pitch distances while preserving the contour. He played tunes backward and forward and changed their rhythms. The warped tune was recognized more often than not.
- White showed that most listeners can recognize a song in position almost immediately and without error. And they could recognize all kinds of deformations of the original tune as well. The constructivist interpretation of this is that the memory system must be extracting some generalized, invariant information about songs and storing that
- A Russian patient known as S. affected by **hypermnesia** (opposite of amnesia – as he remembered everything). S. was unable to recognize that different views of the same person were related to a single individual. Same happened with different facial expressions. S. was unable to form abstract generalizations, only his record-keeping system was intact

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How we Categorize Music

How can a song is able to retain its identity in spite of transposition in pitch and time?

- **Ludwig Wittgenstein** (Austrian-British philosopher) proposed that category membership is determined not by a definition, but by family resemblance
  We call something a "game" if it resembles other things we have previously called "games"
- This idea forms the basis for the most compelling theory in contemporary memory research, the **multiple-trace memory models** (cognitive scientists Douglas Hintzman and Stephen Goldinger)
- **Multiple trace theory** is a memory consolidation model advanced as an alternative model to strength theory. It posits that each time some information is presented to a person, it is neurally encoded in a unique memory trace composed of a combination of its attributes
- The mode in which the information is presented and subsequently encoded can be flexibly incorporated into the model
- This memory trace is unique from all others resembling it due to differences in some aspects of the item's attributes, and all memory traces incorporated since birth are combined into a multiple-trace representation in the brain
- In memory research, a mathematical formulation of this theory can successfully explain empirical phenomena observed in recognition and recall tasks

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How we Categorize Music

Based on these ideas, the cognitive psychology Eleanor Rosch (UCB), developed the well-known **prototype theory**, based on a number of intuitions:

1. something can belong to a category in a “graded” fashion
2. experiments on categories that had been done before her used artificial concepts and sets of artificial stimuli that had little to do with the real world and were likely to introduce a bias
3. certain stimuli hold a privileged position in our perceptual system or our conceptual system, and these become prototypes for a category: Categories are formed around these prototypes e.g.: categories like “red” and “blue” are a consequence of our retinal physiology

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How we Categorize Music

- Eleanor Rosch's conclusions and thoughts on "Category Formation"
  1. Categories are formed around prototypes
  2. These prototypes can have a biological or physiological foundation;
  3. Category membership can be thought of as a question of degree, with some tokens being "better" exemplars than others;
  4. New items are judged in relation to the prototypes, forming gradients of category membership;
  5. There don't need to be any attributes which all category members have in common, and boundaries don't have to be definite

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How we Categorize Music

According to Roger Shepard (American cognitive scientist, author of the Universal Law of Generalization) **there are three basic appearance-reality problems that need to be solved by all higher animals**:

- objects, though in presentation they may be similar, may be inherently different (involves perception)
- objects, though in presentation they may be different, may be inherently identical (involves perception)
- objects, although different in presentation, may be of the same natural kind (involves cognition)

Adaptive behavior depends on a computational system that can analyze the information available at the sensory surfaces into

1. invariant properties of the external object or scene
2. momentary circumstances of the manifestation of that object or scene

classification is essential to enable composers, performers, and listeners to internalize the norms governing musical relationships, and consequently, to comprehend the implications of patterns, and experience deviations from stylistic norms

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How we Categorize Music

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This is like what a jazz artist does with a well-known song, or standard

musical variations share a family resemblance and each version of a song can be thought of as a variation on a prototype

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How we Categorize Music

Music is quite robust in the face of transformations and distortions of its basic features.

We can change all of the pitches used in the song (transposition), the tempo, and the instrumentation, and the song is still recognized as the same song. We can change the intervals, the scales, even the tonality from major to minor or vice versa.

With such dramatic changes, the song is still recognizable as the song

Smile (Charlie Chaplin)	Original https://youtu.be/xq45pfU5_nU	Avishai Cohen https://youtu.be/tL61H4m97l4
50 ways to leave your lover (Paul Simon)	P. Simon https://youtu.be/ABXtWqmArUU	Brad Mehldau Trio https://youtu.be/MNUU2lktnmY

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Absolute Pitch (and Tempo)

- People with AP can name notes as effortlessly as most of us name colors
- Why do only a few people have AP? Why don't we all?
- Yet, although people tend not to sing in the same keys as one another, they do tend to sing a song consistently in the same key from one occasion to the other. This suggests that they had encoded the pitches of the songs in long-term memory
- Some suggest that these results could be accounted for without memory for pitch by simply relying on muscle memory. Earlier studies, however, showed that muscle memory isn't that good, as it gets you at best within a third of an octave of the correct tone
- On the other hand, when subjects are asked to sing their chosen songs (those they are very familiar with), they get the correct pitch with surprising accuracy
- *The same experiments done for pitch showed that the majority of subjects sing at the correct tempo as well*

Memory and Music

- Findings from memory for popular songs provide strong evidence that absolute features of music are encoded in memory. This tends to support the record-keeping hypothesis
- We can also scan songs in our mind's ear and we can imagine transformations of them, therefore we also have evidence supporting the constructivist theory. How is this information stored and abstracted?
- Our memory for music involves hierarchical encoding (not all elements are equally salient, and we always have certain special "entry points")
- Most musicians cannot start playing a piece of music they know at any arbitrary location; musicians learn music according to a hierarchical phrase structure

Memory and Music

- The multiple-trace memory model is gradually replacing the two competing memory theories (record-keeping and constructivist)
- This is the model that most closely resembles the exemplar model of categorization
  - As we listen to a melody, in addition to registering the absolute values, we compute melodic intervals and tempo-free rhythmic information. Melodic "calculation centers" in the dorsal (upper) temporal lobes—just above your ears—seem to be paying attention to interval size and distances between pitches as we listen to music, creating a pitch-free template of the very melodic values we will need in order to recognize songs in transposition
  - familiar music activates both these regions and the hippocampus, a structure deep in the center of the brain that is known to be crucial to memory encoding and retrieval
  - This suggests that we are storing both the abstract and the specific in-formation contained in melodies. This may be the case for all kinds of sensory stimuli
  - Because they preserve context, multiple-trace memory models can also explain how we sometimes retrieve old and nearly forgotten memoriess

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What Makes a Musician: Expertise Dissected

- Traditionally musical expertise is defined as a technical achievement, i.e. mastery of an instrument or of compositional skills
- Either high levels of musical achievement are based on innate brain structures (talent) or they are simply the result of training and practice.
- Talent is usually seen as something that
  - originates in genetic structures;
  - is identifiable at an early stage by trained people who can recognize it even before exceptional levels of performance have been acquired;
  - can be used to predict who is likely to excel
  - that only a minority can be identified as having because if everyone were "talented," the concept would lose meaning
- The emphasis on early identification entails studying the development of skills in children
- in a domain such as music, "talent" might be manifested differently in different children

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What Makes a Musician: Expertise Dissected

- Expert: someone who has reached a high degree of accomplishment relative to other people
  - ten thousand hours of practice is required to achieve the level of mastery associated with being a world-class expert, in anything
  - equivalent to roughly three hours a day, or twenty hours a week, of practice over ten years
  - learning requires assimilation and consolidation of information in neural tissue. The more experiences we have with something, the stronger the memory/learning trace for that experience becomes. The strength of a memory is related to how many times the original stimulus has been experienced
  - Motivation and attention are important factors
  - This does not address the emotional dimension of musics

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What Makes a Musician: Expertise Dissected

- Musical memory
  - Expertise in any domain is characterized by a superior memory, but only for things within the domain of expertise
  - Experts in music rely on their knowledge of musical structure. Expert musicians excel at remembering chord sequences that are "legal" or make sense within the harmonic systems that they have experience with, but they do no better than anyone else at learning sequences of random chords
  - When musicians memorize songs, they are relying on a structure for their memory, and the details fit into that structure. This is an efficient and parsimonious way for the brain to function. Rather than memorizing every chord or every note, we build up a framework within which many different songs can fit, a mental template that can accommodate a large number of musical piecess
  - **Chunking** refers to the process of tying together units of information into groups, and remembering the group as a whole rather than the individual pieces

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What Makes a Musician: Expertise Dissected

- Musicians also use chunking in several ways:
  - they tend to encode in memory an entire chord, rather than the individual notes of the chord
  - musicians tend to encode sequences of chords, rather than isolated chords
  - listeners obtain knowledge about stylistic norms, players obtain knowledge on how to produce such norms
    - Musicians know how to take a song and apply this knowledge to make the song sound like salsa, or grunge, or disco, or heavy metal; each genre and era has stylistic tics or characteristic rhythmic, timbral, or harmonic elements that define it
- Identification memory: the ability that most of us have to identify pieces of music that we've heard before
  - similar to memory for faces, photos, even tastes and smells
    - individual variability
    - domain specific
    - being able to rapidly retrieve a familiar piece of music from memory is one skill, but being able to then quickly and effortlessly attach a label to it, involves a separate cortical network: planum temporale (associated with absolute pitch) and regions of the inferior prefrontal cortex (required for attaching labels to sensory impressions)

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What Makes a Musician: Expertise Dissected

- Being an expert musician takes many forms
  - dexterity at playing an instrument
  - emotional communication
  - creativity
  - special mental structures for remembering music
- Being an expert listener involves having incorporated the grammar of our musical culture into mental schemas that allow us to form musical expectations, the heart of the aesthetic experience in music
- Musical expertise is not one thing, but involves many components, and not all musical experts will be endowed with these different components equally
- Becoming a famous musician is another matter entirely, and may not have as much to do with intrinsic factors or ability as with charisma, opportunity, and luck
- We are all expert musical listeners, able to make quite subtle determinations of what we like and don’t like, even when we’re unable to articulate the reasons why

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Why do We Like the Music We Like?

Alexandra Lamont's experiment (Keele Univ., UK)

- The auditory system of the fetus is fully functional about 20 wks after conception
- A year after they are born, children recognize and prefer music they were exposed to in the womb
- In Lamont's experiment, mothers played a single piece of music to their babies repeatedly during the final three months of gestation. One particular piece was singled out for each baby to hear on a regular basis. After birth, the mothers were not allowed to play the experimental song to their infants. Then, one year later, Lamont played babies the music that they had heard in the womb, along with another piece of music chosen to be matched for style and tempo. Children tended to look longer at the speaker that was playing music they had heard in the womb than at the speaker playing the novel music, confirming that they preferred the music to which they had the prenatal exposure
- A control group of one-year-olds who had not heard any of the music before showed no preference, confirming that there was nothing about the music itself that caused these results. Lamont also found that, all things being equal, the young infant prefers fast, upbeat music to slow music
- **Approach: conditioned head-turning procedure.** Infant placed between two loudspeakers. When the infant looks at one speaker, it starts to play music or some other sound, and when he looks at the other speaker, it starts to play different music or a different sound. The infant quickly learns that he can control what is playing by where he is looking; he learns, that is, that the conditions of the experiment are under his controls

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Why do We Like the Music We Like?

- These findings contradict the long-standing notion of childhood amnesia, that we can't have any veridical memories before around the age of five
- Many people claim to have memories from early childhood around age two and three, but it is difficult to know whether these are true memories of the original event, or rather, memory of someone telling us about the event later
- The young child's brain is still undeveloped, functional specialization of the brain isn't complete, and neural pathways are still in the process of being made. The child's mind is trying to assimilate as much information as possible in as short a time as possible; there are typically large gaps in the child's understanding, awareness, or memory for events because he hasn't yet learned how to distinguish important events from unimportant ones, or to encode experience systematically.
  Thus, the young child is a prime candidate for suggestion, and could unwittingly encode, as his own, stories that were told to him about himself. It appears that for music even prenatal experience is encoded in memory, and can be accessed in the absence of language or explicit awareness of the memory

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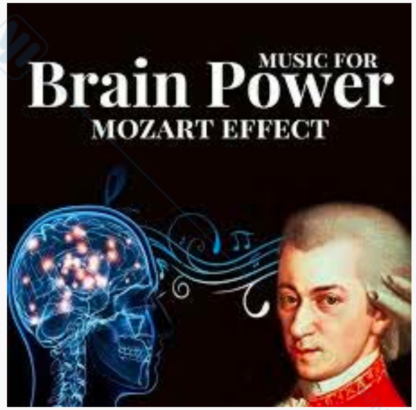
Why do We Like the Music We Like?



- The popular "music makes you smarter" studies tend to be flawed (flawed experimental controls)
- It is also important to distinguishing between short-term and long-term effects of music. Popular "Mozart Effect" beliefs refer to immediate benefits, but research has revealed long-term effects of musical activity
- Music listening enhances or changes certain neural circuits, including the density of dendritic connections in the primary auditory cortex
  - The Harvard neuroscientist Gottfried Schlaug showed that the front portion of the corpus callosum (the mass of fibers connecting the two cerebral hemispheres) is significantly larger in musicians than nonmusicians, and particularly for musicians who began their training early, reinforcing the notion that musical operations become bilateral with increased training, as musicians coordinate and recruit neural structures in both the left and right hemispheres
  - Several studies have found microstructural changes in the cerebellum after the acquisition of motor skills, such as are acquired by musicians, including an increased number and density of synapses
  - Schlaug found that musicians tended to have larger cerebellums than nonmusicians, and an increased concentration of gray matter; gray matter is that part of the brain that contains the cell bodies, axons, and dendrites, and is understood to be responsible for information processing, as opposed to white matter, which is responsible for information transmission

Correlation is not causation!

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Why do We Like the Music We Like?

- Going back to musical taste, Lamont's findings are important because they show that **the prenatal and newborn brain are able to store memories and retrieve them over long periods of time**
- More practically, the results indicate that the **environment can affect a child's development and preferences**
  - musical preferences are influenced, but not determined, by what we hear in the womb. There also is an extended period of acculturation, during which the infant takes in the music of the culture she is born into
  - infants show a preference for consonance over dissonance. Appreciating dissonance comes later in life
  - Although infant ears are fully functioning four months before birth, the developing brain requires months or years to reach full auditory processing capacity. Infants recognize transpositions of pitch and of time (tempo changes), indicating they are capable of relational processing
- Contour is the most salient musical feature for infants, who can detect contour similarities and differences even across thirty seconds of retention. Infants' sensitivity to musical contour parallels their sensitivity to linguistic contours (prosody)
- Trehub also showed that infants are more able to encode consonant intervals such as perfect fourth and perfect fifth than dissonant ones, like the tritone

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Why do We Like the Music We Like?

Trehub found that the **unequal steps of our scale make it easier to process intervals even early in infancy**

- She and her colleagues played nine-month-olds the regular seven-note major scale and two scales she invented
- For one of these invented scales, she divided the octave into eleven equal-space steps and then selected seven tones that made one- and two-step patterns, and for the other she divided the octave into seven equal steps
- The infants' task was to detect a mistuned tone. Adults performed well with the major scale, but poorly with both of the artificial, never-before-heard scales
- In contrast, the infants did equally well on both unequally tuned scales and on the equally tuned ones

=> nine-month-olds have not yet incorporated a mental schema for the major scale, so this suggests a general processing advantage for unequal steps, something our major scale has

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Why do We Like the Music We Like?

- Young children start to show a preference for the music of their culture by age two, around the same time they begin to develop specialized speech processing
- At first, children tend to like simple songs. As they mature, they start to tire of predictable music and search for music that holds more challenge.
- According to Mike Posner, the frontal lobes (information processing) and the anterior cingulate (attention) are not fully formed in children, leading to an inability to pay attention to several things at once. This explains why children under the age of eight or so have a hard time singing "rounds" (canons)
- Researchers point to the teen years as the turning point for musical preferences. It is around the age of ten or eleven that most children take on music as a real interest, even those children who didn't express such an interest in music earlier
- Part of the reason we remember songs from our teenage years is because those years were times of self-discovery, and they were emotionally charged; in general, we tend to remember things that have an emotional component because our amygdala and neurotransmitters act in concert to "tag" the memories as something important. Part of the reason also has to do with neural maturation and pruning; it is around fourteen that the wiring of our musical brains is approaching adultlike levels of completion

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Why do We Like the Music We Like?

- there are critical periods for acquiring new skills, such as language. If a child doesn't learn language by the age of six or so the child will never learn to speak with the effortlessness that characterizes most native speakers of a language
- Music and mathematics have an extended window, but not an unlimited one: If a student hasn't had music lessons or mathematical training prior to about age twenty, he can still learn these subjects, but only with great difficulty, and it's likely that he will never "speak" math or music like someone who learned them early
- This is because of the biological course for synaptic growth. The brain's synapses are programmed to grow for a number of years, making new connections. After that time, there is a shift toward pruning, to get rid of unneeded connections

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Why do We Like the Music We Like?

The issue of complexity

- The balance between simplicity and complexity in music also informs our preferences
- Scientific studies of like and dislike across a variety of aesthetic domains have shown that an orderly relationship exists between the complexity of an artistic work and how much we like it
- Schemas are everything: they frame our understanding; they're the system into which we place the elements and interpretations of an aesthetic object. Schemas inform our cognitive models and expectations
- **When a musical piece is too simple, we tend not to like it, finding it trivial. When it is too complex, we tend not to like it, finding it unpredictable**
- **Music, or any art form for that matter, has to strike the right balance between simplicity and complexity in order for us to like it. Simplicity and complexity relate to familiarity, and familiarity is just another word for a schema**

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Why do We Like the Music We Like?

What is "too simple" or "too complex"?

- An operational definition is that we find a piece too simple when we find it trivially predictable and without the slightest challenge
- Music that involves too many chord changes, or unfamiliar structure, can lead many listeners straight to the nearest exit, or to the "skip" button on their music players. The structure presents a steep learning curve, and the novice can't be sure that the time invested will be worth it
- Structural processing is one source of difficulty in appreciating a new piece of music

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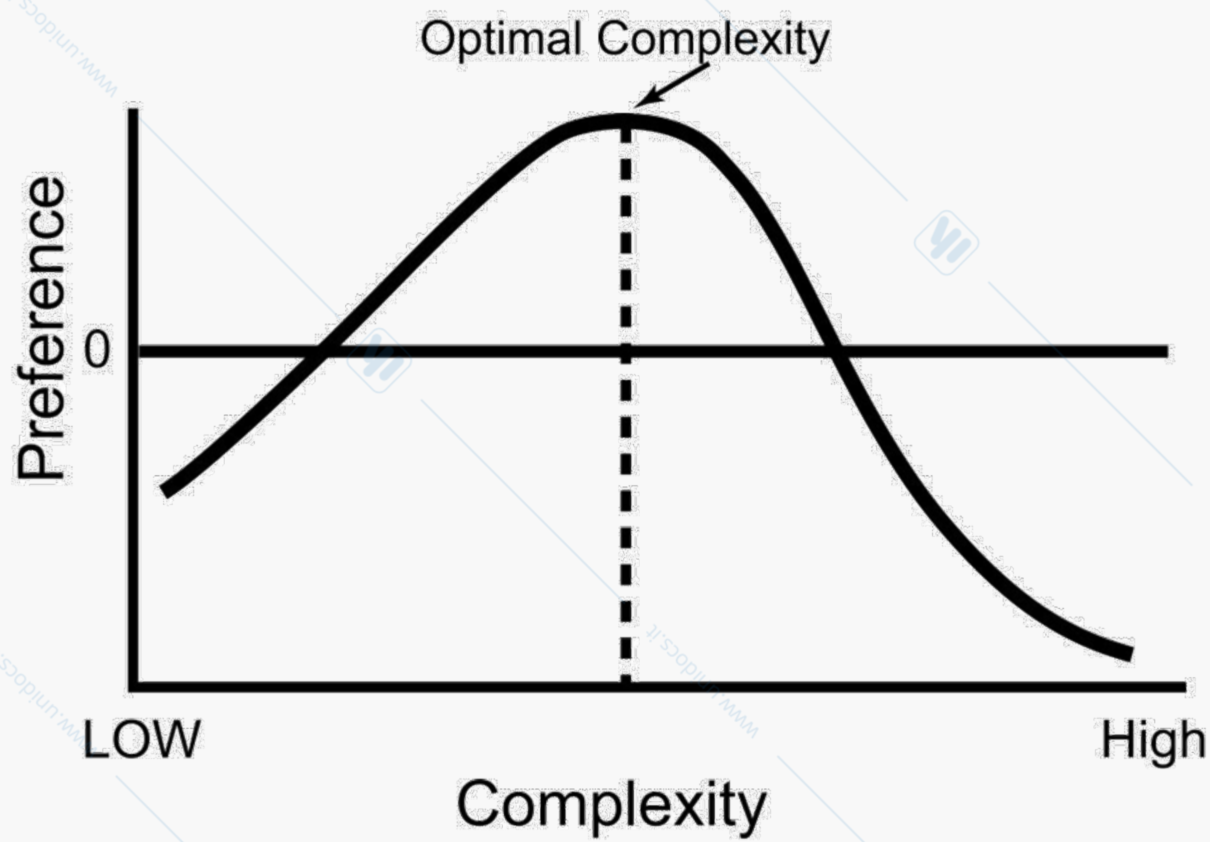
Why do We Like the Music We Like?

What is “too simple” or “too complex”?

- The orderly relationship between complexity and liking is referred to as the inverted-U function



Why do We Like the Music We Like?

The inverted-U hypothesis is not meant to imply that the only reason you might like or dislike a piece of music is because of its simplicity or complexity

- Other reasons for liking/disliking a musical piece
  - Loudness
  - Dynamic range
  - Pitch
  - Rhythm and rhythmic patterns
  - Timbre
- Trust/safety: we surrender to music when we listen to it we allow ourselves to trust the composers and musicians with a part of our hearts and our spirits
- The types of sounds, rhythms, and musical textures we find pleasing are generally extensions of previous positive experiences we've had with music in our lives

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Music listening and brain response

Listening to music causes a cascade of brain regions to become activated in a particular order:

- auditory cortex for initial processing of the components of the sound.
- frontal regions (e.g. BA44 and BA47), involved in processing musical structure and expectations
- a network of regions (the mesolimbic system) involved in arousal, pleasure, and the transmission of opioids and the production of dopamine, culminating in activation in the nucleus accumbens
- cerebellum and basal ganglia, presumably supporting the processing of rhythm and meter

The rewarding and reinforcing aspects of listening to music seem, then, to be mediated by increasing dopamine levels in the nucleus accumbens, and by the cerebellum’s contribution to regulating emotion through its connections to the frontal lobe and the limbic system. Current neuropsychological theories associate positive mood and affect with increased dopamine levels, one of the reasons that many of the newer antidepressants act on the dopaminergic system

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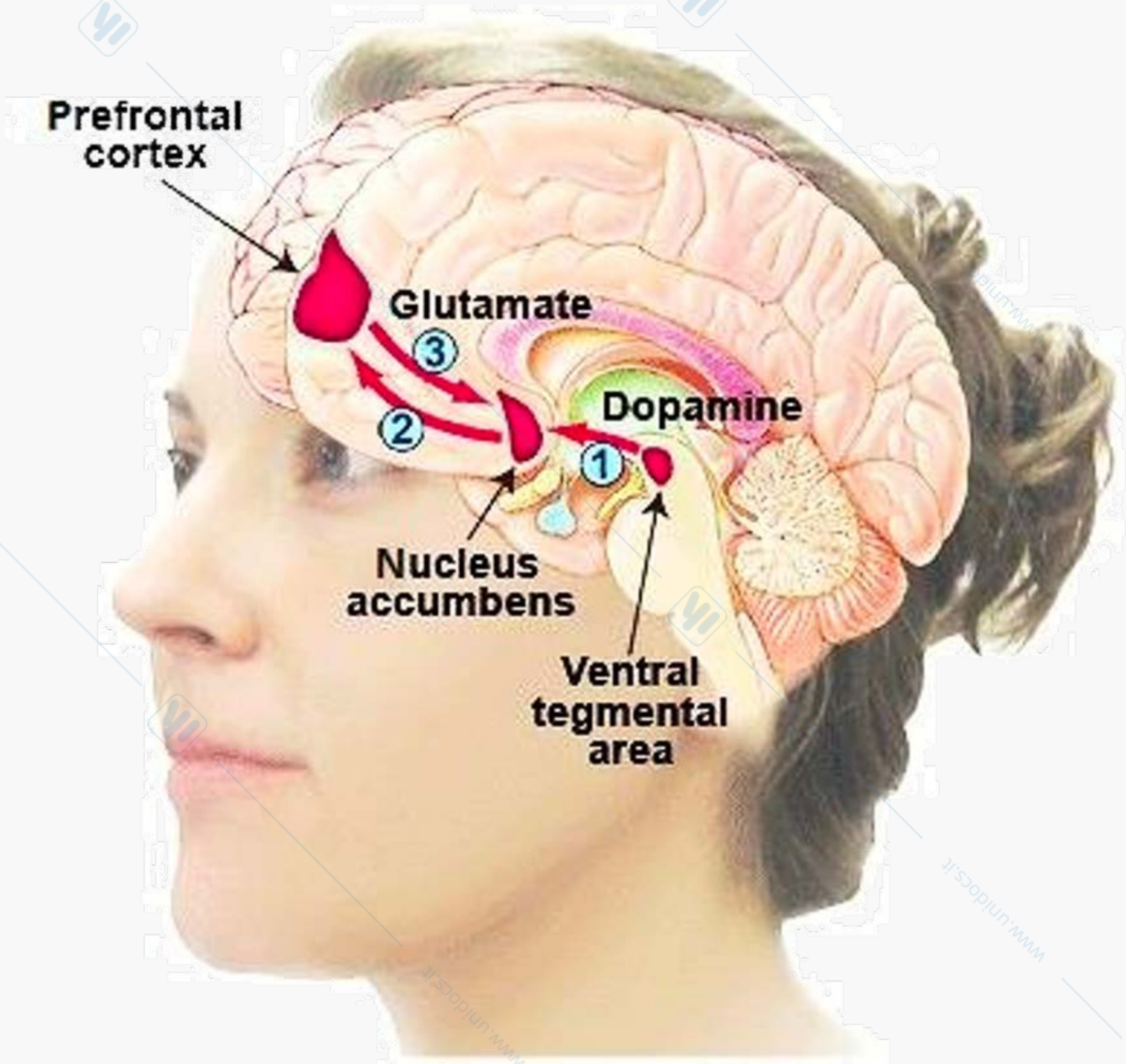
Music enjoyment

The release of dopamine into the nucleus accumbens is a precursor of the mechanism through which the brain gets pleasure signals.
Feeling pleasure abets us to repeat behaviors that are vital for survival
But, drugs of abuse also causes alike phenomenon and in some cases, these drugs are accountable for augmented dopamine release than the natural rewards



https://www.youtube.com/watch?v=f7E0mTJQ2KM

https://www.youtube.com/watch?v=3_zgB19TE-M

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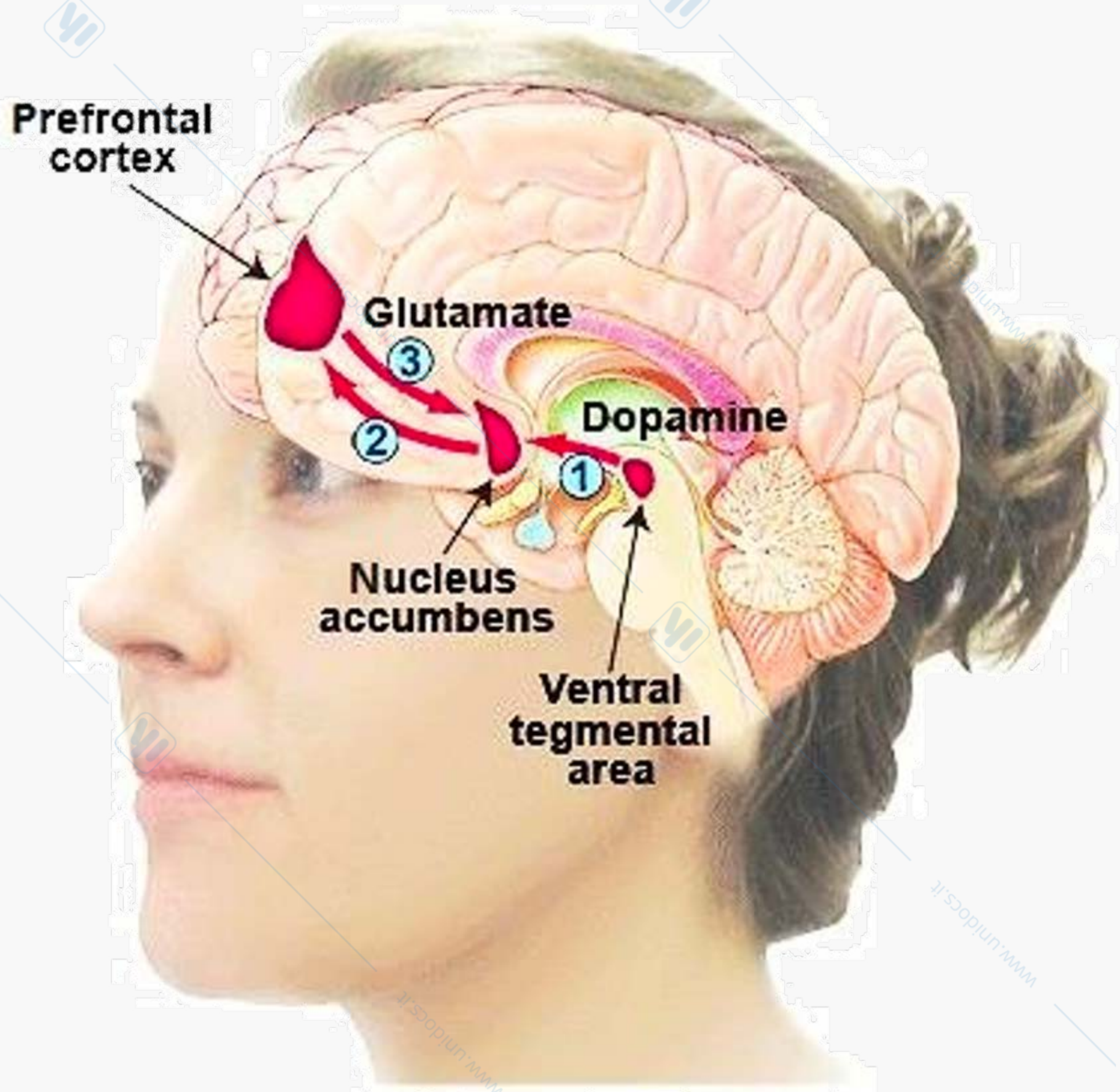
Music enjoyment

The Nucleus Accumbens (NA) is at the center of the brain's reward system, playing an important role in pleasure and addiction
By releasing dopamine (neurotransmitter) the NA regulates the mood

Ventral Tegmental Area (VTA) produces dopamine and sends it to the Nucleus Accumbens (NA)



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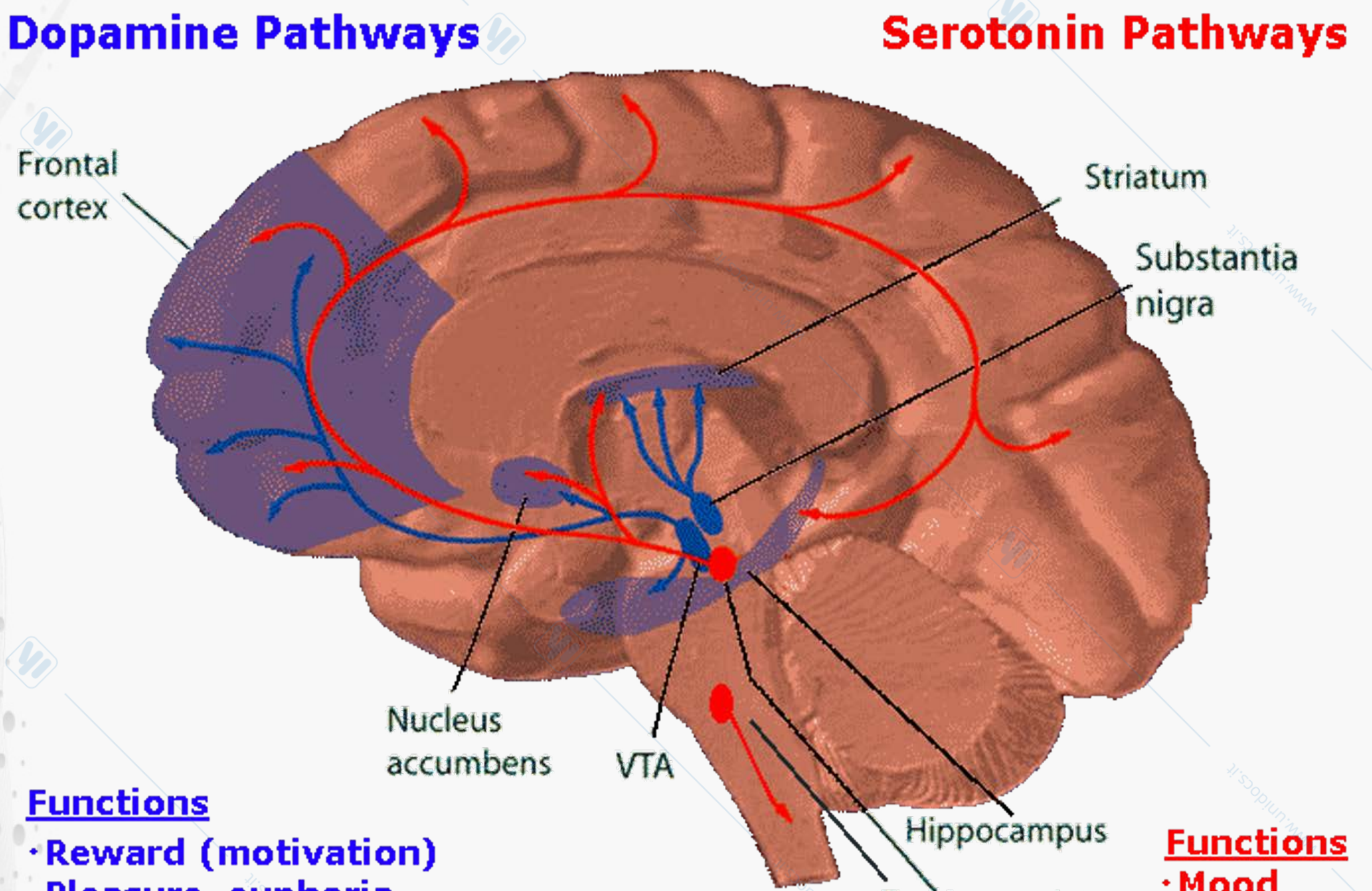
Music enjoyment



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

Functions
- **Mood**
- **Memory processing**
- **Sleep**
- **Cognition**

Music enjoyment

- VTA = experience
  - Fires in response to stimuli proportionally to reward value
- NA = expectation
  - Releases dopamine in relation to the expectation of reward

https://www.youtube.com/watch?v=6J73tzP2zFg

https://www.youtube.com/watch?v=YzCYuKX6zp8

Music enjoyment

- Brain imaging studies using fMRI found that the experience of musical pleasure was reflected in three brain regions:
  - Amygdala (processing emotions)
  - Hippocampus (memory)
  - Auditory cortex (processing sounds)

  Activity in the nucleus accumbens (processing reward expectations) had previously been believed to play a role in musical pleasure. Today it only reflects uncertainty
- Musical pleasure depends on the dynamic interplay between prospective and retrospective states of expectation
- Our fundamental ability to predict is therefore an important mechanism through which abstract sound sequences acquire affective meaning and transform into a universal cultural phenomenon that we call 'music'

Cheung, V. K., Harrison, P. M., Meyer, L., Pearce, M. T., Haynes, J. D., & Koelsch, S. (2019). Uncertainty and surprise jointly predict musical pleasure and Amygdala, Hippocampus, and auditory cortex activity. *Current Biology*, *29*(23), 4084-4092.

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Music enjoyment

- Recent research suggests that musical pleasure comes from positive reward prediction errors, which arise when what is heard proves to be better than expected
- Central to this view is the engagement of the nucleus accumbens (a brain region that processes reward expectations) to pleasurable music and surprising musical events
- However, expectancy violations along multiple musical dimensions (e.g., harmony and melody) have failed to implicate the nucleus accumbens, and it is unknown how music reward value is assigned
- Whether changes in musical expectancy elicit pleasure has thus remained elusive
- In (*) authors showed that pleasure varies nonlinearly as a function of the listener's uncertainty when anticipating a musical event, and the surprise it evokes when it deviates from expectations. Taking Western tonal harmony as a model of musical syntax, they used a machine-learning model to mathematically quantify the uncertainty and surprise of 80,000 chords in US Billboard pop songs.
  - Behaviorally, they found that chords elicited high pleasure ratings when they deviated substantially from what the listener had expected (low uncertainty, high surprise) or, conversely, when they conformed to expectations in an uninformative context (high uncertainty, low surprise)
  - Neurally, they found using fMRI that activity in the amygdala, hippocampus, and auditory cortex reflected this interaction, while the nucleus accumbens only reflected uncertainty
- These findings challenge current neurocognitive models of music-evoked pleasure and highlight the synergistic interplay between prospective and retrospective states of expectation in the musical experience

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Music and the Creative Process

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Stages of the Sleep Cycle

- There are four stages of sleep: Non-REM (NREM) sleep (Stages 1, 2 & 3) and REM sleep. Periods of wakefulness occur before and intermittently throughout the various sleep stages or as one shifts sleeping position.
- Wake is the period when brain wave activity is at its highest and muscle tone is active

Stage 1 | **Stage 2** | **Stage 3** | **REM Sleep**

Stage 1 is the lightest stage of NREM sleep. Often defined by the presence of slow eye movements, this drowsy sleep stage can be easily disrupted causing awakenings or arousals. Muscle tone throughout the body relaxes and brain wave activity begins to slow from that of wake. Occasionally people may experience hypnic jerks or abrupt muscle spasms and may even experience sensation of falling while drifting in and out of Stage 1.

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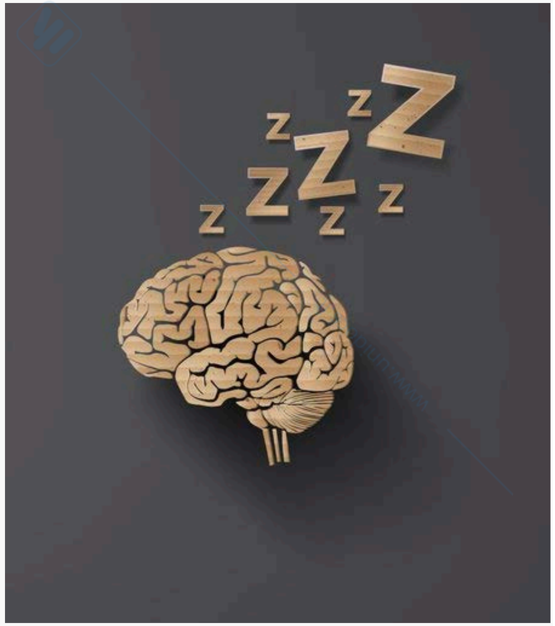
Importance of sleep



- Sleeping plays a crucial role in memory consolidation and creativity (not to mention health and well-being)
- Sleep phases are characterized by eye movements and are classified accordingly
  - NREM: Non Rapid-Eye-Movement sleep phase
  - REM: Rapid-Eye-Movement sleep phase
- Sleep is thought to be regulated by two mechanisms:
  - a homeostatic mechanism, which responds to the body's internal cues for sleep
  - a circadian mechanism that responds to external cues such as darkness and light, signaling appropriate times for sleep and wakefulness

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Stages of the Sleep Cycle

	WAKE	NREM SLEEP			REM SLEEP
		LIGHT SLEEP		DEEP SLEEP	
Stage of Sleep:	Stage 0	Stage 1	Stage 2	Stage 3	Stage R
Description:	Eyes open, responsive to external stimuli, can hold intelligible conversation	Transition between waking and sleep. If awakened, person will claim was never asleep.	Main body of light sleep. Memory consolidation. Synaptic pruning.	Slow waves on EEG readings.	Brain waves similar to waking. Most vivid dreams happen in this stage. Body does not move.
Time Spent In:	16 to 18 hours per day	4 to 7 hours per night			90 to 120 min/night

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Sleep Cycles

- A sleep cycle is the progression through the various stages of NREM sleep to REM sleep before beginning the progression again with NREM sleep.
  - Typically, a person would begin a sleep cycle every 90-120 minutes resulting in four to five cycles per sleep time, or hours spent asleep.
- A sleep cycle progresses through the stages of non-REM sleep from light to deep sleep, then reverse back from deep sleep to light sleep, ending with time in REM sleep before starting over in light sleep again
  - Stage 1: the body begins to relax and a drowsy state occurs with slow rolling eye movements. Though arousals or awakenings are prevalent, Stage 1 is important as it allows for the body to enter Stage 2; the first quantifiable stage of NREM sleep
  - Stage 2 occurs for longer periods than Stage 1. For most, Stage 2 sleep comprises approximately 40-60% of total sleep time
  - Stage 3 is most often found next in the progression. This restorative stage does not last as long as Stage 2, lasting between 5-15% of total time asleep for most adults. For children and adolescents Stage 3 is much higher in duration
  - REM can occur at at time during the sleep cycle, but on average it begins 90 minutes following sleep onset and is short in duration as it is the first REM period of the night. Following REM, the process resumes starting with periods of Stage 1, 2 & 3 intermixed before returning to REM again for longer periods of time as sleep time continues
  - Deep Sleep occurs in Stage 3 of NREM sleep. Brain waves during Stage 3 are called delta waves due to the slow speed and large amplitude. Of all of the sleep stages, Stage 3 is the most restorative and the sleep stage least likely to be affected by external stimuli.

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Sleep Cycles

- REM Sleep: A person's sleep time (approximately 6-8 hours for adults) can be thought of as 2 halves. The first half for a majority of people consists mostly of Stages 2 and 3 with sporadic periods of Stage 1 and short REM periods. As the night progresses, Stage 3 begins to diminish in quantity while Stages 1 and 2 remain with lengthening periods of REM occurring.
- A person typically experiences three to five REM periods throughout sleep time with the longest REM period right before awakening for the day. If woken prematurely from completing the REM period a person can experience a period of sleep inertia whereby a heightened sensation of sleepiness can occur for several minutes or even several hours.
- In the REM period, breathing becomes more rapid, irregular and shallow, eyes jerk rapidly and **limb muscles are temporarily paralyzed**. Brain waves during this stage increase to levels experienced when a person is awake

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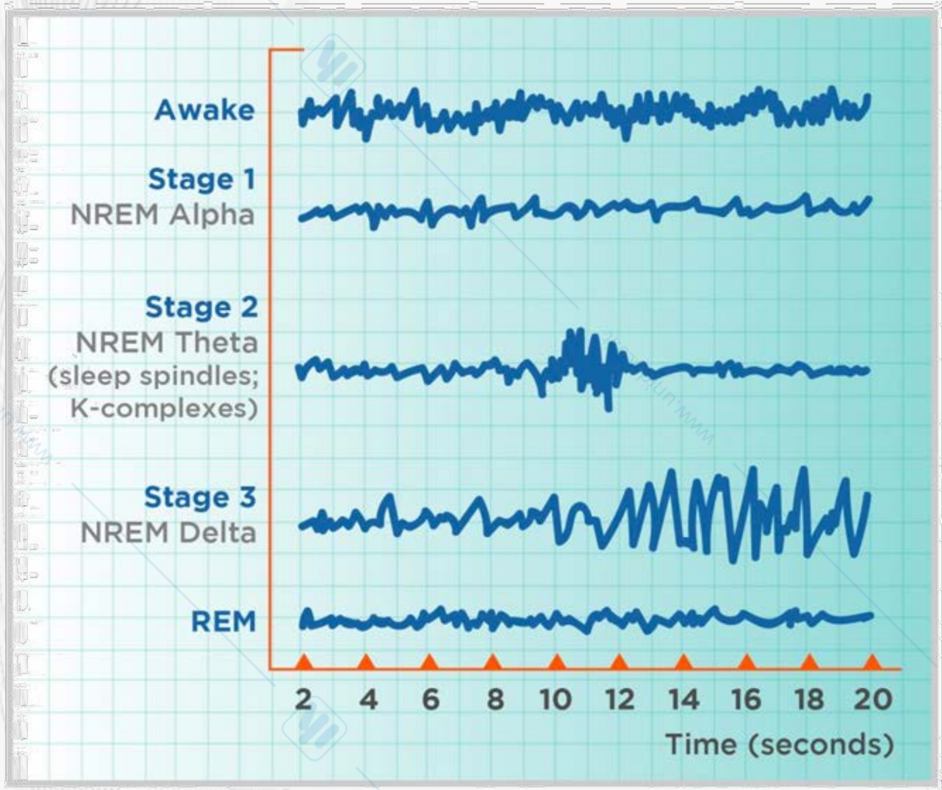
Sleep Cycles and Dreams

EEG RECORDINGS DURING SLEEP



- REM is the time when the most vivid dreams occur. Brain waves during REM sleep are of low amplitude and mixed frequency
- A person may dream 4 to 6 times each night
- Muscle paralysis often accompanies REM sleep (to prevent us from acting out our dreams)
- During REM respirations are irregular and shallow and irregularities in heart rate and body temperature also occur.

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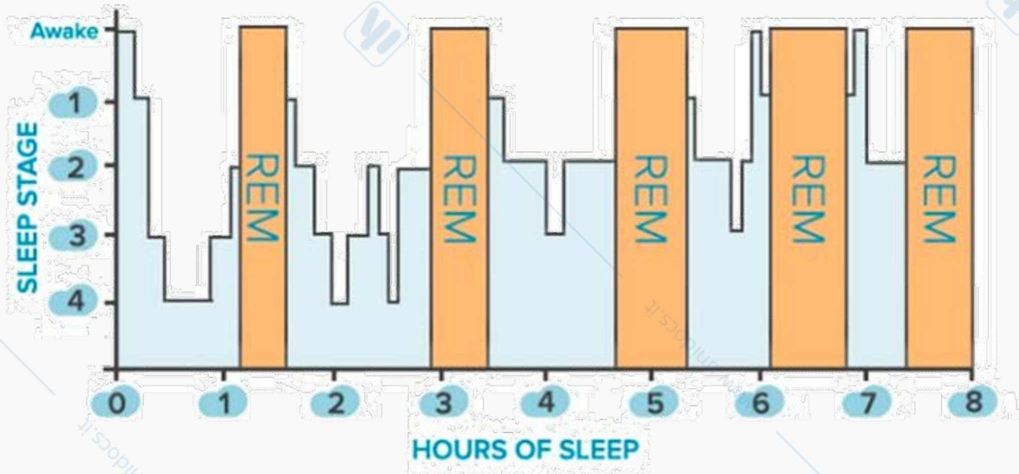
Sleep Cycles



- REM: sleep time (~6-8hrs for adults) can be thought of as 2 halves
  – First half usually consists of Stages 2 and 3 with sporadic periods of Stage 1 and short REM periods
  – As the night progresses, Stage 3 begins to diminish in quantity while Stages 1 and 2 remain with lengthening periods of REM occurring
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  – During REM, breathing becomes more rapid, irregular and shallow, eyes jerk rapidly and **limb muscles are temporarily paralyzed**.
  – During REM brain waves increase to levels experienced when a person is awake

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Sleep and the creative process

- NREM sleep: crucial for memory consolidation
  - Revise memory traces and transfer them onto long-term memory
  - Clean up & recycle process
- REM sleep: ramdom association of memory traces
  - Go over memory traces and try associations between them to attempt modeling, in order to decide what to keep (in long-term memory) and what to get rid of
  - This also involves motor cortex memory traces, which is why we often experience «sleep learning» of difficult musical passages
  - Dreams are a manifestation of random associations of memory traces and so are creative ideas

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The creative process (in the wake state) (*)

- Daydreaming is the stream of consciousness that detaches from current external tasks when attention drifts to a more personal and internal direction
  - This phenomenon is common in people's daily life shown by a large-scale study in which participants spend 47% of their waking time on average on daydreaming [1]
  - Other names: mind wandering, fantasy, spontaneous thoughts, etc.
  - Research with fMRI shows that brain areas associated with complex problem-solving become activated during daydreaming episodes
- Creative thoughts arise when we allow ourselves to enter the daydreaming mode under pressure of time
- If you are engaged in any kind of creative pursuit, your goal is to maximize creativity. When we get blissfully lost in an activity, losing track of time and ignoring outside signals or our own problems
- A humanistic psychologist, Abraham Maslow, (1908-1970) named this situation «state of flow» in 1950
- The state of flow was later described in better detail by by the Hungarian-American psychologist Mihaly Csikszentmihalyi in «Flow and the psychology of discovery and invention» [2]

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1. *Gilbert, Daniel T.; Killingsworth, Matthew A.: «A Wandering Mind Is an Unhappy Mind». Science.* ***330*** *(6006): 932.*
2. *Csikszentmihalyi, M. (1996). «Creativity: Flow and the psychology of discovery and invention». New York: Harper/Collins*

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The creative process

- The «state of flow» feels like a completely different state of being, a state of heightened awareness coupled with feelings of well-being and contentment.
- It’s a neurochemically and neuro-anatomically distinct state as well.
- Across individuals, flow states appear to activate the same regions of the brain, including the the left prefrontal cortex (specifically areas 44, 45, and 47) and the basal ganglia
- During flow two key regions of the brain deactivate:
  - the portion of the prefrontal cortex responsible for self-criticysm
  - the amygdala, the brain’s fear center. This res po . .

This is why creative artists often report feeling fearless and as though they are taking creative risks they hadn't taken before. it's because the two parts of their brain that would otherwise prevent them from doing so have significantly reduced activity

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The creative process

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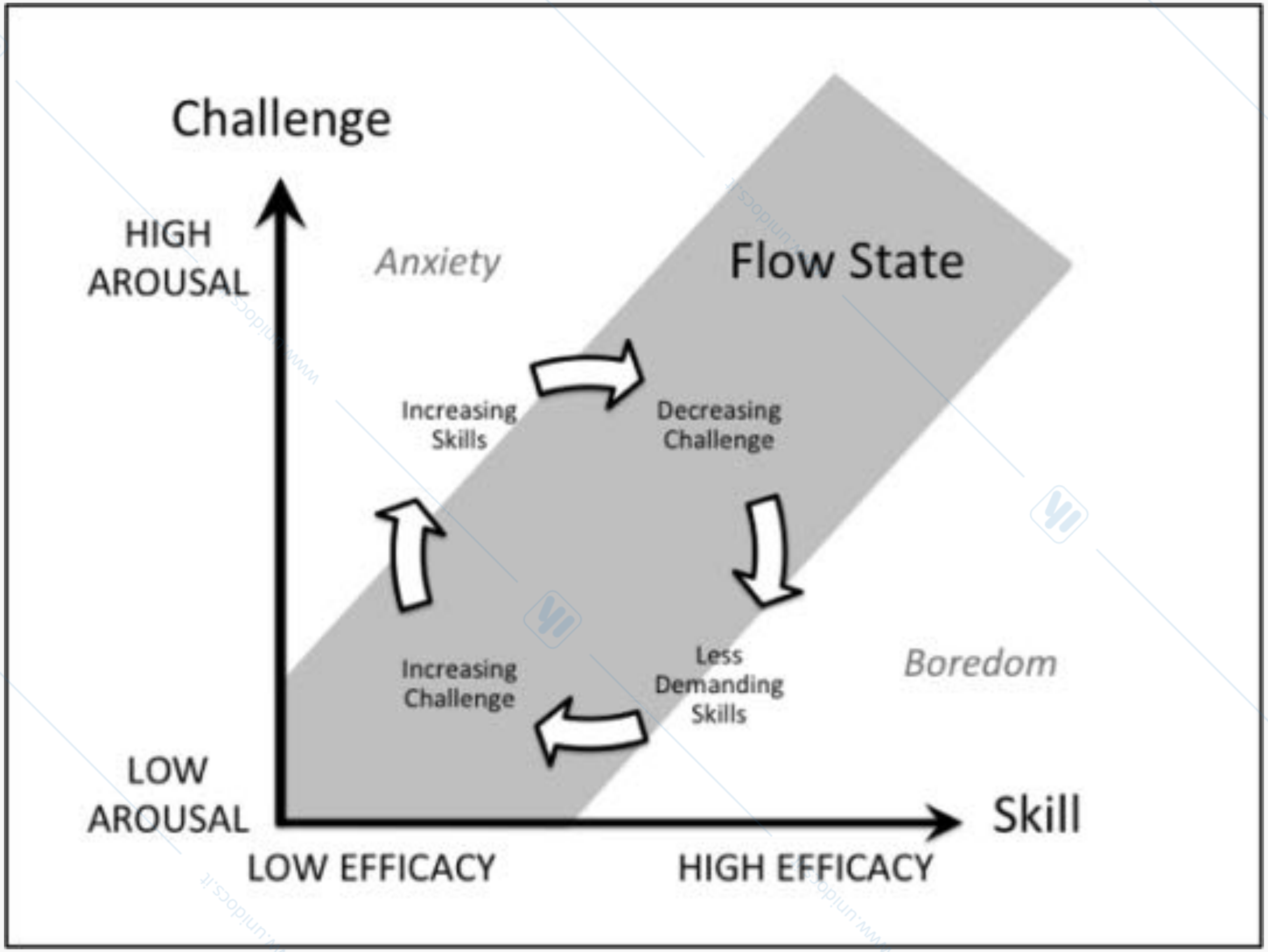

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Achieving a «state of flow»

Tips offered by Mihaly Csikszentmihalyi:

- Tip #1: Define clear borders for the task at hand
  - Flow grows within constraints. It is part of human nature to try and overstep a limit. If a task has clearly defined borders, your inner drive to cross those borders will bring you towards a state of flow
- Tip #2: Do things that require skill
  - Your mind wanders 47% of the time and, according to psychologist Matthew Killingsworth, this wandering hampers your flow. Your mind belongs in one place and so the requirement to use a skill to fulfil a task will help you to focus which in turn will bring you closer to being in flow.
- Tip #3: Do things that are intrinsically rewarding
  - You can't get into flow for 'have to do' tasks. Of course, we all have to do things we don't get very excited about, but with a bit of effort, you can easily identify the small things which will give you personal fulfilment in even the most tedious tasks.
- Tip #4: Focus on ongoing feedback
  - For a task to become effortless, you need to know how you are doing. Trust your senses and, more importantly, trust yourself. By continuously evaluating what you are doing, flow will become your dominating force.
- Tip #5: Do the task intentionally
- Tip #6: Realise that Flow isn't instantaneous.
  - Flow requires skill, and so it requires the investment of time. Only the most accomplished practitioners can make something look effortless. Don't expect miracles, expect to need some time to get warmed up.
- Tip #7: Be free of interruptions and avoid multi-tasking
  - Turn off your phone, close your browser and shut the door. Flow requires focus and time, your chances are best when you're alone concentrating on the one task at hand. The world isn't as hurried as we make it to be: things can wait.
- Tip #8: Remember that flow and happiness are different

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Progression of research in music science

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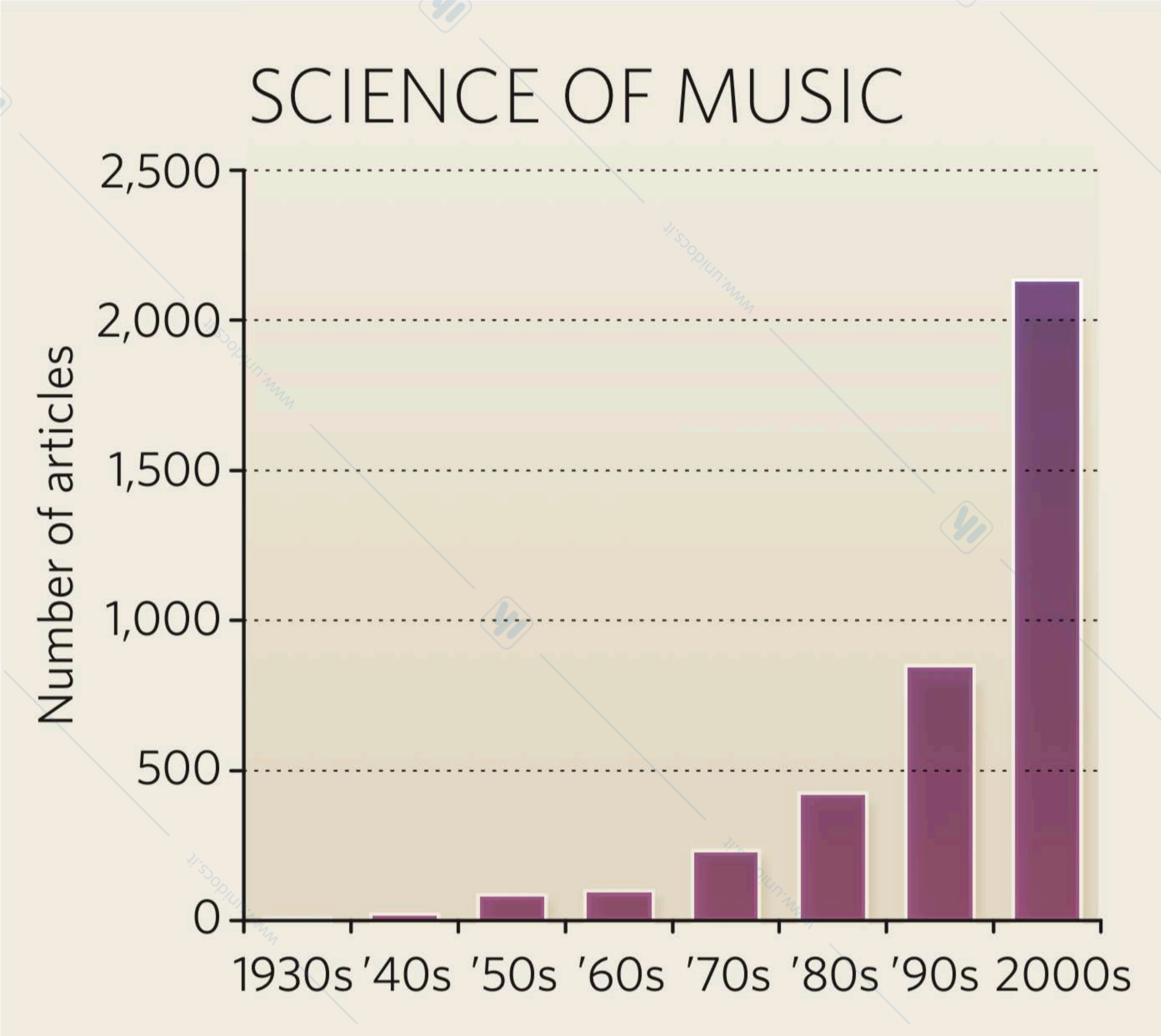

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