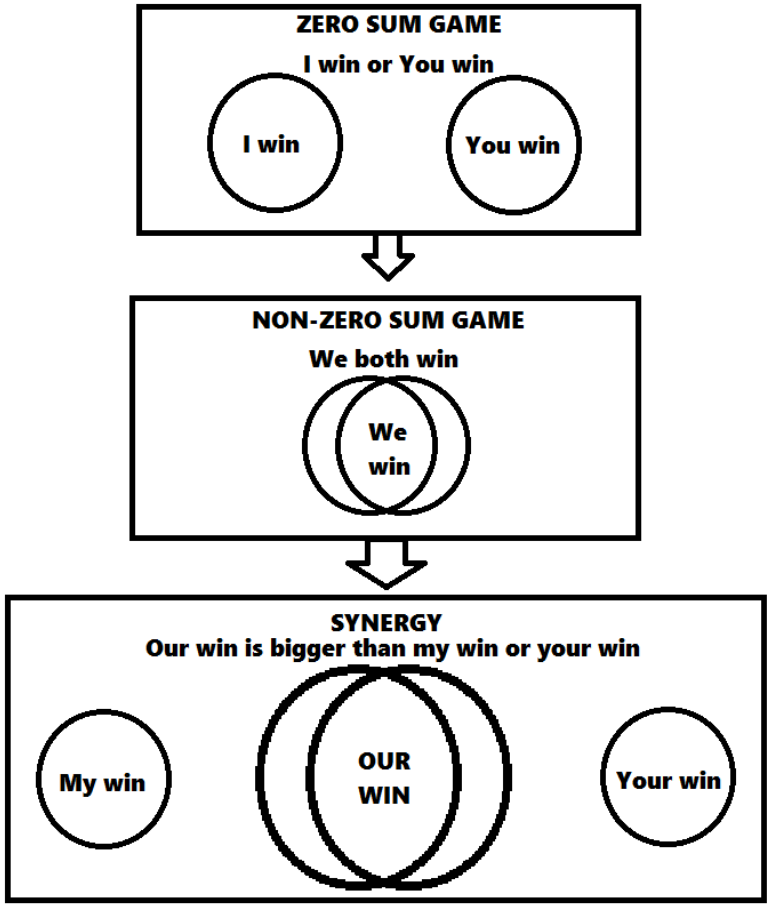
The when/what hierarchies

MAKING SENSE OF SONIC PATTERNS

The game of music

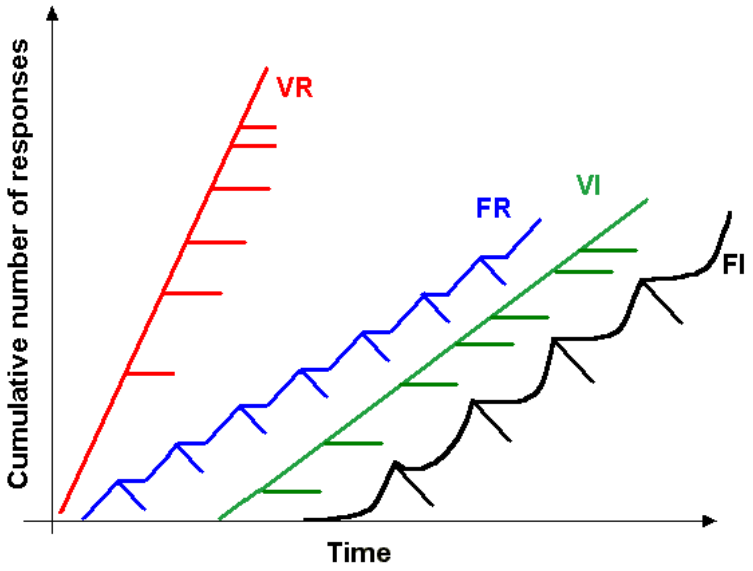


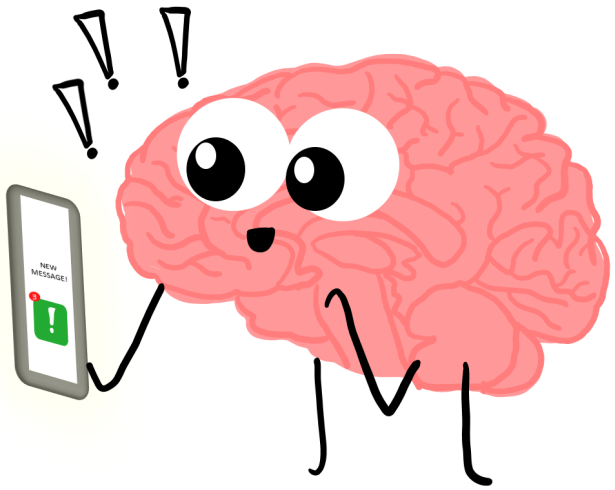
"Music is a non-zero sum infinite game"

Players: you against composer+performer

Goal: anticipating to what will happen in the music

Reward: intermittent

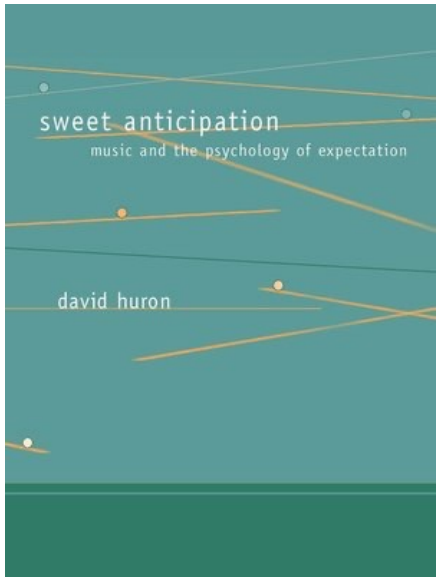


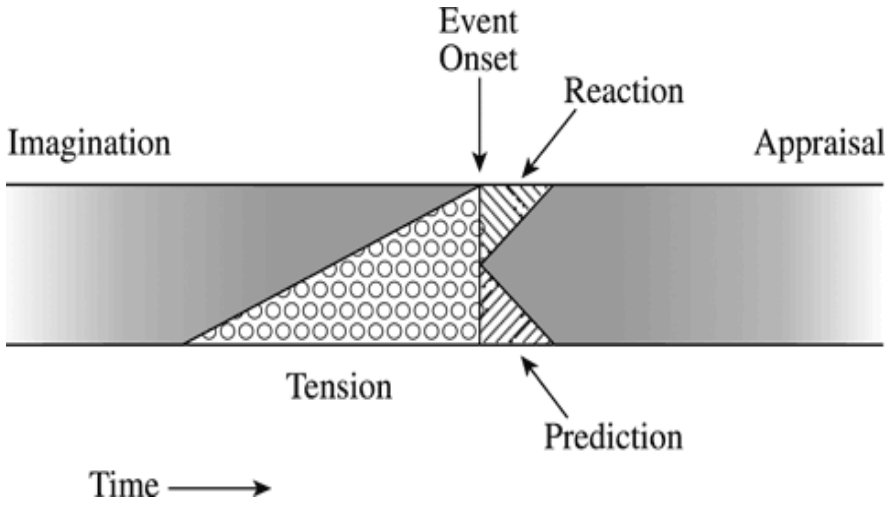


Music as a variable-ratio reinforcement system

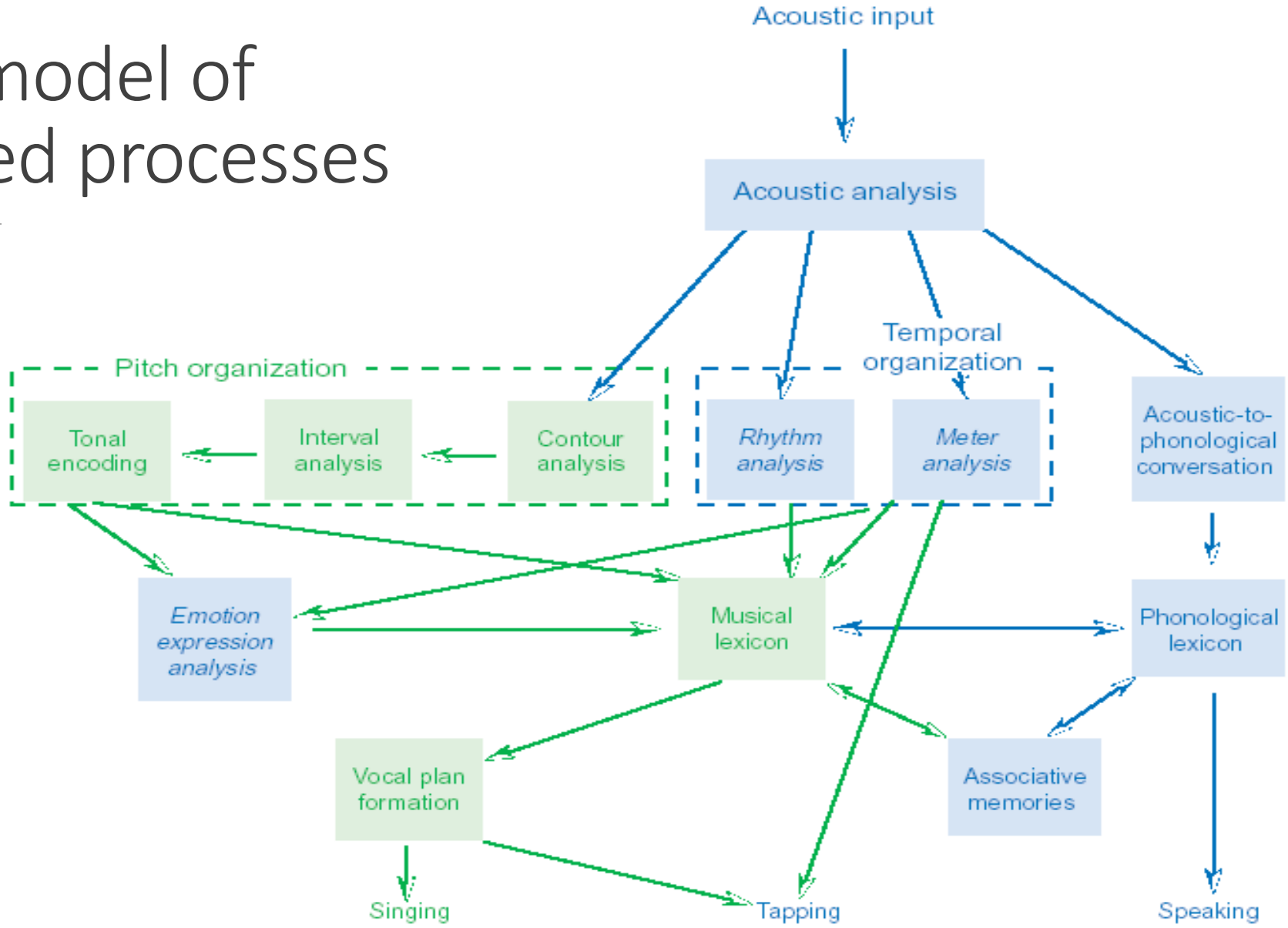
David Huron’s ITPRA

Fig. 21.1 Illustration of the time course for Huron's ITPRA theory of expectation . Feeling states are first activated by imagining different outcomes (I). As an anticipated event approaches, physiological arousal typically increases, often leading to a feeling of increasing tension (T). Once the event has happened, some feelings are immediately evoked related to whether one's predictions were borne out (P). In addition, a fast reaction response is activated based on a very cursory and conservative assessment of the situation (R). Finally, feeling states are evoked that represent a less hasty appraisal of the outcome (A) (from Huron, 2006).





A graphical model of some involved processes



Peretz i Coltheart (2003), Modularity of music processing, Nature Neuroscience, 6(7)

What / When frameworks

They “frame” our listening experience (“when” can we expect something, “what” to be expected)

Rhythm hierarchies (*when*): pulse, tempo, meter make certain “moments” more important than others

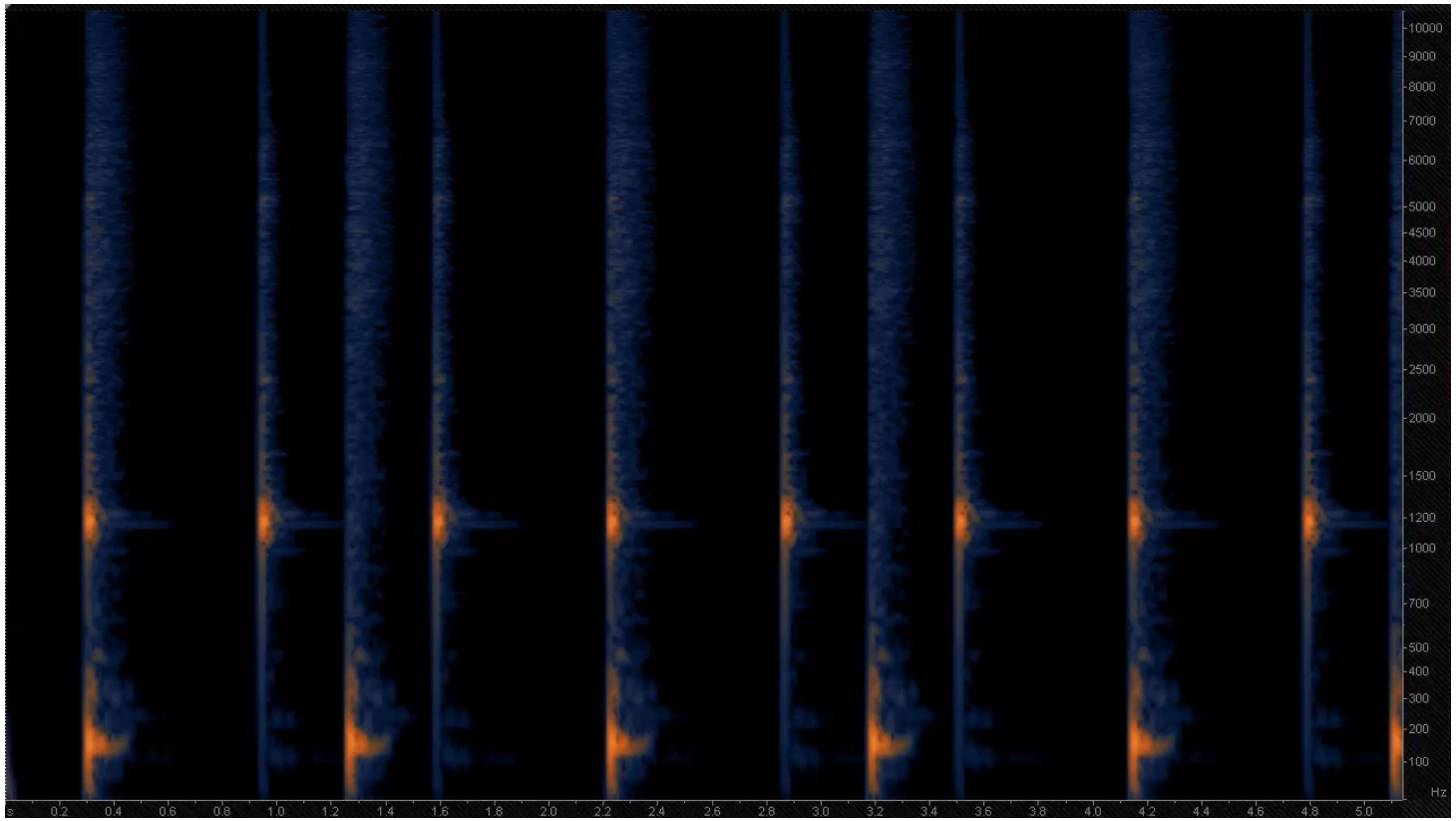
Tonal hierarchies (*what*): scales, keys, modes make certain “notes” more important than others

Music is a matter of time
Time is the matter of music

Probably you never considered the continuity between rhythm and tonality

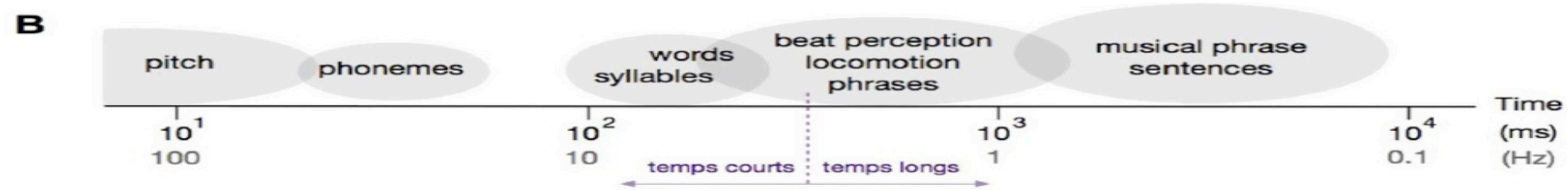
6 to 5 to 4 becomes a major chord

5 to 4 rhythm becomes a perfect 4th

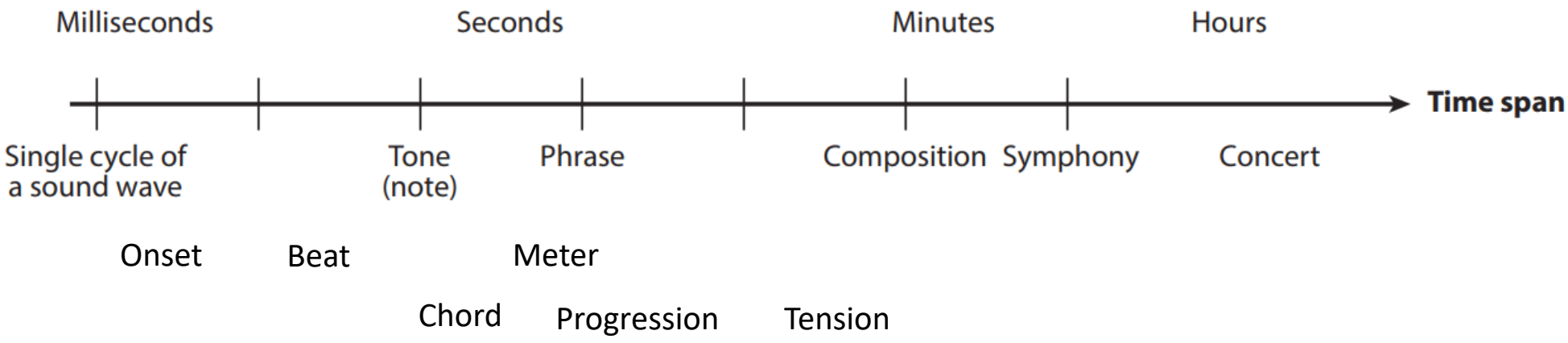


https://vimeo.com/32408748

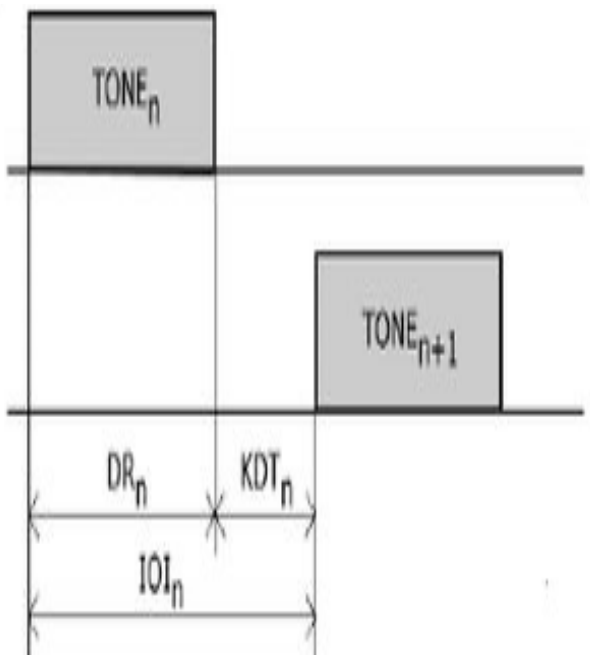
Temporal scales of musical events



Musical events and time



IOI: Inter Onset Interval



IOI: time between the onset of successive events

What is an “onset”?

- Change in loudness
- Change in pitch
- Change in timbre

What is an “event”?

- Whatever happens between two onsets or between an onset and an offset

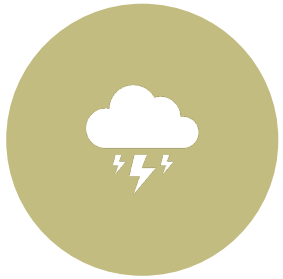
Perceived IOI may differ from physical IOI (e.g. lengthened when playing staccato –the sensed event lasts longer than the physical note-, visual info can bias our sensation, reverb…)

IOI

Simple relationships (1:1, 1:2, 1:3) are usually found in music

Simple ratios help our memory and production processes; when asked to produce arrhythmic patterns subjects produce near-equal IOI (isocrhony)

Rhythmic sequences usually combine short times (200-300ms) and long times (450-800ms)



Short-Term Memory constraints

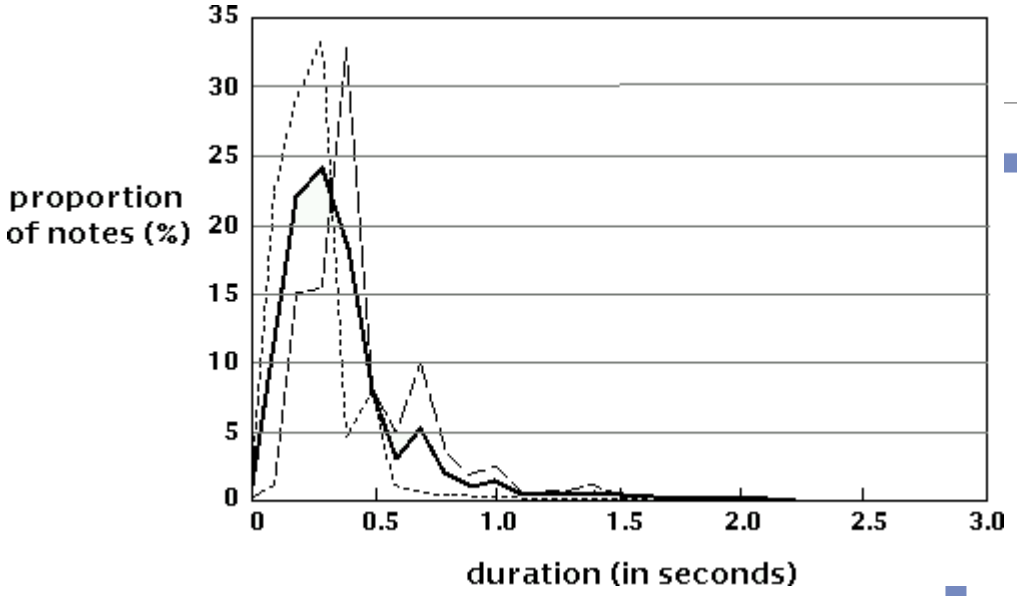
Musical Speed Limits

A melody that is too fast:

A melody that is too slow:

A melody that is understandable:

Distribution of note durations



Distribution of note durations in 52 instrumental and vocal works. Dotted line: note durations for the combined upper and lower voices from J.S. Bach's two-part Inventions (*BWV*s 772-786). Dashed line: note durations in 38 songs (vocal lines only) by Stephen Foster. Solid line: mean distribution for both samples (equally weighted). From Huron (2001)

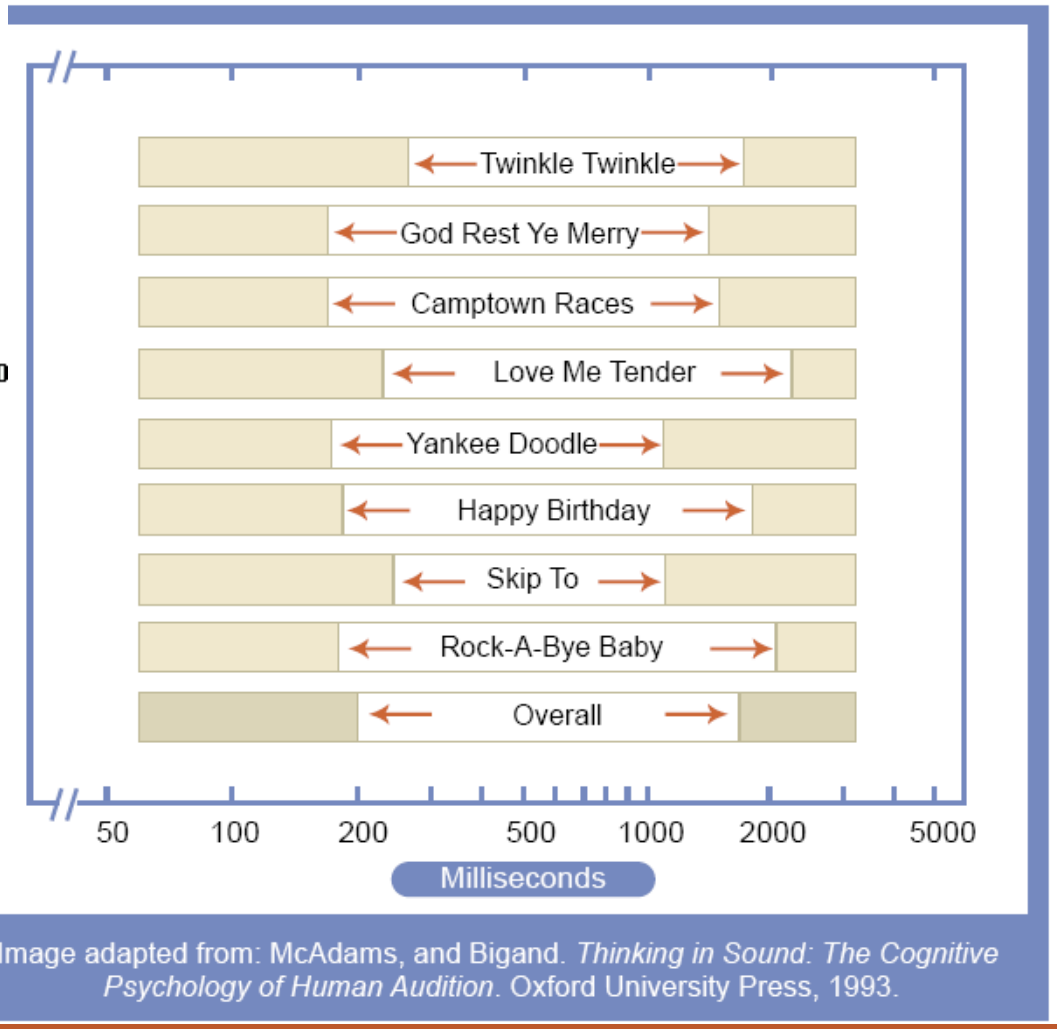


Image adapted from: McAdams, and Bigand. *Thinking in Sound: The Cognitive Psychology of Human Audition*. Oxford University Press, 1993.

Beat/Tempo

Beat: *A series of regularly recurring, precisely equivalent stimuli* (Cooper and Meyer, 1960); *A chain of events, roughly equally spaced in time* (Parncutt,1987)

- Many basic activities occur with periods between 500ms to 1s (baby sucking, rocking, heart beating, walking…)
- Beat induction is “universal”
- Beat induction favours “entrainment” (being “in-synch”)
- Is beat to be found in the IOIs?

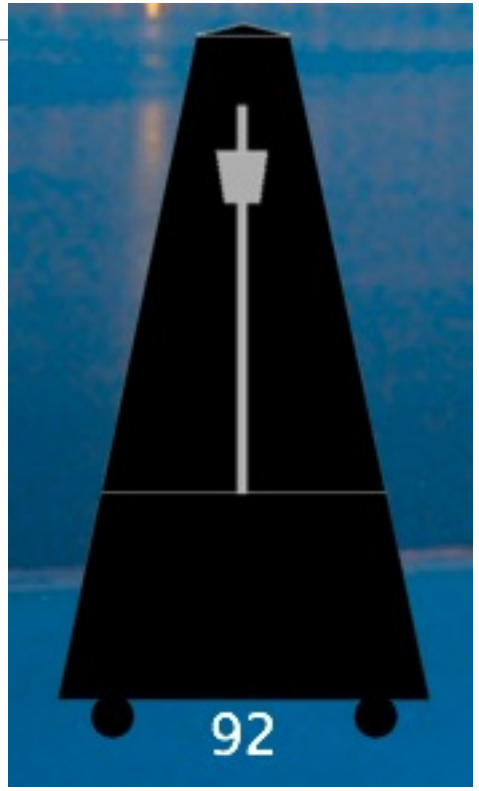
Tempo*:* Count of beats per time unit

- It can range from 30 to 600 bpm (IOI between 100ms to 2 seconds)
- *Preferred tempo*: listeners adjustment to make music more “natural” (on average: 100 bpm). Most of popular music is set around this value and ranges.

Beat induction

Beat induction is favored when:

- Beat coincides with note onsets
- Beat coincides with longer notes
- Beat is regular
- Beat aligns with begining of musical phrases
- Beat aligns with points of harmonic change
- Beat aligns with onsets of repeating melodic patterns



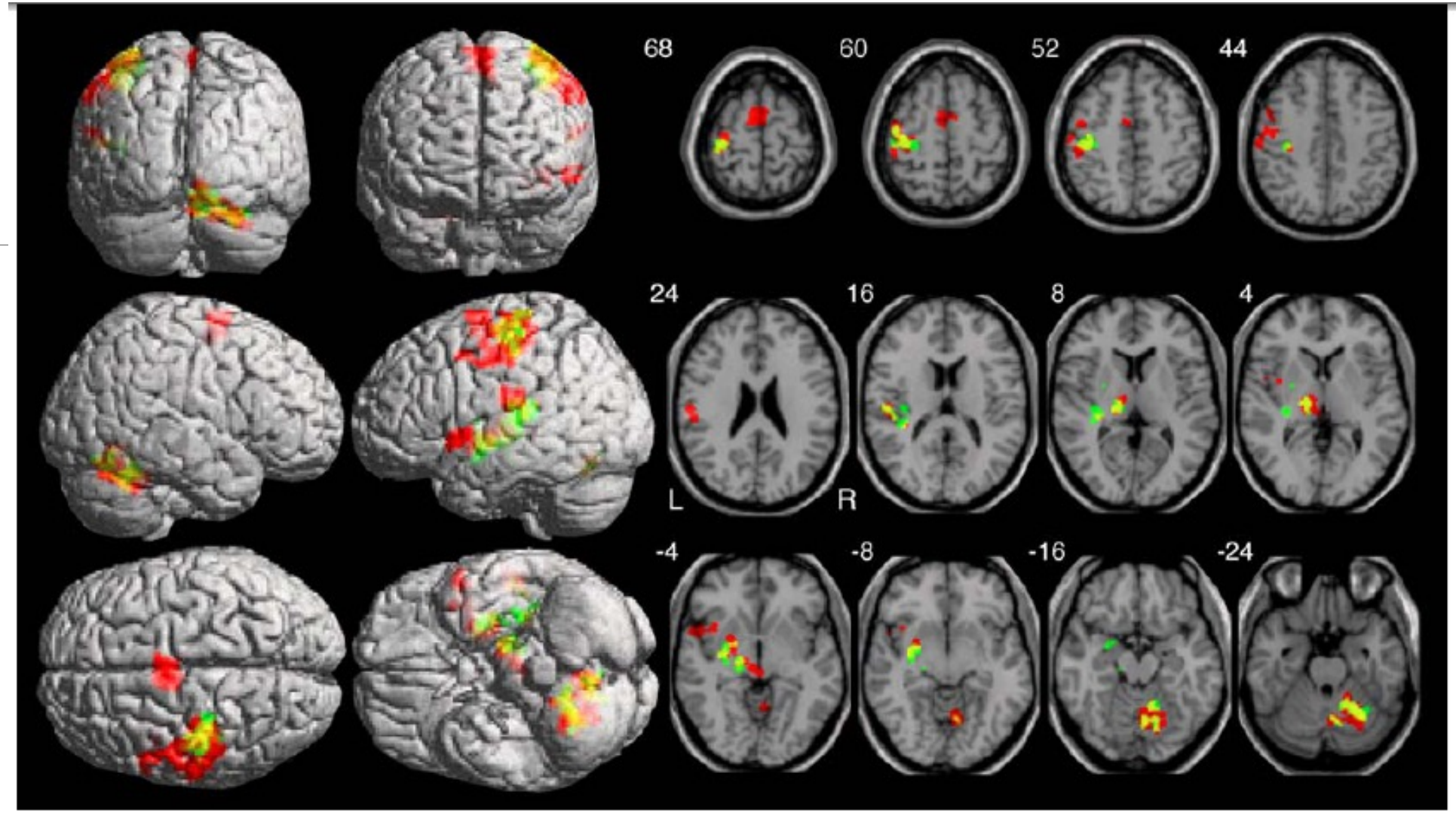


Figure 3. Brain activation during paced tapping. Foci of activation for isorhythmic-only tapping (green label), polyrhythmic-only tapping (red), and overlap (yellow) depicted on rendered projection images (left) and selected axial slice (right). Isorhythmic tapping activated M1, S1, and PMA, and the temporal operculum in contralateral neocortex as well as the basal ganglia and cerebellum. Polyrhythmic tapping activated the same structures, as well as the supramarginal gyrus, SMA, preSMA, cingulate cortex, and the middle and superior temporal gyri. Note greater extent of activation for polyrhythmic then isorhythmic tapping in commonly activated areas, and new areas of activation mostly for polyrhythmic tapping. **Numbers next to upper left of each horizontal brain slice refer z-axis in MNI-Talairach space. Additional details in text; full reporting of the activated areas appears in Table 1.**

doi:10.1371/journal.pone.0002312.g003

Snowball, the dancing queen of cockatoos

https://www.youtube.com/watch?v=DhxOS7xYbIs

Experiment in classroom (I)

You're going to hear a melody and I want you to tap in time to it with the index finger of your dominant hand and I want you to do it in such a way that no-one around you can either hear or see you tapping

You'll hear a melody repeated three times. The first two times it will be played unaccompanied but on the third repetition it will be accompanied by a regular beat played on a drum

I want you to listen to the melody and, as soon as you can, I want you to start tapping along in time to it silently with the index finger of your dominant hand. I want you tap with a regular beat so that the time interval between each pair of consecutive taps is constant. I want you tap at the most natural speed

And when you get to the third repetition, I want you to notice if the drum is beating at the same times that you are tapping at

Does anyone not understand what they have to do?

Experiment in classroom (II)

How many of you found that the drum was not beating at the same points that you were tapping at?

How many of you tapped faster than the drum beat?

How many of you tapped more slowly than the drum beat?

How many of you were tapping at roughly the same rate but at different time points?

Now this time I want you to again tap a regular beat in time with the melody but I want you to tap **faster than comes naturally**

Experiment in classroom (III)

How many of you found that the drum was not beating at the same points that you were tapping at?

How many of you tapped faster than the drum beat?

How many of you tapped more slowly than the drum beat?

How many of you were tapping at roughly the same rate but at different time points?

Now do the experiment for the final time, **tapping more slowly than you did the first time** (i.e., more slowly than what you consider to be the 'most natural speed').

How many of you found that the drum was not beating at the same points that you were tapping at?

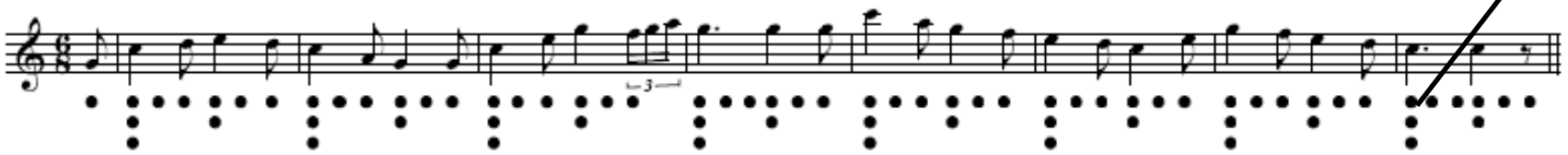
How many of you tapped faster than the drum beat?

How many of you tapped more slowly than the drum beat?

How many of you were tapping at roughly the same rate but at different time points?

Rhythm hierarchies / beat induction

- subtactus
- tactus
- supertactus



There is general agreement about most appropriate times to tap or clap (what do they share, how do they differ?)

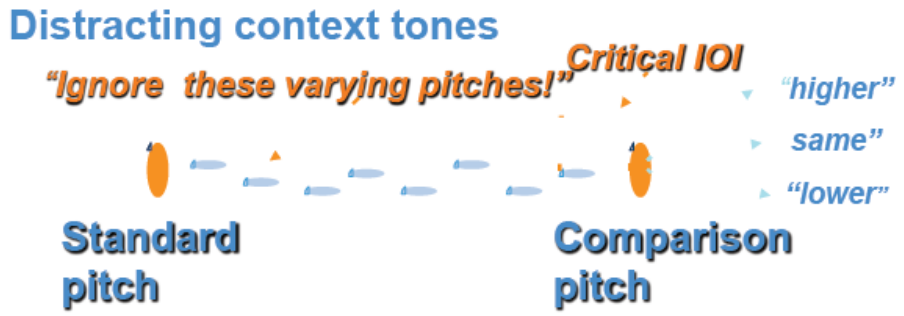
Different subjects give different responses, even though there is a “central tendency”; different “solutions” are “good”!!!

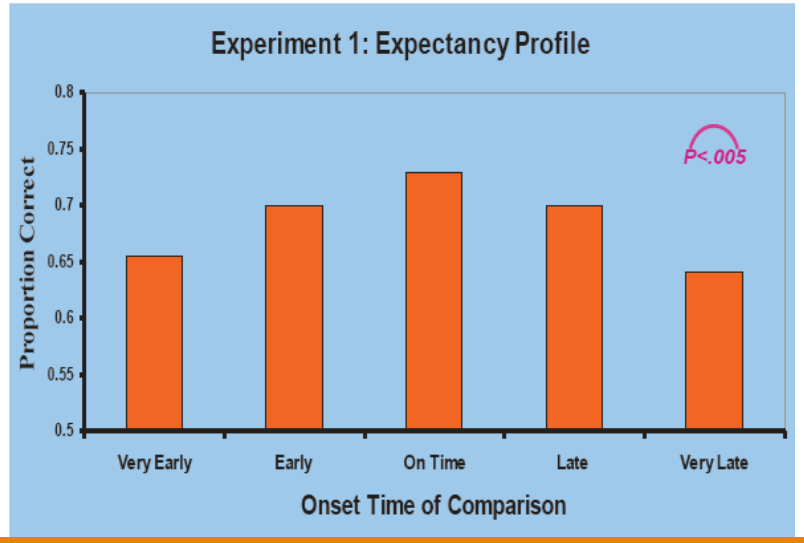
Different patterns offer different degree of difficulty degree to be tapped

Unconscious mental processes are involved in deciding when to tap

Beat as a patterning device framing our attention and expectations

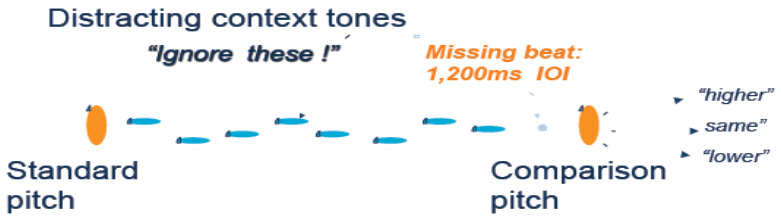
Is a comparison pitch: "same", "higher" ,"lower" than a standard pitch?



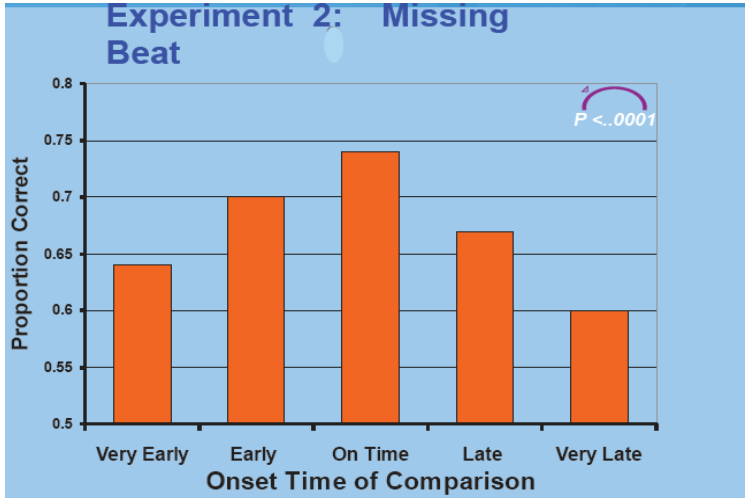


Experiment 2: Missing Beat

Same Task

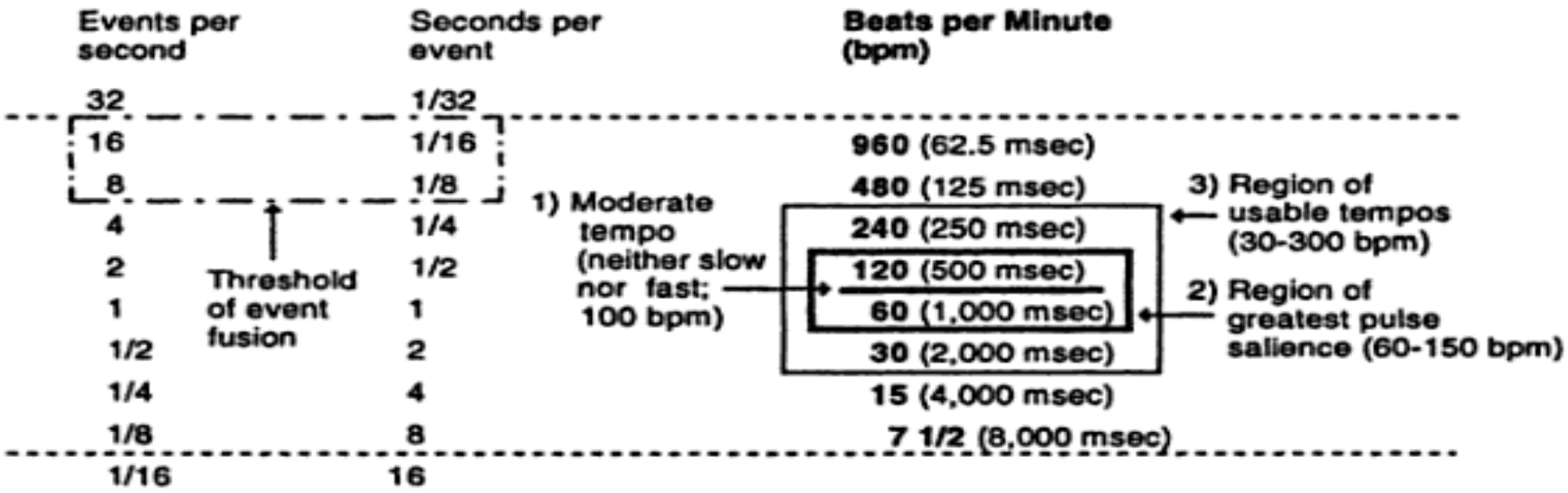


The final expected IOI now is twice 600 ms



Jones MR[1], Moynihan H, MacKenzie N, Puente J. **Temporal aspects of stimulus-driven attending in dynamic arrays.** Psychol Sci. 2002 Jul;13(4):313-9.

Time(s) and tempo



John Cage: As slow as possible https://universes.art/en/specials/john-cage-organ-project-halberstadt

Jem Finer: Longplayer http://longplayer.org/about/

Moby: Thousand (1000bpm) https://www.youtube.com/watch?v=k2ViG4vNj-M

What is the fastest music humanly possible? https://www.youtube.com/watch?v=h3kqBX1j7f8

Test your spontaneous tempo

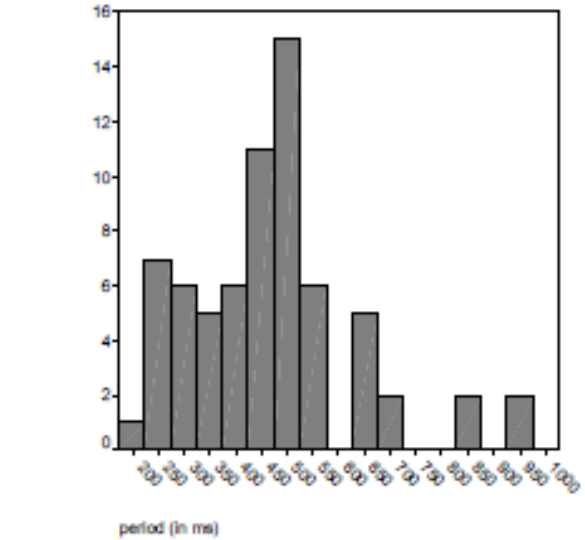


Figure 1: Distribution of the periods of 'spontaneous tempo' as found by Moelants (2002).

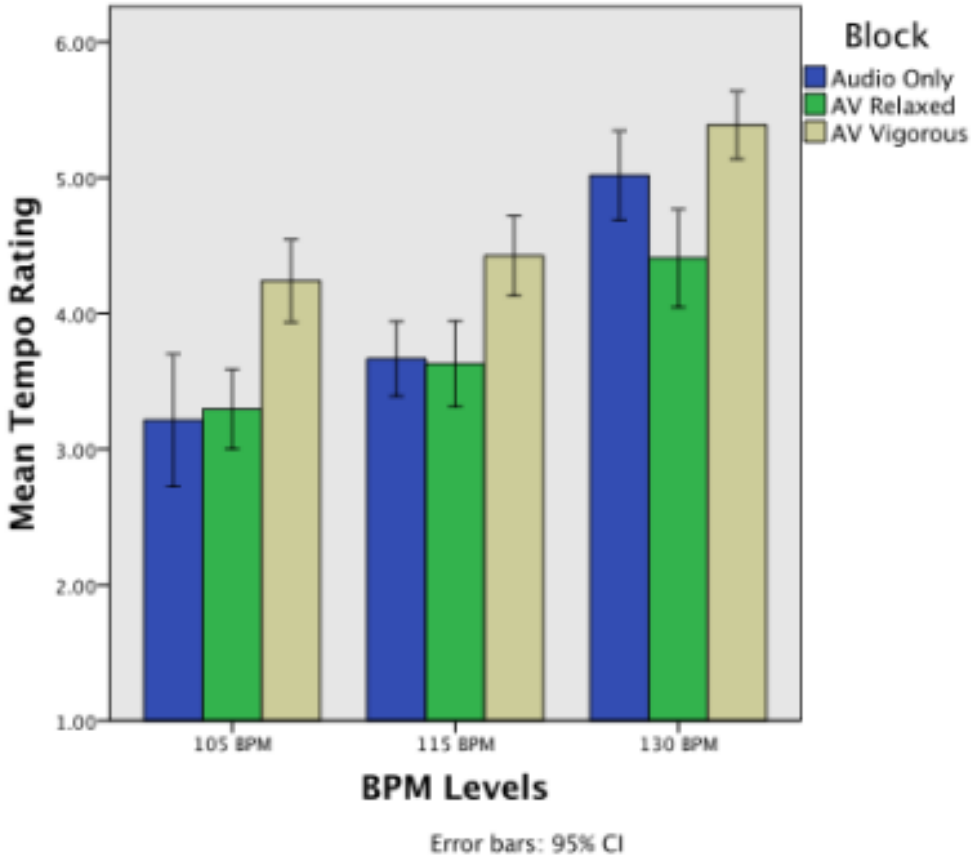
Close your eyes, and when I say “start”, start silently tapping with your foot, finger or hand

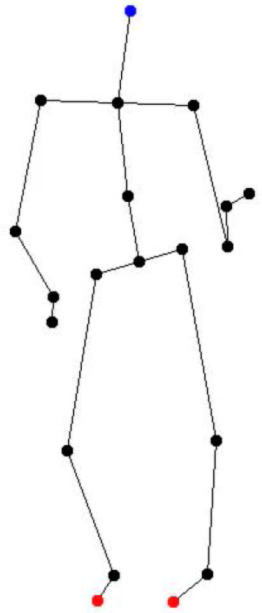
Count the number of taps

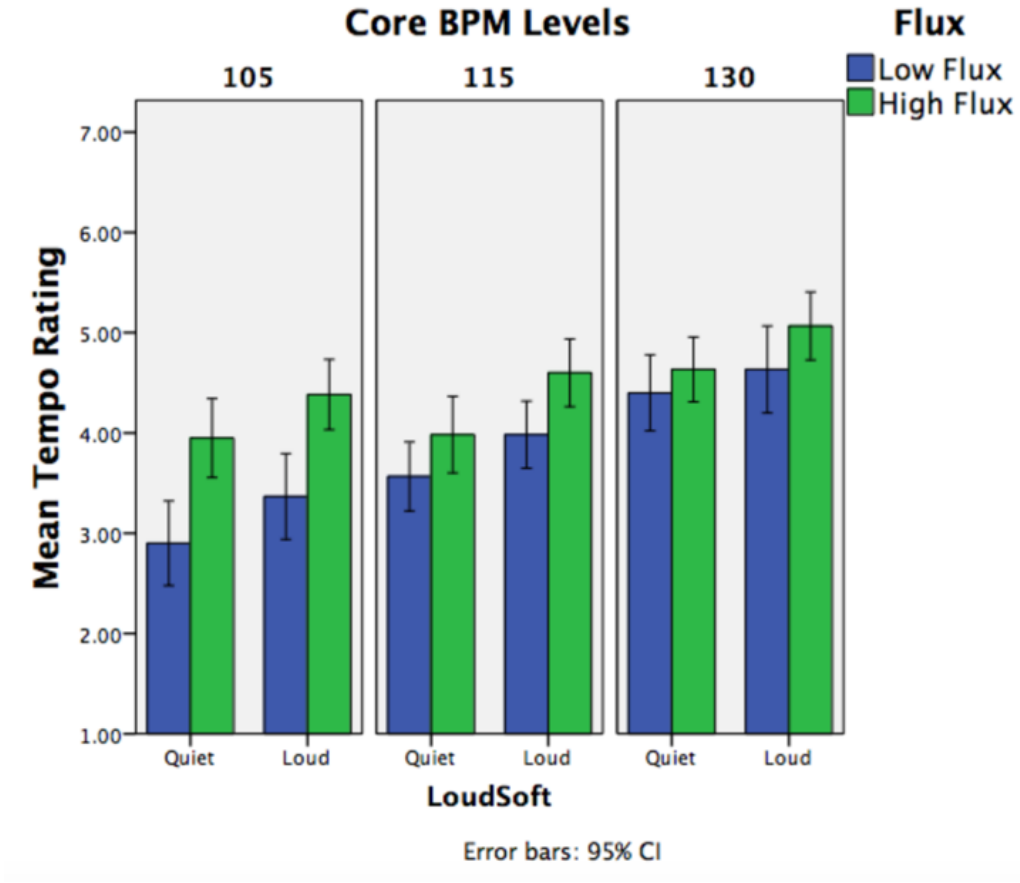
When I say “stop”, keep the number in your short-term-memory

Spontaneous tempo: the “natural” speed of regular tapping using the hand, finger or foot (on average:100 bpm, variation 60 to 150 bpm)
Physically our body can better react inside this range

Factors affecting tempo estimation



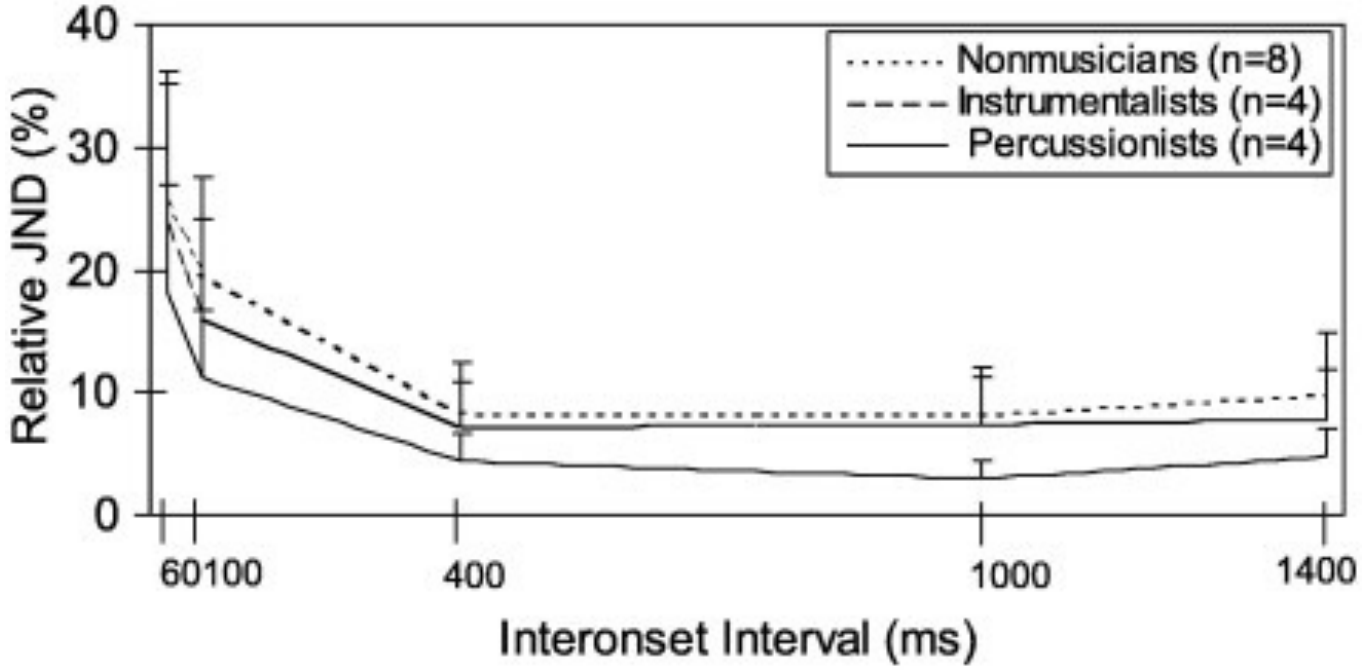




London, J., Burger, B., Thompson, M., & Toiviainen, P. (2016). Speed on the dance floor : auditory and visual cues for musical tempo. *Acta Psychologica*, *164*, 70-80

Tempo JND

At 100 bpm a listener can discriminate a change of about 10% in spacing (60 ms or ~10bpm)



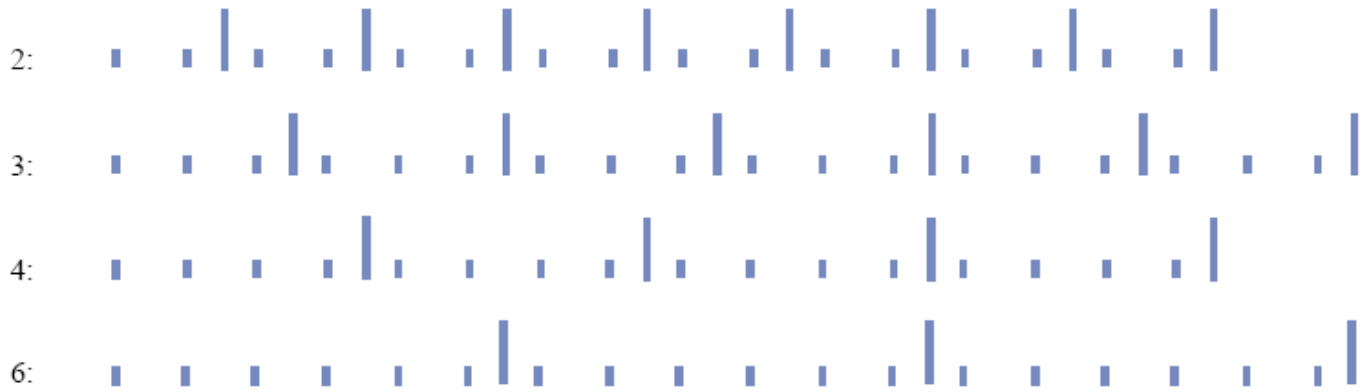
Accent

A stimulus (in a series of stimuli) which is marked for consciousness in some way (Cooper and Meyer, 1960)

A perceivable element that increases the perceptual salience of an event

How can we add accent? accent = contrast

- Lengthening IOIs
- Increasing intensity (dynamics)
- Changing articulation (from legato to staccato)
- Timbre variations
- Changing the direction of a melodic contour (from ascending to descending)
- Big leaps (large pitch differences in consecutive notes)
- Modulating (to dissonant or different key)
- Deviating from regularity (in timing, in pitch)



Meter and Accent

The recurrent groups of pulsations are called *meters*: for example, duple meter, triple meter, and quadruple meter. The beats within the measures are counted and accented:

2: one, two | one, two |
3: one, two, three | one, two, three |
4: one, two, three, four | one, two, three, four |
6: one, two, three, four, five, six |

Accent and meter

BEATS CAN BE WEAK OR STRONG (ACCENTED), THIS LEADS TO METER

Influences of native language on segmentation/meter strategies

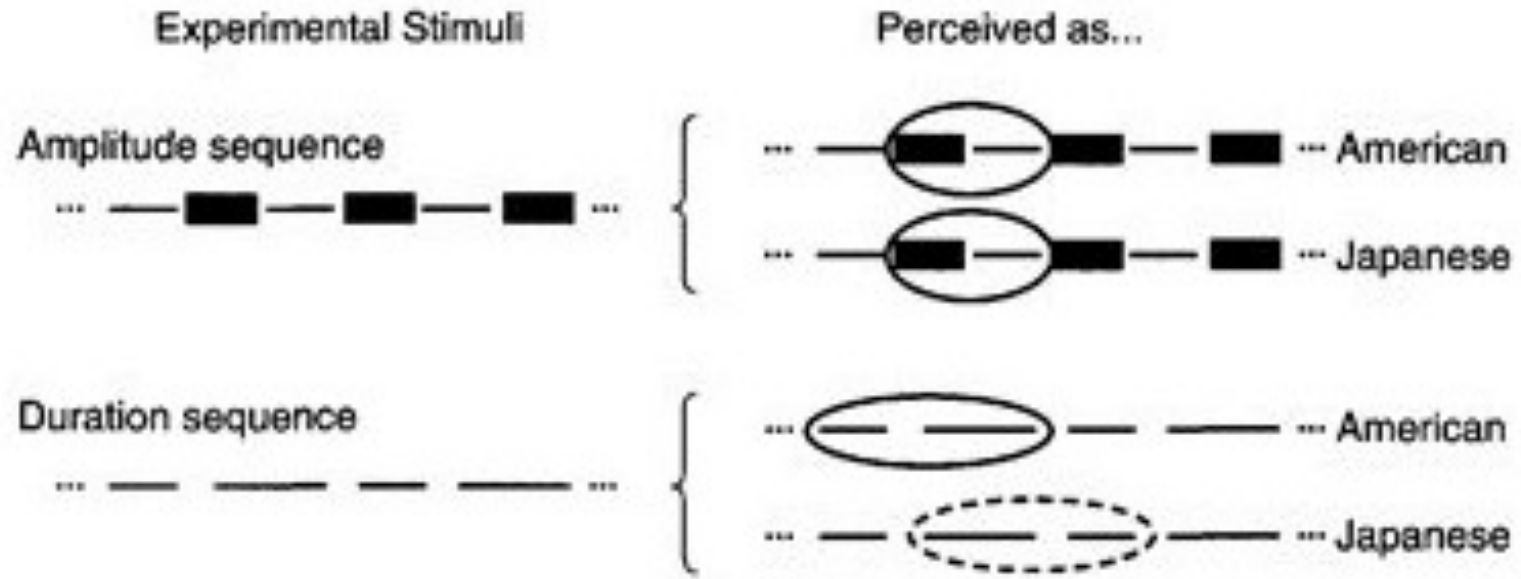
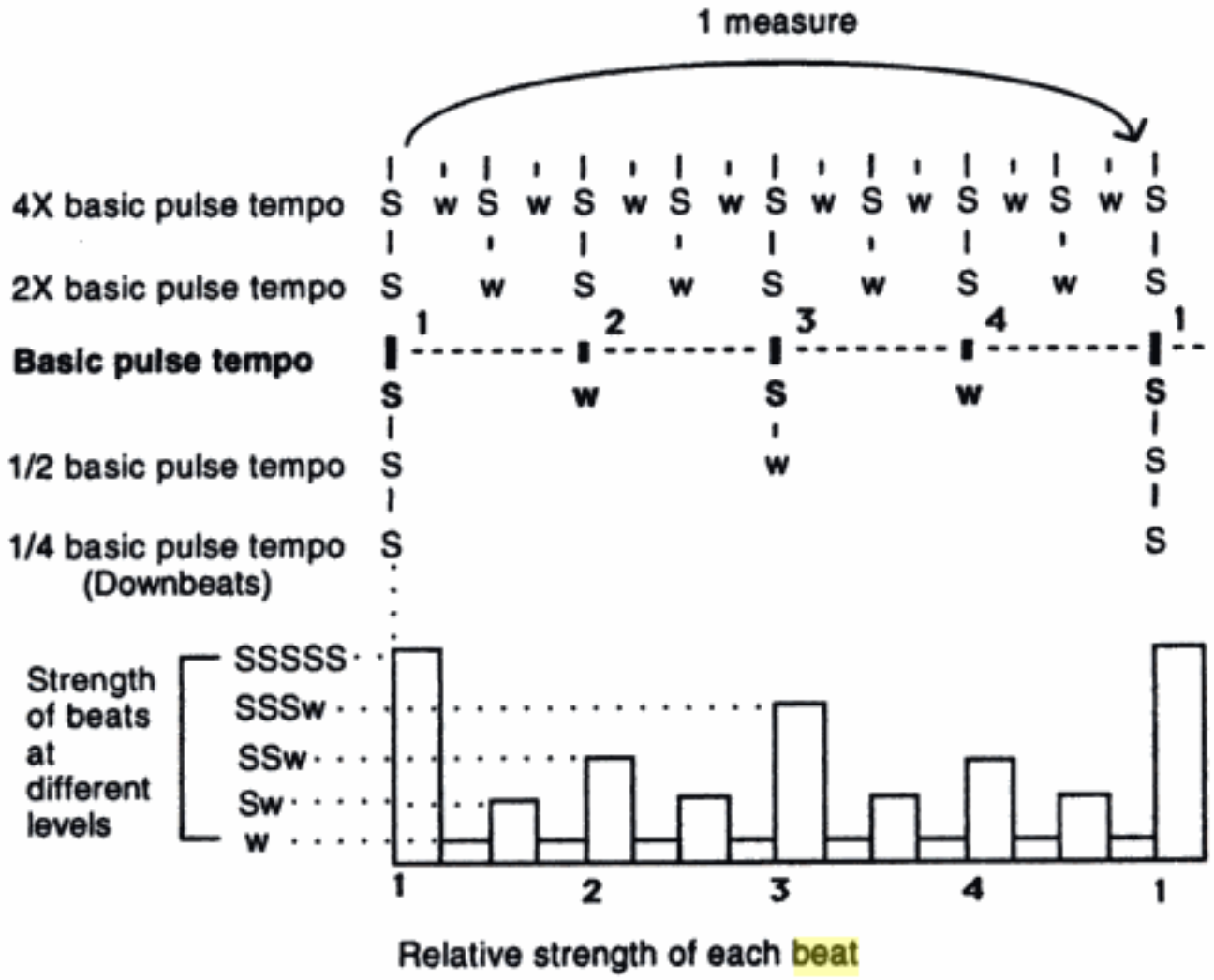


Figure 3.19 *Left side:* Schematic of sound sequences used in the perception experiment. These sequences consist of tones alternating in loudness ("amplitude sequence," top), or duration ("duration sequence," bottom). In the amplitude sequence, thin bars correspond to softer sounds and thick bars correspond to louder sounds. In the duration sequence, short bars correspond to briefer sounds and long bars correspond to longer sounds. The dots before and after the sequences indicate that only an excerpt of a longer sequence of alternating tones is shown. *Right side:* Perceived rhythmic grouping by American and Japanese listeners, indicated by ovals. Solid black ovals indicate prefer-

Metrical hierarchy

The weaker a beat, the greater the metrical tension when placing an accented event on it (we expect it to be placed in the strong one)



Exotic meters in pop music

Money - Pink Floyd: https://www.youtube.com/watch?v=cpbbuaIA3Ds 7 (4+3)/4 meter

Dave Brubeck Quartet - Blue Rondo à la Turk: https://www.youtube.com/watch?v=j9GgmGLPbWU

(3+3+3) 9/8

Genesis - Apocalypse in 9/8 (Supper's Ready): https://youtu.be/IlkiFtCPXts?t=78

Mike Oldfield - Tubular Bells: https://www.youtube.com/watch?v=bv_4sZCLlr0 7/8 + 8/8

Björk – Crystalline: https://www.youtube.com/watch?v=MSV3ujF5uuc (9+8)/8

The Beatles - Strawberry Fields Forever: https://www.youtube.com/watch?v=HtUH9z_Oey8

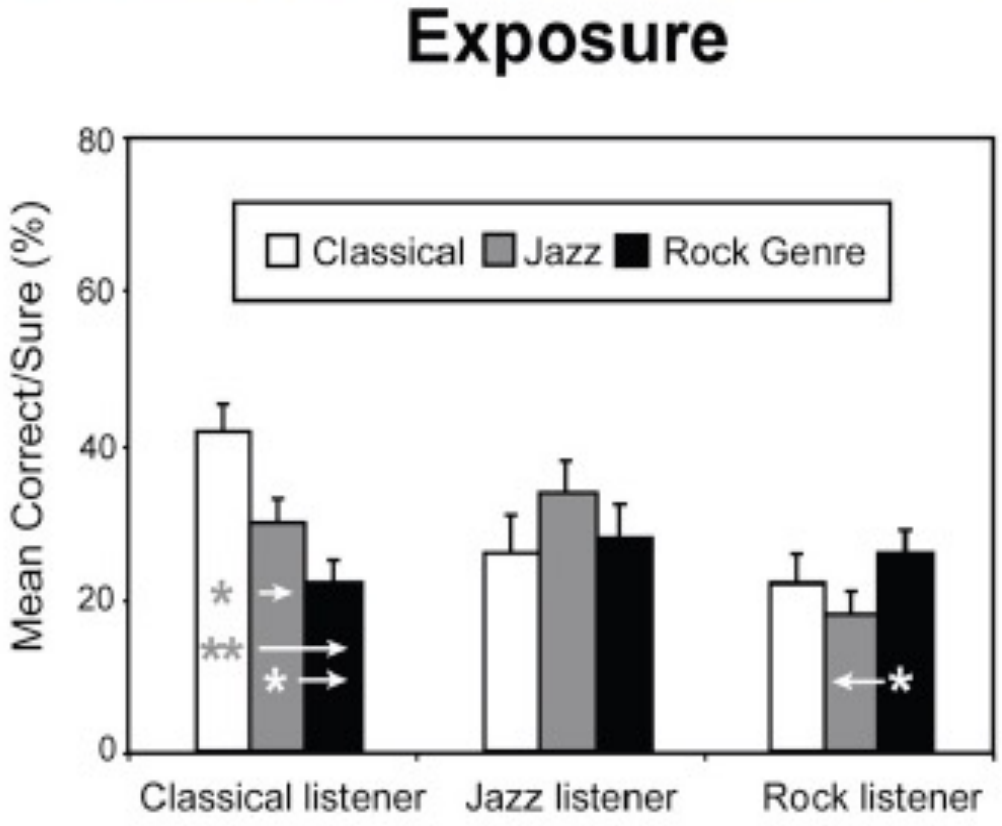
Expressive timing & expectation

Timing: temporal microstructure characteristic of a music performance (is the outcome of the performer's *interpretation* of the score)

Deviations from a strictly uniform pulse that occur in live performance. These deviations most commonly occur near the ends of phrases and other grouping units

At phrase boundaries listeners are most sentive to timing alterations

Exposure-dependent sensitivity to timing alterations



Honing, H. & Ladinig, O. (in press, 2008). Exposure influences timing judgments in music. *Journal of Experimental Psychology: Human Perception and Performance*, 34(5).

Honing, H. (2008). Musical competence and the role of exposure. *Proceedings of the Music and Language II Conference*, Boston: Tufts University.

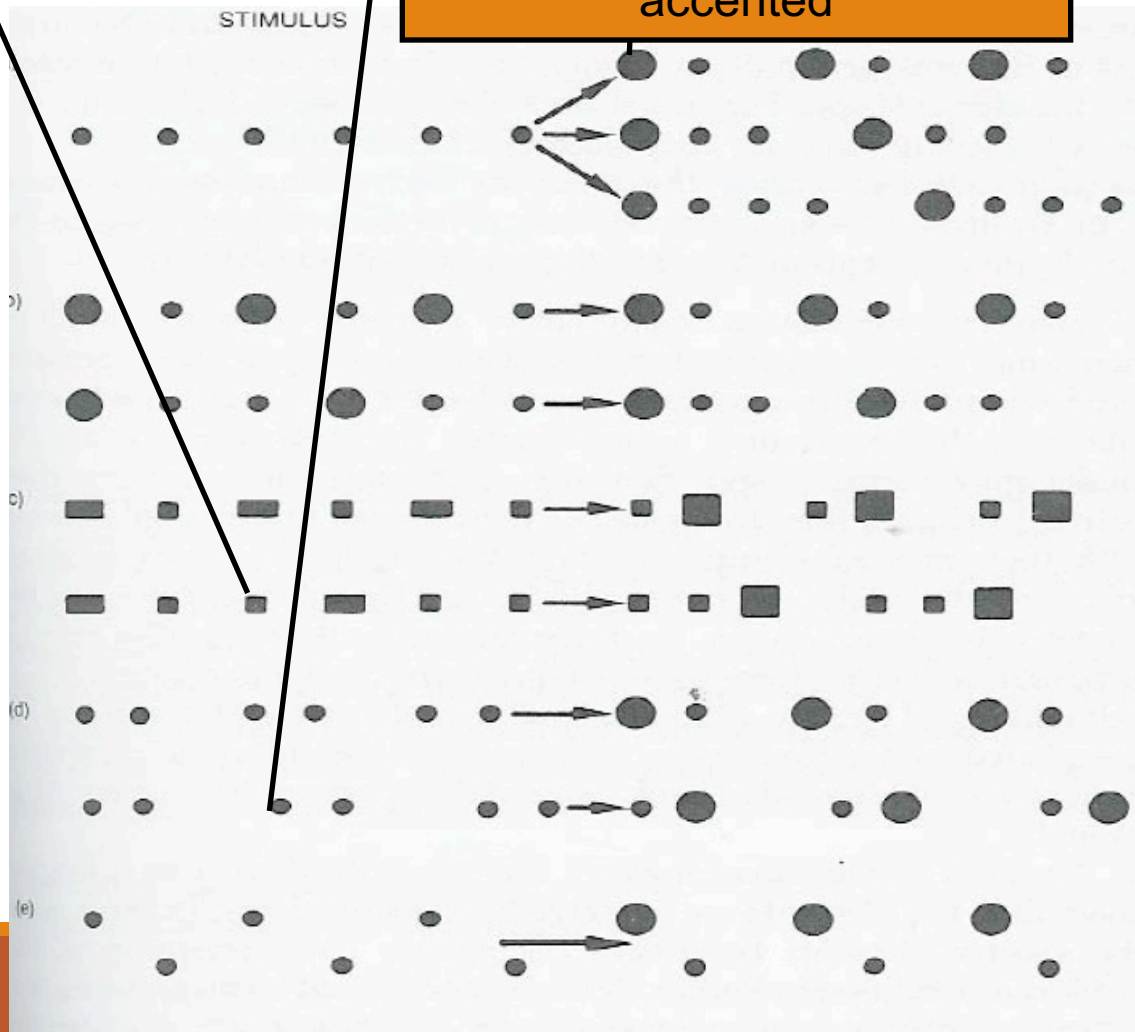
Rhythmic pattern

Separating an element makes the event to be perceived as accented

Depending on the accented event, the grouping changes

A longer silence makes the previous event to be accented

- Accent causes grouping which determines periodicities and then a perceived rhythmic pattern
- Rhythm is a perceptual attribute (it “emerges” as a combination of bottom-up & top-down processes)
- **Rhythm=grouping+meter**



Rhythm without beat and meter?

Koku-Reibo (Bell Ringing in the Empty Sky): https://www.youtube.com/watch?v=XiGJtperaGY

Louis Couperin Prélude non mesuré d minor: https://www.youtube.com/watch?v=K_G_k1WTdoc

Gregorian Chant: Gloria - Kyrie

Burhan Öçal: Makam Eviç Taksim

Sunn O))) - Black Wedding: https://www.youtube.com/watch?v=MdWAl7vormM

Brian Eno - New Space Music: https://www.youtube.com/watch?v=-dikWB6wm0A

Éliane Radigue - Naldjorlak I (Pour Violoncelle), Mouvement 3: https://www.youtube.com/watch?v=68DsW5JlXSs

Penderecki – Threnody to the victims of Hiroshima: https://www.youtube.com/watch?v=HilGthRhwP8

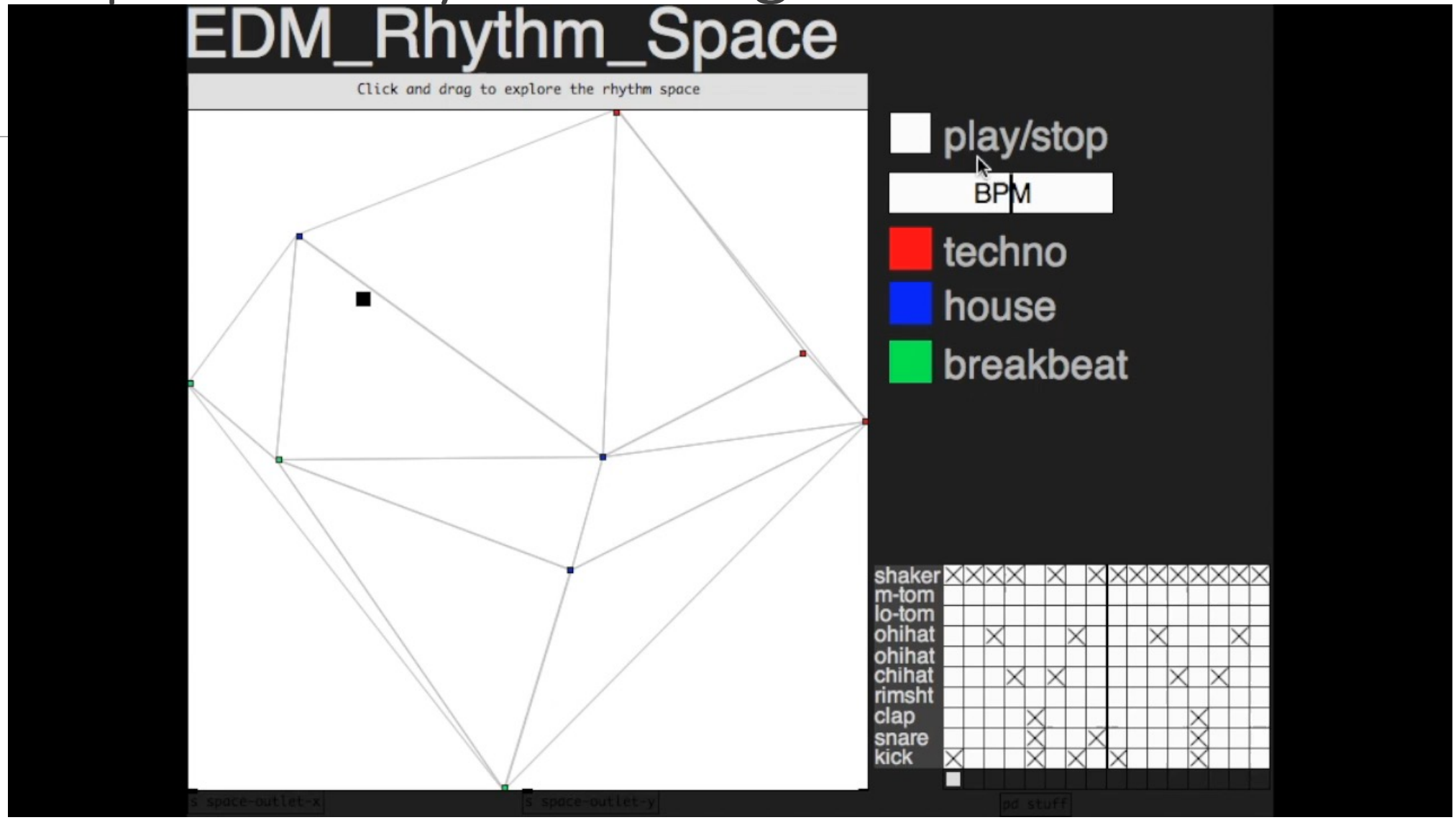
3 dimensions of rhythmic semantic experience (Gabrielson, 1973)

Cognitive-structural: rhythms have meter, accents, clarity and complexity…

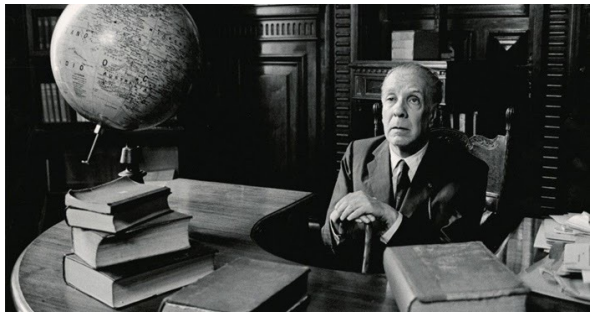
Movement: rhythms can be fast-slow, dense or sparse (number of events per time unit), and can be related to human motoric activities (walking, knocking, dancing, jumping…)

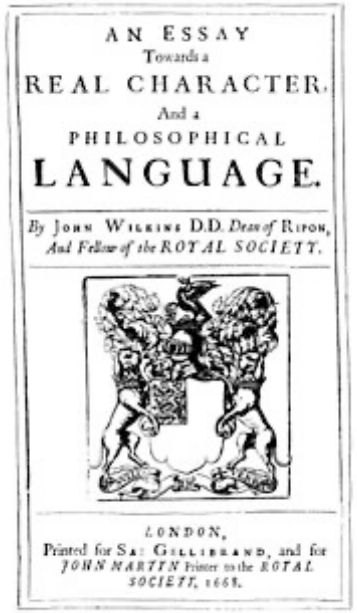
Emotional: rhythms can be playful, solemn, rigid, excited, calm…

Rhythm spaces – rhythm categories



The “what”




AN ESSAY
Towards a
REAL CHARACTER,
And a
PHILOSOPHICAL
LANGUAGE.
By JOHN WILKINS D.D. Dean of RIPON, And Fellow of the ROYAL SOCIETY.
LONDON,
Printed for SA. GILLIBRAND, and for JOHN MARTYN Printer to the ROYAL SOCIETY, 1668.

The animals are divided into: (a) belonging to the emperor, (b) embalmed, (c) tame, (d) sucking pigs, (e) sirens, (f) fabulous, (g) stray dogs, (h) included in the present classification, (i) frenzied, (j) innumerable, (k) drawn with a very fine camelhair brush, (l) et cetera, (m) having just broken the water pitcher, (n) that from along way off look like flies.

Jorge Luis Borges,

The analytical language of John Wilkins

Knowledge structures: Categories

A group of nonidentical objects or events that an individual treats as equivalent

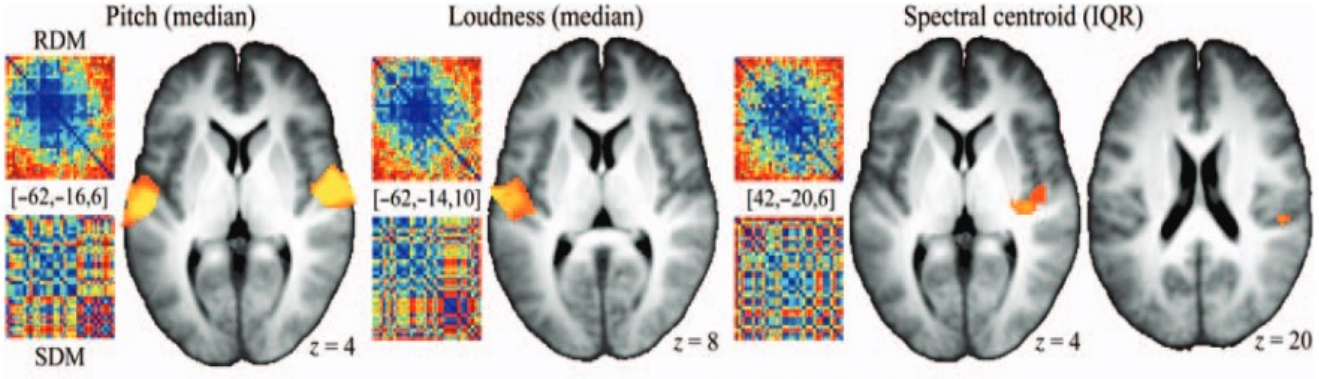
Equivalent could mean:

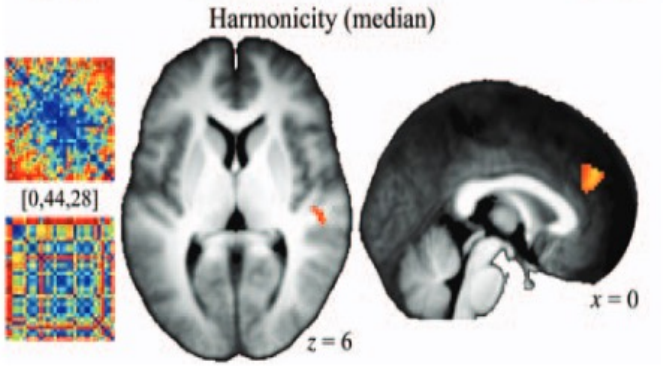
- Their internal representations are similar or close
- They generate similar behaviours (avoidance / approach)
- They generate similar internal states (e.g., emotions) (pleasure / pain)

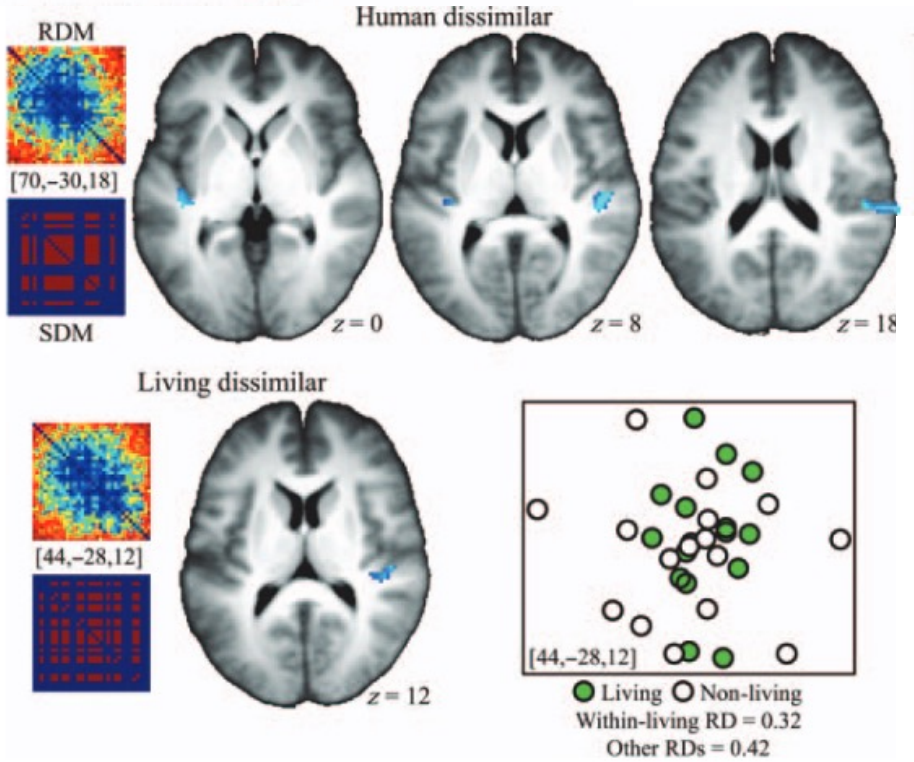
Categorization reduces the overwhelming complexity of the natural world (frequencies -> notes, spectro-temporal profiles -> instruments)

“Static” knowledge structure for representing facts and hierarchical relationships between them

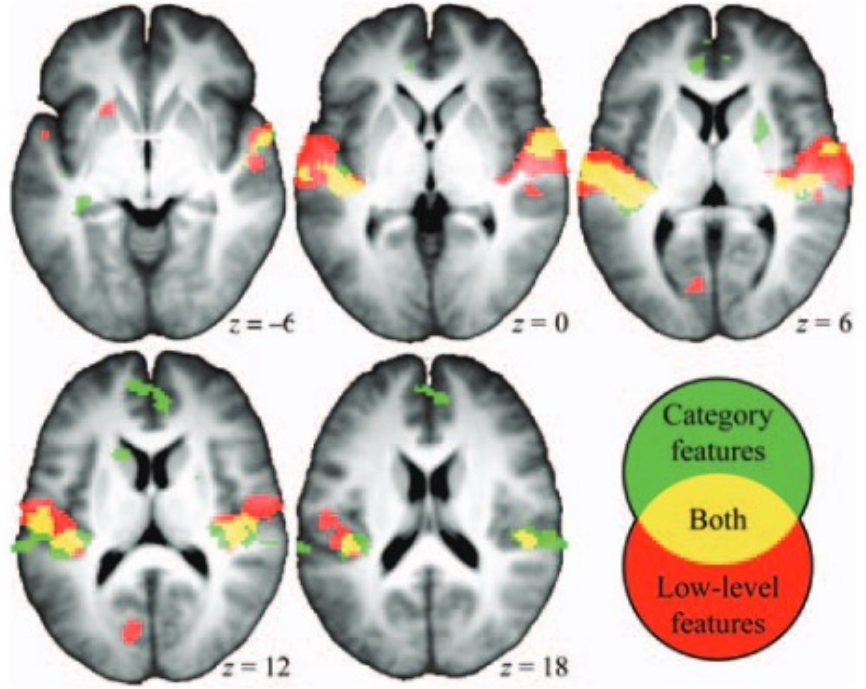
Sensory qualities and categories in the brain







Living vs non-living,
human vs non-human
Also music vs speech!



Giordano, B.L., McAdams, S., Zatorre, R.J., Kriegeskorte, N., & Belin, P. (2013). Abstract encoding of auditory objects in cortical activity patterns. Cerebral cortex, 23 9, 2025-37

Explicit musical categories

?

- Note (vs silence)
- Note (C, C#, D…)
- Dynamics (mezzo-forte, pianissimo…)
- Instrument (Flute, string section, brass, Contralto voice…)
- Rhythm pattern (waltz, march, reggae, swing…)
- Duration (black, quaver…)
- Key (A, C#, atonal, bi-tonic…)
- Mode (Major, minor, Phrygian, Mixolydian…)
- Chord (C Major, D minor 7^{th}…)
- Genre (Be-bop, Gregorian, Italian Opera, Thrash-metal…)
- Expression (Sforzando, col legno, frullato…)

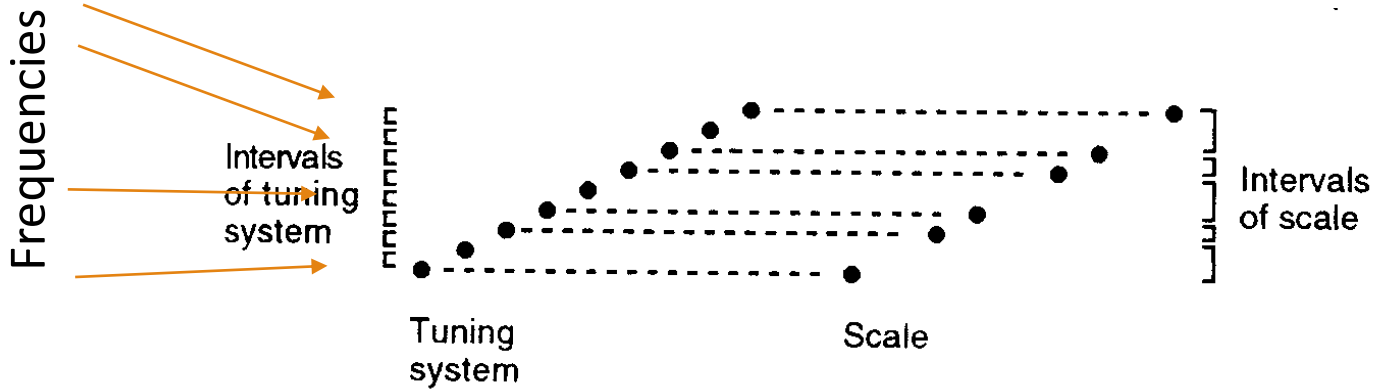
Tuning systems reduce the variety of audible frequencies into a small number of classes to be discriminated

(preference for selecting simple ratios: 2/3,3/4, 2/5, 3/5…)

Scales are “subpopulations” of a tuning system that allow pitch information to be managed under the constraints of our memories

(<=7 pitches considered)

Scales provide a framework to admit “pitch nuances” and small mistunings as instances of the learned categories



Melodic categories: tuning systems, scales, pitches

Representation of Melodic Knowledge

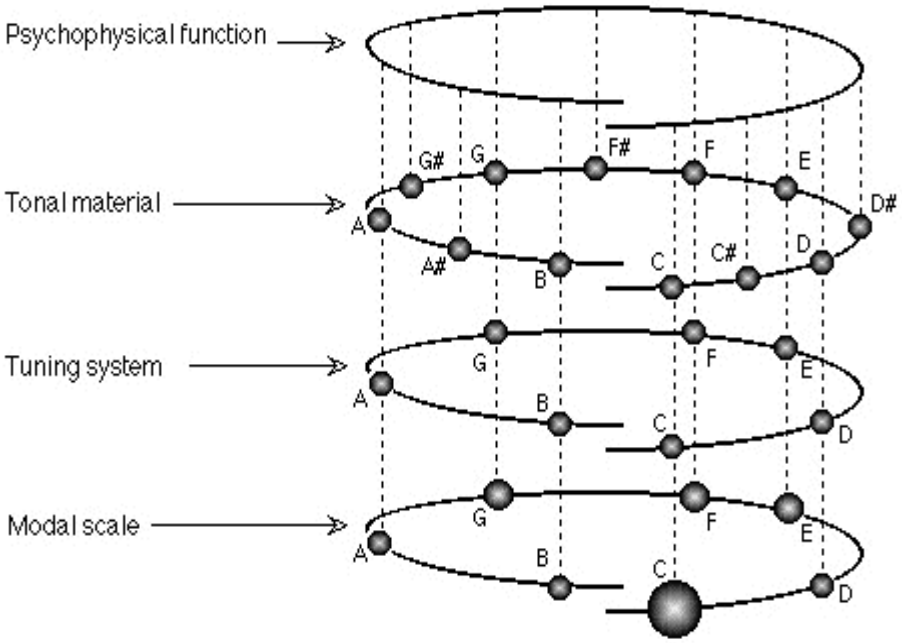
Psychophysical function (frequencies **->** pitches)

Pitches (all pitches usable in a musical culture)

Tuning system (“available” pitches for building melodies)

Modal Scale (some pitches are assigned roles, weighted with different importance, etc.)

Melodic schema (in a given context, we expect or can anticipate the most likely melodic evolution)



Row - Retrograde – Inversion – R+I

What happens with these melodies?

From harmonics to notes and intervals in Western music

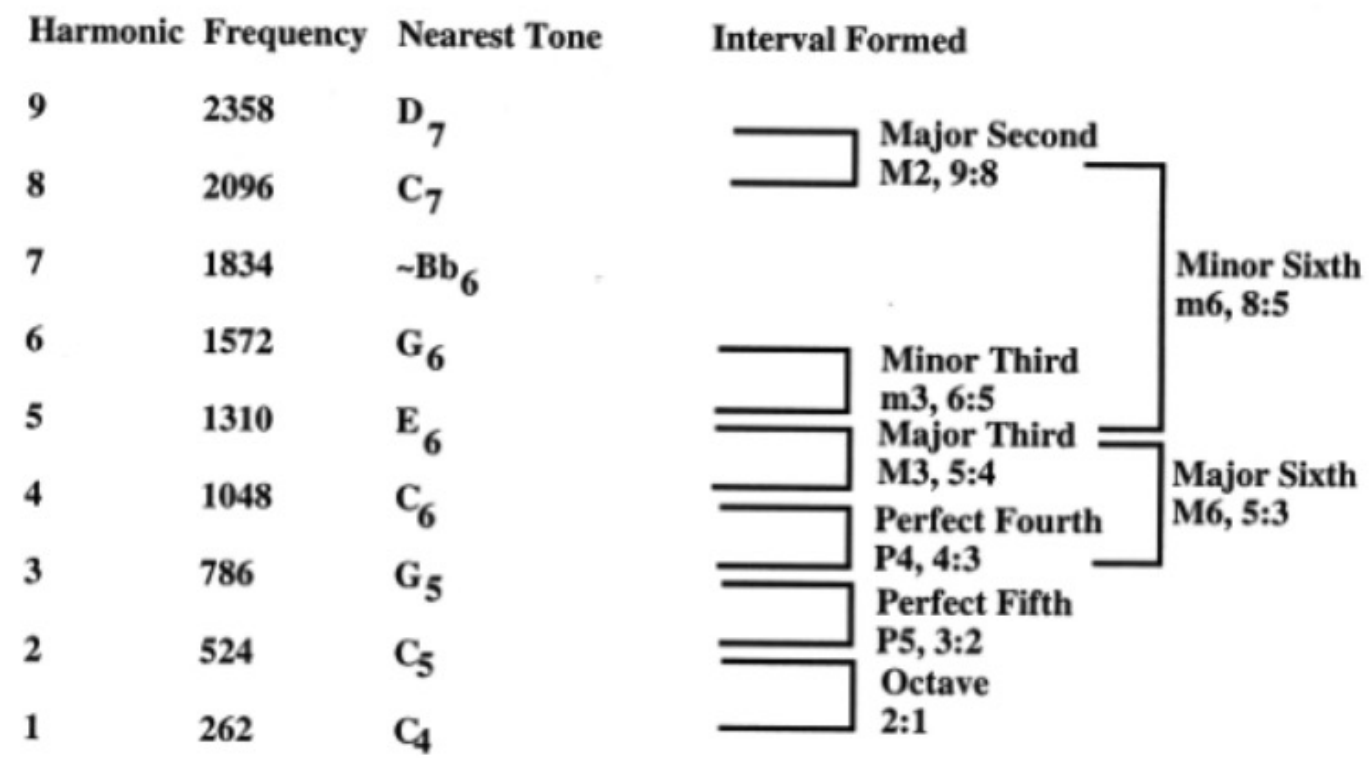
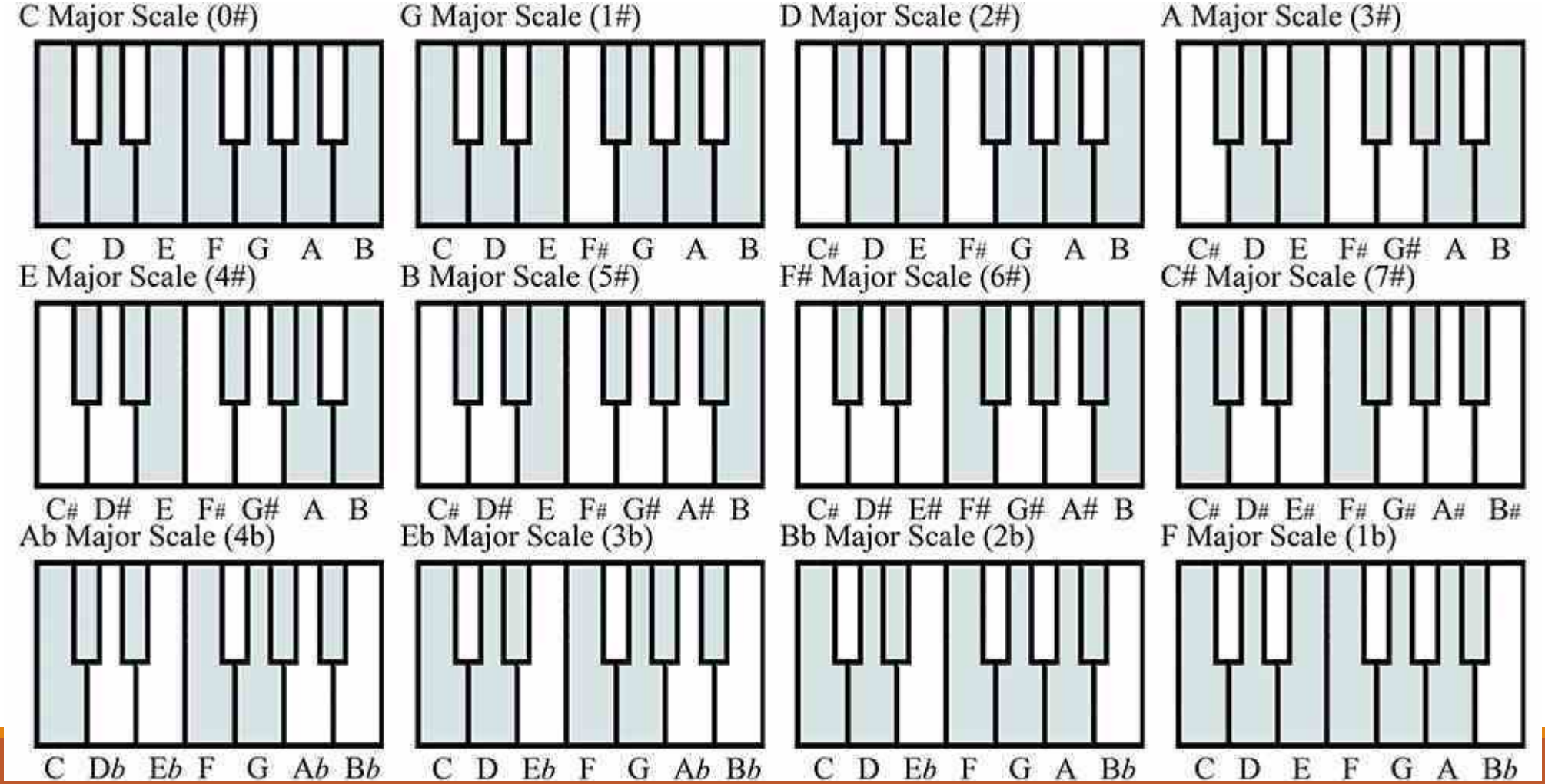


Fig. 2. The first nine harmonics of middle C. The frequencies and nearest tones are indicated, as well as intervals described as elements of Western tonal-harmonic music.

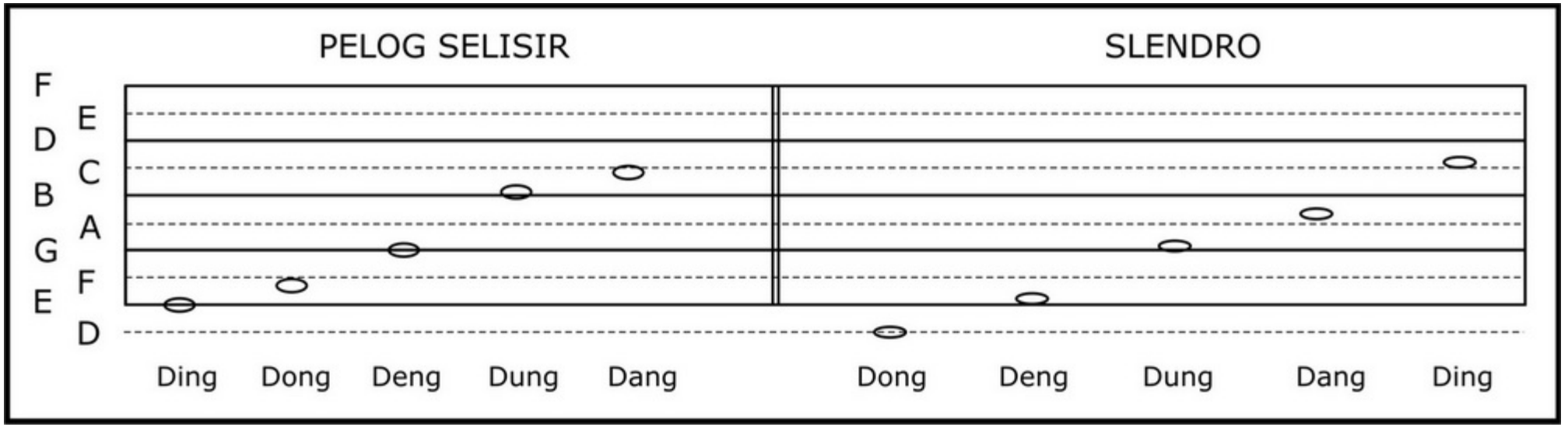
Tuning

	EQUAL TEMPERAMENT		PYTHAGOREAN		JUST		MEAN–TONE	
	Ratio	Cents	Ratio	Cents	Ratio	Cents	Ratio	Cents
Unison	1:1	0	1:1	0	1:1	0	1:1	0
Aug unis					1:1.055	92	1:1.045	76
Mi 2nd	1:1.059	100	1:1.053	90	1:1.067	112	1:1.070	117
Maj 2nd	1:1.122	200	1:1.125	204	1:1.125	204	1:1.118	193
Mi 3rd	1:1.189	300	1:1.185	294	1:1.200	316	1:1.196	310
Maj 3rd	1:1.260	400	1:1.265	408	1:1.250	386	1:1.250	386
P 4th	1:1.335	500	1:1.333	498	1:1.333	498	1:1.337	503
Tritone	1:1.414	600						
Aug 4th			1:1.404	588	1:1.406	590	1:1.398	580
Dim 5th			1:1.424	612	1:1.422	610		
P 5th	1:1.498	700	1:1.500	702	1:1.500	702	1:1.496	697
Mi 6th	1:1.587	800	1:1.580	792	1:1.600	814	1:1.600	814
Maj 6th	1:1.682	900	1:1.687	906	1:1.667	884	1:1.672	890
Aug 6th					1:1.778	996	1:1.747	966
Mi 7th	1:1.782	1000	1:1.778	996	1:1.800	1018	1:1.789	1007
Maj 7th	1:1.888	1100	1:1.898	1109	1:1.875	1088	1:1.869	1083
Octave	1:2	1200	1:2	1200	1:2	1200	1:2	1200

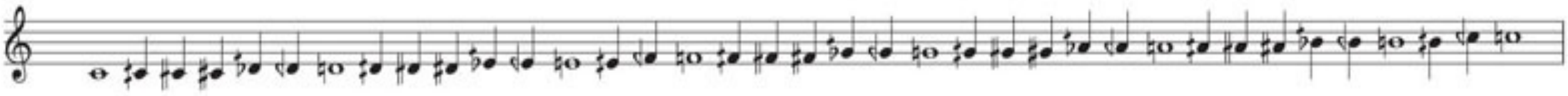
Some Scales in Western Music



Scales in Gamelan music



Scales (Makams) in Turkish music



deg.	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
cent	0	49	80	98	153	182	199	251	282	304	352	382	396	453	484	501	550	580	594	654	683	700	749	780	802	853	882	897	951	982	1002	1051	1080	1095	1155	1186	1200
int.	0	49	31	18	56	29	16	52	31	22	49	29	14	57	31	17	49	29	14	60	29	16	49	31	22	51	29	14	54	31	20	49	29	14	60	31	14
SÜPÜRDE	*Rast*	dik rast	nim zengule	nerm zengule	zengule	dik zengule	*Dügah*	dik dügah	kürdi	dik kürdi	nerm segah	segah	*Buselik*	dik buselik	nerm çargah	*Çargah*	dik çargah	nim hicaz	nerm hicaz	hicaz	dik hicaz	*Neva*	dik neva	nim hisar	nerm hisar	hisar	dik hisar	*Hüseyni*	dik hüseyni	aşem	dik aşem	nerm evç	evç	*Mahur*	dik mahur	nerm gerdaniye	*Gerdaniye*

Scale structure

- Scale: 7 tones (scale degrees) per octave with an asymmetric pattern of pitch spacing (intervals) between them.
- The different tones take on different roles in the fabric of music, with one tone being the most central and stable (the tonic).
- Diverse musical traditions make use of a tonic
  - Utility of psychological reference points in organizing mental categories.
- Listeners are very sensitive to scale structure
- Sour notes are very salient.

Trainor & Trehub (1992)

- Nonmusician adults were sensitive to notes in a melody that were changed by one semitone (outside of the scale) compared to four semitones (inside the scale), but 8-month old infants were not

Trainor & Trehub (1994)

- 5 year-old children with no formal training in music were sensitive to out-of-scale alterations.

Recovering the flavours of music?

Robert Rich – Coils: https://www.youtube.com/watch?v=PLYFAXYOBiY

Terry Riley - The Harp of New Albion: IV. Cadence on the Wind:
https://www.youtube.com/watch?v=n5gJEM7q2Rk

Easley Blackwood - 13 notes Etude. Sostenuto:

https://www.youtube.com/watch?v=NPZvcAyDY8M

Mashroon (microtonal drum & bass, Bohlen Pierce scale):
https://www.youtube.com/watch?v=jQ7T9oRi7Cs

Sevish - Droplet (53-tone microtonal music):

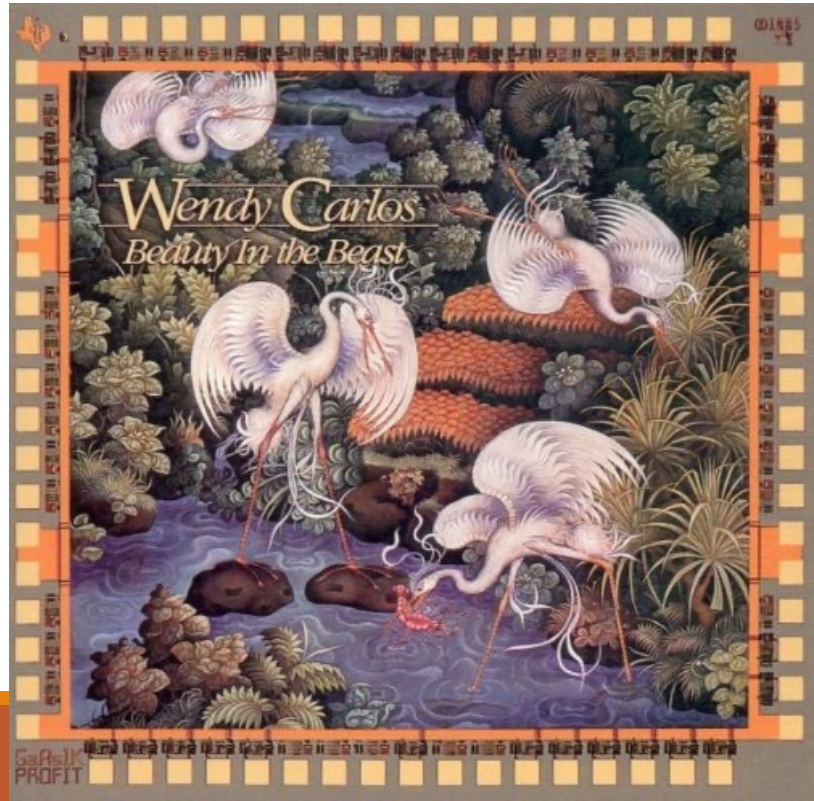
https://www.youtube.com/watch?v=xVZy9GUeMqY

Harry Partch - The World Of Harry Partch (1969):

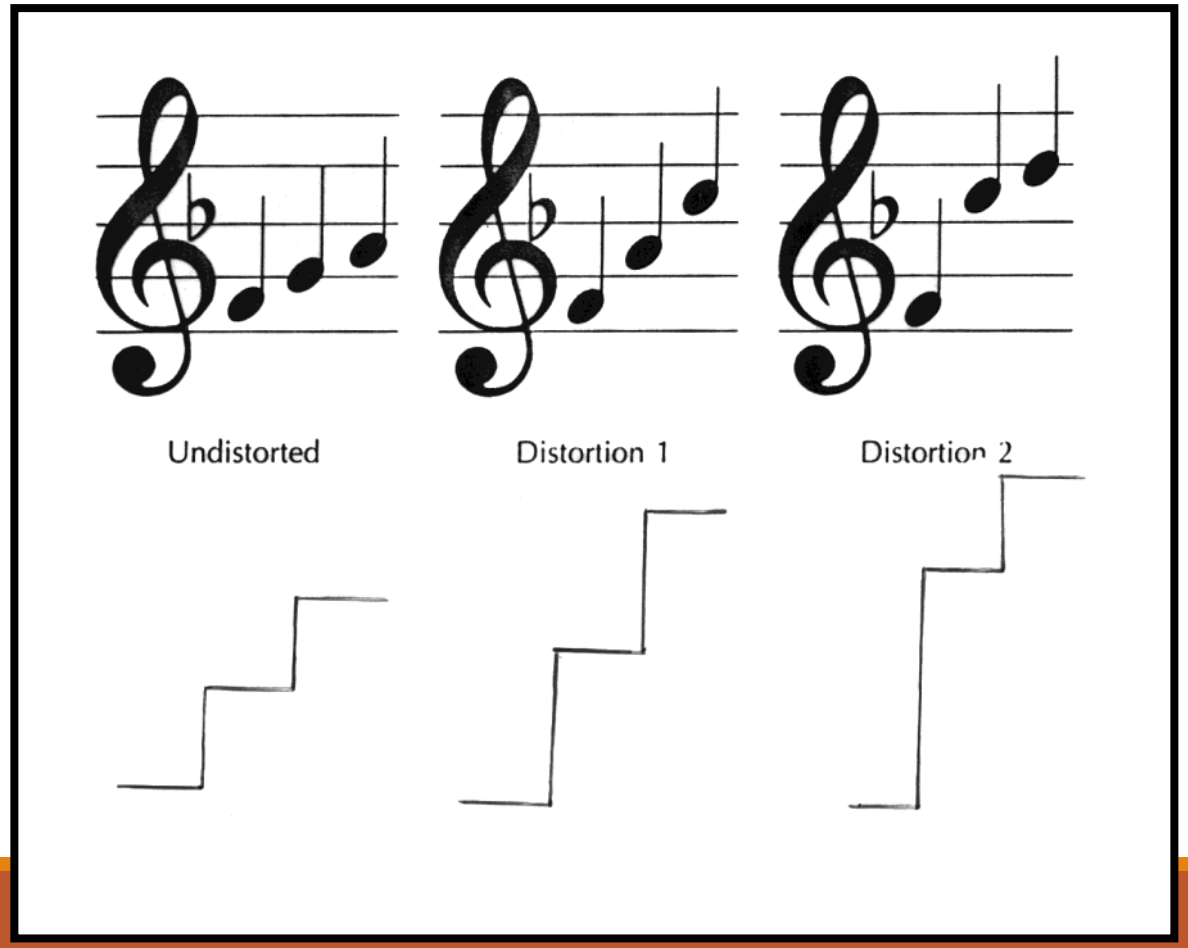
https://www.youtube.com/watch?v=WrJDdt5OS_Y

Harry Partch Documentary – The Outsider:

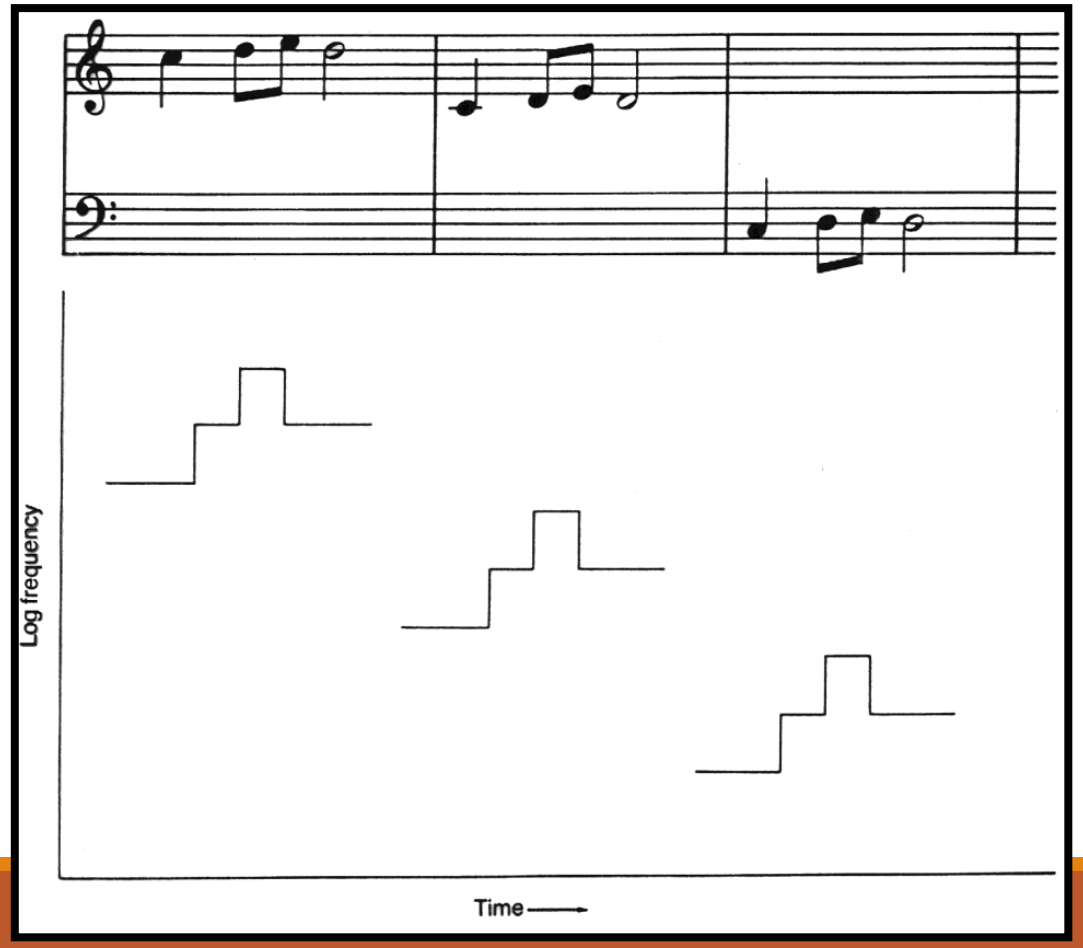
https://www.youtube.com/watch?v=aKD3zm0WZjA



Contour - the pattern of successive pitch changes within a melody defines its contour (what is important is the direction of pitch changes, rather than the extent of the change).

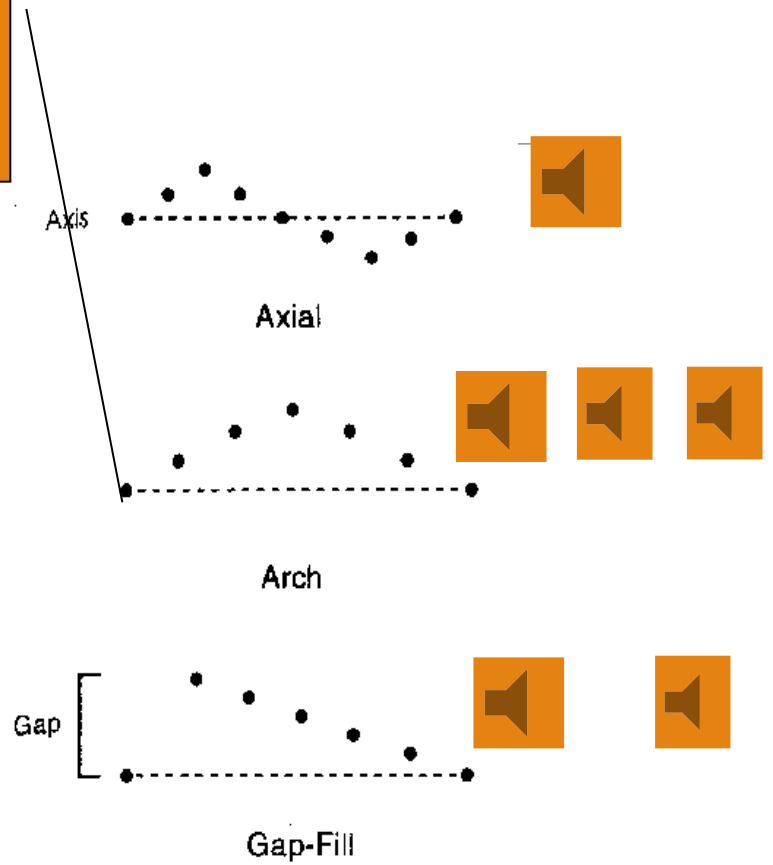


Transposition



Melodic schemata

3 different melodic schemata, based on Meyer (1958)



Schemas are dynamic knowledge structures

Some of them related to physical or visual concepts

Help to recognize and to code a series of events or objects

Help to predict possible next musical notes, directions of contour, etc

Tuning systems and scales do not include temporal information, schemata do

Tonality is one of the most powerful music schemas as it includes, implicitly, temporal dependencies derived from the sequential pattern of notes

Tonal hierarchies

By being exposed to organized musical input our brain “implicitly” learns the statistics of pitch ocurrences (either in melodies as in chords)

The cues for the tonal hierarchy (the key) are present in the surface details of a melody – duration and frequency of occurrence of pitches

Statistical learning

Is it enough with transition matrices of order 1 (i.e., considering the previous note)?

Are we “markovian learners”?

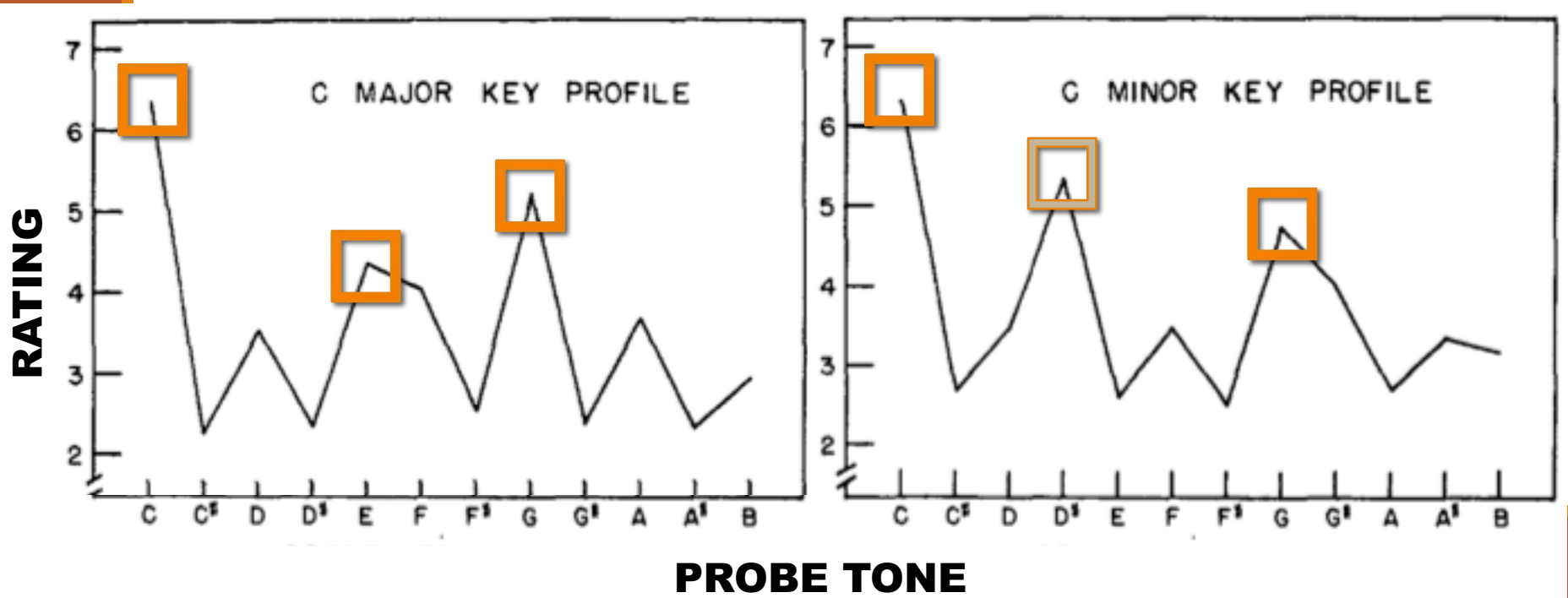
	do	do#	re	re#	mi	fa	fa#	so	so#	la	la#	ti
do	26.42	0.06	21.70	0.17	15.27	1.62	0.10	10.22	0.00	6.49	0.00	17.95
do#	5.88	11.76	61.76	8.82	0.00	0.00	0.00	0.00	0.00	5.88	0.00	5.88
re	33.53	0.26	21.06	0.55	26.26	5.43	0.00	6.60	0.00	1.61	0.00	4.69
re#	12.50	0.00	45.00	0.00	8.33	30.00	0.00	4.17	0.00	0.00	0.00	0.00
mi	10.38	0.03	32.47	0.03	20.97	17.65	0.59	15.79	0.02	1.88	0.00	0.19
fa	0.58	0.02	13.51	0.90	44.26	16.15	0.04	18.36	0.03	4.73	0.06	1.34
fa#	1.57	0.00	8.38	0.00	19.37	5.24	20.94	20.94	1.05	20.94	0.00	1.57
so	14.87	0.01	3.08	0.22	16.60	21.25	1.20	28.12	0.11	12.08	0.31	2.15
so#	2.70	0.00	0.00	0.00	2.70	5.41	2.70	29.73	5.41	37.84	8.11	5.41
la	3.55	0.06	2.51	0.00	0.97	5.11	0.55	54.37	0.25	18.83	1.05	12.75
la#	21.60	0.00	1.05	2.79	0.35	1.05	0.00	14.98	0.00	41.46	16.72	0.00
ti	33.59	0.00	8.46	0.00	0.58	0.48	0.17	5.36	21.91	22.01	0.02	7.43

Likelihood that a pitch on the y axis is followed by a pitch on the x axis in a sample of 50,000 notes of German folk music.

Western Tonal Hierarchies

Krumhansl & Kessler (1982):

- Certain notes are sort of more important than others (first level: Tonic; second level: Dominant & Mediant; etc.)
- Key profiles: play a sequence setting a tonal context, play a probe tone (does it fit or not?)
- Listeners may notice “in-scale” vs. “out-of-scale” pitches
- Connection with Harmonic Pitch Class Profiles (HPCP) in MIR



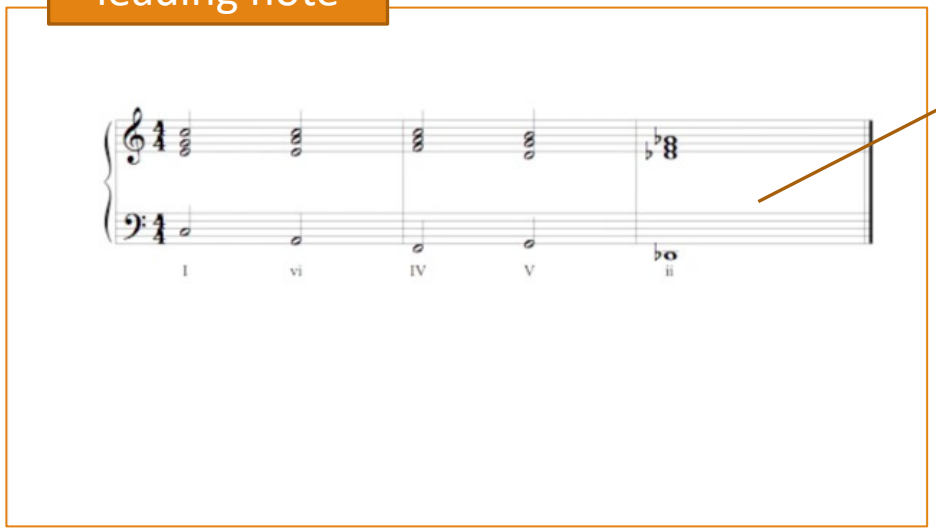
Explain your “sensations”

Dominant - tonic

Tonic-subdominant

Ends with leading note

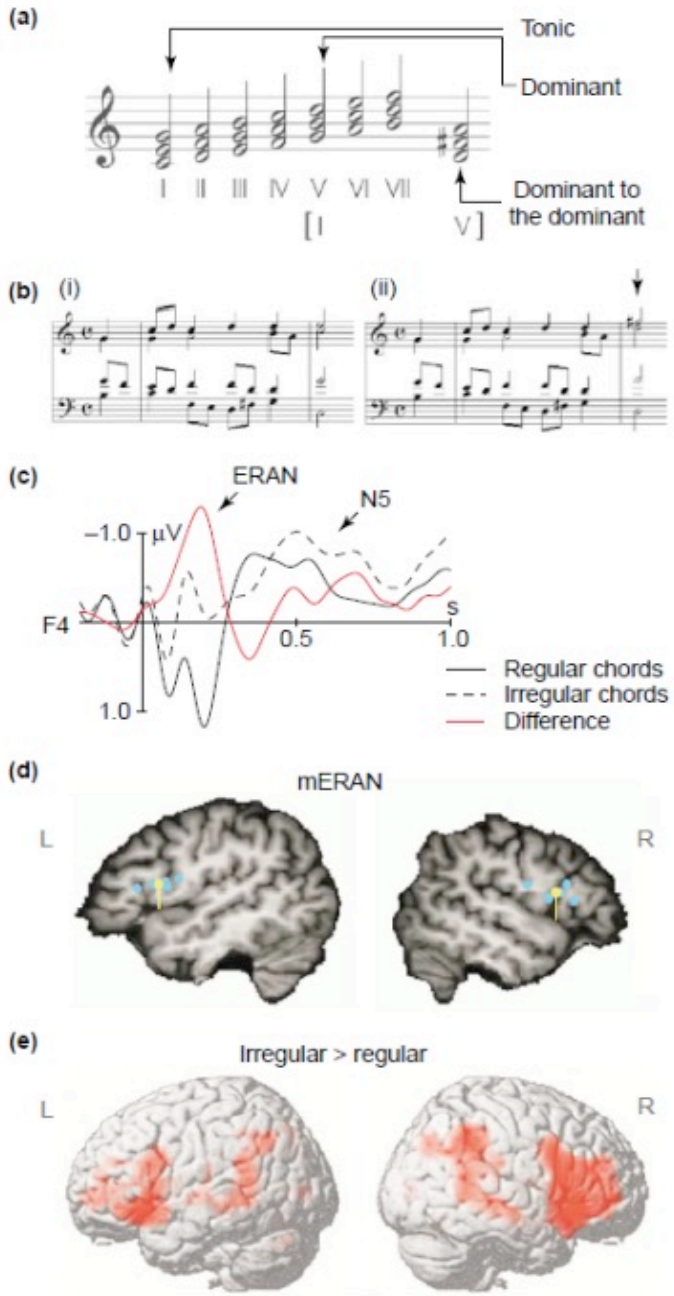
Ends with the tonic



A “deceptive cadence”, nice name, uh?

https://www.youtube.com/watch?v=dcn9qP1DehU

Music Syntax processing in the brain



Neural correlates of music-syntactic processing. **(a)** In major–minor tonal music, chord functions are arranged within harmonic sequences according to certain regularities. Chord functions are the chords built on the tones of a scale. The chord on the first scale tone, for example, is denoted as the tonic and the chord on the fifth scale tone as the dominant. The major chord on the second tone of a major scale can be interpreted as the dominant to the dominant (square brackets). **(b)** One example for a regularity-based arrangement of chord functions is that the dominant–tonic progressio is a prominent marker for the end of a harmonic sequence, whereas a tonic–dominant progression is unacceptable as a marker of the end of a harmonic sequence. **(i)** The sequence shown ends on a regular dominant–tonic progression, **(ii)** the final chord of this sequence is a dominant to the dominant (arrow). This chord function is irregular, especially at the end of a harmonic progression (sound examples are available at www.stefan-koelsch.de/TC_DD). **(c)** Electric brain potentials (in μV) elicited by the final chords of the two sequence types presented in b (recorded from a right-frontal electrode site [F4] from twelve subjects). Both sequence types were presented in pseudorandom order with equal probability in all twelve major keys. Brain responses to irregular chords clearly differ from those to regular chords. The first difference between the two black waveforms is maximal at about 0.2 s after the onset of the chord (this is best seen in the red difference wave, which represents regular subtracted from irregular chords) and has a right-frontal preponderance. This early right anterior negativity (ERAN) is usually followed by a later negativity, the N5 (short arrow). **(d)** With MEG, the magnetic equivalent of the ERAN was localized to the inferior frontolateral cortex (adapted from Maess *et al.* with permission of Nature Publishing Group [http://www.nature.com/] [8]; single-subject dipole solutions are indicated by blue disks, yellow dipoles indicate the grand-average of these source reconstructions). **(e)** fMRI data obtained from 20 subjects using a similar chord-sequence paradigm (the statistical parametric maps show areas that are more strongly activated during the processing of irregular than during the processi of regular chords). Corroborating the MEG data, the fMRI data indicate activations of IFLC. Additionally, the fMRI data indicate activations of the ventrolateral premotor cortex, the anterior portion of the STG, and posterior temporal lobe structures.

Current Opinion in Neurobiology 2005, **15**:1–6