8 It Thrills My Soul to Hear the Songs: The Case of Musicolepsia

Arturo Nuara

Some men there are, love not a gaping pig;
Some that are mad, if they behold a cat;
And others, when the bagpipe sings i' the nose,
Cannot contain their urine.
Shakespeare, Merchant of Venice (Act IV, Scene I).

8.1 Introduction

The term "musicogenic epilepsy" (or "musicolepsia") was first adopted by Critchley [1] to classify a series of neurological cases characterized by "*the occurrence of epileptiform attacks in factual association with the hearing of music*."

Musicogenic seizures (MSs) are a rare phenomenon, showing a prevalence as low as 1 case per 10,000,000 population [2]. However, this prevalence may be underestimated due to the high latency between stimulus onset and seizure beginning, as well as to the limited musical education of people and physicians [3].

Musicolepsia is usually enclosed in the framework of reflex epilepsies, even if not all cases fulfill the criteria for such a classification. In fact, in most patients, music is not the only stimulus that evokes seizures, as spontaneously

A. Nuara (✉)
Consiglio Nazionale delle Ricerche, Istituto di Neuroscienze, Parma, Italy

B. Colombo (ed.), *The Musical Neurons*, Neurocultural Health and Wellbeing,
https://doi.org/10.1007/978-3-031-08132-3_8

occurring seizures and music-associated ones often coexist. In addition, different features of the musical stimulus can trigger the seizure, spanning from a specific genre to musical instruments, to the emotional charge of music; rarely, seizures are selectively provoked by specific tunes [4] or songs [5]. Finally, the sporadic cases where the musical stimulus is highly specific, e.g., a particular frequency band of sound [6], are unlikely categorizable as musicolepsia, since the ictogenic stimulus is not endowed with the complexity needed to define music for itself.

When we listen to a musical piece, in addition to the auditory cortices, widespread brain networks are recruited, including frontotemporal circuits involved in reward and expectance [7], networks for the syntactic organization of sounds [8], and motor areas involved in rhythmic entrainment [9]. Moreover, listening to intensely pleasurable music additionally activates limbic regions, subcallosal, orbitofrontal, and frontal polar cortex [10], indicating the presence of a pervasive brain activity when listening to "emotionally charged" music.

Given this evidence, the heterogeneity in terms of epileptogenic trigger (e.g., rhythmic features, melodic contour, emotional charge) may be justified as a consequence of a hyperexcitability confined to particular brain regions underlying a specific domain of music perception. Thus, offering the possibility to link clinical symptoms with specific brain topographies, musicolepsia may provide relevant insight into the functional role of brain regions in multiple domains of music processing.

Adopting the same systematic approach described in Nuara et al. [11], I upgraded the review of the cases of musicogenic epilepsy described so far in the neurological literature (last record: November 2021), finally including 73 studies (56 single case report, 11 series of case reports, 1 retrospective study, 4 monograph chapters), from which 146 clinical cases have been extracted (the recorded cases are extensively reported in Table 8.1 and summarized in Fig. 8.1). The findings will be discussed, giving special emphasis to the role of the emotional charge of music on ictogenesis and its putative brain substrates.

Table 8.1 Clinical and neurophysiological features of the reviewed cases of musicogenic epilepsy

ID	Authors	Age, sex	Music training	onset (age)	Music genre	Emotional component	Other seizures	Latency	Aura type
1	Merzheevsky, 1884 (cited in [1])	–	–	–	Unfamiliar tune	–	No	–	Dizziness
2	Steinbrugge, 1889 (cited in [1])	45,M	–	15	Unspecific	–	No	–	–
3	Trutovski, 1892 (cited in [1])	31,M	–	–	Piano music	–	–	–	–
4	Oppenheim, 1905 (cited in [1])	45,F	–	–	Unspecific	Yes	–	–	Anxiety
5	Katchatchoff, 1907 (cited in Vanelle [12])	-,M	–	–	Specific orchestral music	–	–	–	–
6	Lwoff, 1913 (cited in Vanelle [12])	55,F	–	–	Specific song (“La Marseillaise”)	Yes	–	–	–
7	Bechterew, 1914 (cited in [1])	-,M	–	–	Unspecific	Yes	No	–	–
8	Marchand, 1926 (cited in Vanelle [12])	50,F	–	–	Noises, music, songs	–	–	–	–
9	Redlich, 1929 (cited in [1])	-,-	–	–	Violin music in particular	–	–	–	–
10	Goldstein, 1932 (cited in [1])	32,M	–	27	Unspecific	Yes	–	–	–

(continued)

Table 8.1 (continued)

ID	Authors	Age, sex	Music training	onset (age)	Music genre	Emotional component	Other seizures	Latency	Aura type
11	Bonhoeffer, 1932 (cited in [1])	-,F	–	30	Unspecific	–	–	–	–
12	Nikitin, 1935 (cited in [1])	30,M	–	23	A specific song or its imagination	–	–	–	Right sided paresthesia
13	[1]	25,F	–	17	Piano, organ, classical. Not dance music	No	No	–	–
14	[1]	46,F	–	42	Sad music. Not dance music.	Yes	Deep-conversation induced seizures	–	–
15	[1]	51,F	–	44	Dance music, organ. Well-punctuated rhythm. Sing-song voices.	No	No	–	–
16	[1]	33,F	–	30	Classical music, waltzes	Yes	No	–	–
17	[1]	22,M	Pianist	–	Playing piano	No	–	–	–
18	[1]	26,M	Musician	22	Playing piano and cello	No	Yes (unspecified)	–	–
19	[1]	62,M	–	32	Organ, piano, opera	No	–	–	–
20	[1]	25,M	No	–	Brass playing bass notes	No	–	–	–

21	[1]	31,F	Pianist	25	Playing piano	–	"Thinking out tune" induced seizure	–	–
22	[1]	40,M	–	32	Concerts	No	–	–	Auditory aura in left ear
23	[1]	-,M	–	–	Piano	–	–	–	Psychological aura
24	Taylor, 1942 (cited in Vanelle [12])	20,M	–	–	Unspecific music, referee's whistle	–	–	–	–
25	Critchley, 1942 (cited in Vanelle [12])	22,M	–	–	Piano, organ	Yes	–	–	–
26	Critchley, 1942 (cited in Vanelle [12])	30,M	–	–	Specific song	–	–	–	–
27	[13]	44,F	–	–	Unspecific	Yes	–	–	–
28	Reese, 1948 (cited in Vanelle [12])	42,F	–	–	Coral or sentimental music	Yes	–	–	–
29	Reese, 1948 (cited in Vanelle [12])	57,F	–	–	Music, singing	–	–	–	–
30	Hamoir and Titeca, 1948 (cited in Joint et al. [14])	20,F	–	–	Sad songs, where violin predominated	Yes	Generalized T-C seizure	–	Epigastric distress

(continued)

Table 8.1 (continued)

ID	Authors	Age, sex	Music training	onset (age)	Music genre	Emotional component	Other seizures	Latency	Aura type
31	Stubbe-Teglbjaerg [15]	62,F	–	54	Classical music	No	–	–	–
32	Stubbe-Teglbjaerg [15]	38,M	–	22	Classical music	Yes	Non-musicogenic fits	–	–
33	Stubbe-Teglbjaerg [15]	36,F	–	28	Unspecific	No	Music-related only 2 years after onset	–	–
34	Stubbe-Teglbjaerg [15]	54,M	–	37	Classical music	Yes	Remembering-music induced	–	Pleasure sensation
35	Arellano et al. [16]	24,F	–	–	Sounds of specific frequency	–	–	–	–
36	Dow [17]	29,F	–	–	Mornful music	Yes	–	–	–
37	Krayenbuhl, 1952 (cited in Vanelle [12])	37,F	–	–	Unspecific	–	–	–	–
38	Vercelletto [18]	38,F	–	–	Unspecific	Yes	–	–	–
39	Hoheisel and Walch [19]	24,M	–	–	Sax, trumpet, sirens and whistles	–	–	–	–
40	Levi [20]	38,M	–	–	Unspecific	–	–	–	–
41	Szbor, 1955 (cited in Vanelle [12])	32,F	–	–	Unspecific	Yes	–	–	–
42	Bickford [21]	23,F	–	–	Exotic jazz music	–	–	–	–

43	Weber [22]	45,M	–	–	Unspecific, organ music in particular	–	–	–	–
44	Weber [22]	23,F	–	–	Slow, romantic, popular waltz music	–	–	–	–
45	Hess, 1956 (cited in Weber [22])	50,M	–	–	Unspecific	–	–	–	–
46	Daly and Barry [23]	24,F	–	16	Jazz music	No	Non-musicogenic fits	–	Fear (unconstant)
47	Daly and Barry [23]	41,M	–	24	Two popular songs	No	Episodes od deja-vu and TC seizures	–	No
48	Daly and Barry [23]	26,M	Pianist	3	Playin piano	Yes	Generalized nocturnal fits	–	No
49	Cvetko, 1957 (cited in Vanelle [12])	23,F	–	–	Unspecific	–	–	–	–
50	Cvetko, 1957 (cited in Vanelle [12])	51,F	–	–	Unspecific	–	–	–	–
51	Cvetko, 1957 (cited in Vanelle [12])	28,M	–	–	Unspecific	–	–	–	–
52	Reifenberg [24]	46,F	–	–	Music and knocking noises	–	–	–	–

(continued)

Table 8.1 (continued)

ID	Authors	Age, sex	Music training	onset (age)	Music genre	Emotional component	Other seizures	Latency	Aura type
53	Barrios del Risco and Esslen [25]	44,F	–	–	Popular music	Yes	–	–	–
54	Anastasopulos, 1958 (cited in Titeca [26])	22,M	–	–	Unspecific	–	–	–	–
55	Anastasopulos, 1958 (cited in Titeca [26])	27,M	–	–	Unspecific	–	–	–	–
56	Anastasopulos, 1958 (cited in Titeca [26])	45,F	–	–	Unspecific	–	–	–	–
57	Piotrowski [27]	-,F	–	–	Sentimental songs by female artists	Yes	–	–	–
58	Bash and Bash-Lietchti [28]	45,F	–	–	Sentimental music	Yes	–	–	–
59	Lennox, 1960 (Cited in Titeca [26])	-,F	–	–	Unspecific	–	No	–	Panic
60	Lennox, 1960 (Cited in Titeca [26])	69,F	–	25	Piano, vocal, instrumental classical or jazz	–	Non-musicogenic seizures later in life	–	–
61	Lennox, 1960 (Cited in Titeca [26])	-,M	–	–	Unspecific	–	No	–	Unpleasant visceral sensation, paraesthesiae

62	Poskanzer [6]	62,M	No	56	Church bell	No	Non-musicogenic fits	17′‘	Sense of impending consciousness
63	Joynt [14]	62,F	No	56	Organ sound	No	Nocturnal generalized seizures	441′‘	Anxiousness
64	Yvonneau and Barros-Ferreira [29]	72,F	–	–	Loud and unexpected sounds	No	Audiogenic (loud sound)	–	–
65	Gornik et al. [30]	32,M	–	–	Unspecific	–	–	–	–
66	Gornik et al. [30]	33,M	–	–	Unspecific	–	–	–	–
67	Perpiniotis [31]	16,F	–	–	Popular sentimental song	Yes	–	–	–
68	Forster [32]	-,M	–	–	Orchestral music	–	–	–	–
69	Toivakka and Lehtinen [33]	31,M	No	26	Sentimental vocal and romantic popular music	Yes	Nocturnal generalized seizures	–	Feeling of happiness
70	Titeca [26]	38,F	–	–	Languid tune	–	–	–	–
71	Dearman [34]	38,F	No	–	Selected songs	Yes	Yes (unspecified)	–	–
72	Strang et al., 1966 (cited in Vanelle [12])	43,M	–	–	Playing classical music	–	–	–	–

(continued)

Table 8.1 (continued)

ID	Authors	Age, sex	Music training	onset (age)	Music genre	Emotional component	Other seizures	Latency	Aura type
73	Gastaut and Tassinari [35]	16,F	–	–	Sentimental music	Yes	No	–	–
74	Shaper et al., 1967 (cited in Vanelle [12])	28,M	–	–	Popular songs	–	–	–	–
75	Vizioli et al. [36]	35,F	–	31	Popular Sardinian songs	Yes	–	–	–
76	Fujinawa [4]	70,F	–	–	Specific song	Yes	–	–	–
77	Mundt, 1980 (cited in Vanelle [12])	25,F	–	–	Popular songs	–	–	–	–
78	Newman and Saunders [37]	39,F	–	–	Light and background music	No	Nocturnal generalized seizures	–	Feeling anxious and sweaty
79	Sutherling [38]	67,M	No	–	Playing hymn with organ	No	Yes (unspecified)	–	–
80	Vanelle [12]	44,M	–	–	Classical music	–	–	–	–
81	Vanelle [12]	33,M	–	–	Popular repetitive music	–	–	–	–
82	Brien and Murray [39]	53,F	No	15	Particular singer's voices	–	–	Seconds/ minutes	Epigastric sensation, fear and depersonalization
83	Byun et al. [40]	40,F	–	–	Popular korean songs	–	–	1′30’‘	–
84	Jallon et al. [41]	-,M	–	–	Music with high emotional charge	Yes	–	–	–
85	Smeijsters and van den Berk [42]	40,F	Clarinet		Unspecific	Yes	–	–	–

86	Ackerman and Banks [43]	66,M	–	–	Unspecific	–	–	–	–
87	Wieser et al. [44]	32,F	–	18	Favourite Italian songs	–	Nocturnal generalized seizures	–	Pleasing female murmuring voices, which took increasing possession of her mind
88	Nakano et al. [45]	23,F	–	19	American pop music	Yes	Yes (unspecified)	3’	–
89	[46]	43,M	–		“The X-files” theme song	No	–	–	–
90	[5]	48,F	No	32	“Arabesque”	Yes	Sleep seizures	4–5’	Epigastric discomfort
91	Gelisse et al. [47]	39,F	Singer	37	Unspecific	No	No	–	Anxiety and tearfulness
92	Lin et al. [48]	6 months,M	–	6 months	Loud music, Beatles in particular	–	Partial seizures	–	–
93	Morocz et al. [49]	48,F	No	42	Whitney Huston and Boyz II men	–	No	–	Pressure in the abdominal and then pectoral area, “rushing” sensation, palpitations, heart racing
94	Wieser et al. [50]	-,F	–	–	Unspecific	–	Yes (unspecified)	–	–
95	Wieser et al. [50]	-,-	–	–	–	–	–	–	–
96	Wieser et al. [50]	-,-	–	–	–	–	–	–	–

(continued)

Table 8.1 (continued)

ID	Authors	Age, sex	Music training	onset (age)	Music genre	Emotional component	Other seizures	Latency	Aura type
97	Wieser et al. [50]	-,-	–	–	–	–	–	–	–
98	Wieser et al. [50]	-,-	–	–	–	–	–	–	–
99	Wieser et al. [50]	-,-	–	–	–	–	–	–	–
100	Wieser et al. [50]	-,-	–	–	–	–	–	–	–
101	Stern J et al. [51]	46,F	–	–	–	No	–	–	–
102	Sacks O [52]	-,M	–	–	–	Yes	–	–	State of intense attention in music listening
103	Sacks O [52]	-,F	–	–	Neapolitan songs	No	–	–	–
104	Anneken [53]	48,F	No	41	Sorrowful lyrics and predominant instrumental background	Yes	Generalized T-C seizure	2’	Epigastric aura, deja vu
105	[54]	49,M	No	32	Favourite music piece	Yes	Yes (unspecified)	–	–
106	[55]	20,F	No	5	Popular music rhythms	–	Yes (unspecified)	–	Internal rhythm perception that quickly evolved into a musical tune followed by a fearful sensation

107	[55]	24,F	Keyboard player	18	Shania Twain's ballad	Yes	No	–	"Tingling, vibrating" feeling in the right side of head quickly followed by an unpleasant abdominal sensation, nausea, lightheadedness.
108	[55]	19,F	No	5	Church hymns	–	Yes (unspecified)	5–10′‘	Smelling of a not describable odor
109	Claassen DO et al. [56]	65,F	No	46	Slow, melancholic music	Yes	–	–	Fear, tachicardia, crying
110	Cho JW et al. [57]	34,F	No	32	Ballad music at onset, later any type of music	Yes	No	1–5'	Palpitations (no ECG correlate), unpleasant feeling
111	Pittau et al. [58]	36,M	Amateur guitarist	24	Listening or playing music with a strong emotional charge	Yes	No	98–120′‘	–
112	Mehta et al. [59]	24,F	No	–	Music with a strong rhythmic component	No	Yes (unspecified), preceding musicogenic by 2 years	–	Unpleasant odor, "tingling in the head," and vertigo

(continued)

Table 8.1 (continued)

ID	Authors	Age, sex	Music training	onset (age)	Music genre	Emotional component	Other seizures	Latency	Aura type
113	Marrosu et al. [60]	28,F	No	14	Specific song	No	Yes (unspecified), preceding musicogenic	–	"Funny feelings in the throat"
114	Duanyu et al. [61]	16,M	No	14	Popular rhythms, a song in particual (both listening and singing)	–	Yes (unspecified)	–	Tinnitus, fear
115	Sanchez-Carpintero [62]	7,M	No	5	Music of electronic nature in particular	–	Generalized T-C seizure	5′‘	–
116	[63]	32,M	No	–	"Russian chanson"	Yes	No	64′‘	Pleasant feeling, which turns into a non-specific aura with an uncomfortable feeling
117	Seidi [64]	40,M	–	–	Dance traditional music	–	Temporal lobe epilepsy	–	–
118	Seidi [64]	53,M	–	–	Dance traditional music	–	–	–	–
119	Seidi [64]	-,F	–	–	Popular music	–	–	–	–
120	Tezer [65]	33,F	No	17	Affective music in native language	Yes	Yes	2–5'	Boring sensation
121	Wang et al. [66]	42,M	Composer	11	Familiar songs	Yes	Yes (unspecified)	2'	Buzzing/muffled sounds

122	Klamer et al. [67]	22,M	No	6	Rap music	–	Yes (unspecified)	152′‘	Déjà-vu
123	Cheng [68]	42,M	No	39	Music listened to under previous stressful conditions	Yes	Yes (unspecified), preceding musicogenic	120′‘	Déjà-vu
124	Nagahama Y et al [69]	17,M	Viola player	11	Unspecific	No	Yes (unspecified)	–	–
125	[70]	35,M	No	26	“Moonlight” by Cyndi Wang	–	Sleep seizures	–	–
126	[70]	36,F	Amateur pianist	32	Unspecific	–	Generalized T-C seizure	–	–
127	[70]	55,M	No	28	“Grandma words” by Ricky Hsiao	–	Sleep seizures	–	–
128	Falip et al. [71]	63,M	–	39	Flamenco music in particular	Yes	Yes (unspecified), preceding musicogenic	14’	Epigastric aura
129	Falip et al. [71]	39,M	Amateur guitarist	30	Playing rick music on guitar	Yes	–	–	Epigastric sensation, déjà-vu and fear. Sometimes olfactory sensation
130	Falip et al. [71]	39,F	–	Childhood	Lullabies singed by mother in particular	Yes	Yes (unspecified)	–	Sound distortion

(continued)

Table 8.1 (continued)

ID	Authors	Age, sex	Music training	onset (age)	Music genre	Emotional component	Other seizures	Latency	Aura type
131	Pelliccia et al. [72]	27,F	No	17	Italian pop melodic songs	Yes	Yes (unspecified)	15–28′‘	Epigastric aura, nausea, tachycardia, déjà-vu
132	[11]	38,F	No	20	Italian pop melodic songs	No	Generalized T-C seizure	–	–
133	[11]	50,F	No	47	Italian and English pop songs	Yes	No	7’	–
134	[73]	19,F	Singer	15	Unspecific songs and singing	–	Yes (unspecified)	–	–
135	[74]	25,M	No	18	Pop	–	Yes (unspecified)	–	–
136	[74]	36,F	No	36	Country	–	Yes (unspecified)	–	–
137	[74]	31,F	No	17	Pop	–	Yes (unspecified)	–	–
138	[74]	28,F	No	23	Unspecific	–	Yes (unspecified)	–	–
139	[74]	61,F	No	46	Melanchonic, church hymns	Yes	Yes (unspecified)	–	–
140	[74]	26,F	No	23	Pop, soft rock	–	Yes (unspecified)	–	–
141	[74]	34,F	No	4	Unfamiliar hymns, classical	–	Yes (unspecified)	–	–
142	[74]	36,F	No	34	Pop and techno	–	Yes (unspecified)	–	–

143	[74]	52,F	No	14	Organ music	–	Yes (unspecified)	–	–
144	Al-Attas et al. [75]	50,F	No	36	Arabic music in a specific tone	–	–	–	Olfactory
145	Benoit et al. [76]	-,-	–	–	–	–	–	–	–
146	[77]	25,M	Yes	–	Hard rock music	No	Yes (unspecified)	–	Déjà-vu

ID	Seizure type	Interictal EEG	Ictal EEG	MRI/fMRI	PET	SPECT	MEG	Hypotised EZ
1	–	–	–	–	–	–	–	–
2	Generalized	–	–	–	–	–	–	–
3	–	–	–	–	–	–	–	–
4	Simple partial; secondary generalized	–	–	–	–	–	–	–
5	–	–	–	–	–	–	–	–
6	–	–	–	–	–	–	–	–
7	–	–	–	–	–	–	–	–
8	–	–	–	–	–	–	–	–
9	–	–	–	–	–	–	–	–
10	–	–	–	–	–	–	–	–
11	–	–	–	–	–	–	–	–
12	–	–	–	–	–	–	–	–
13	–	–	–	–	–	–	–	Right temporal

(continued)

Table 8.1 (continued)

ID	Seizure type	Interictal EEG	Ictal EEG	MRI/fMRI	PET	SPECT	MEG	Hypotised EZ
14	Generalized	–	–	–	–	–	–	–
15	Generalized	–	–	–	–	–	–	Temporal lobe
16	–	–	–	–	–	–	–	–
17	–	–	–	–	–	–	–	–
18	Generalized	–	–	–	–	–	–	–
19	Secondary generalized	–	–	–	–	–	–	Temporal lobe
20	–	–	–	–	–	–	–	–
21	–	–	–	–	–	–	–	–
22	Secondary generalized	–	–	–	–	–	–	Right temporal
23	Secondary generalized	–	–	–	–	–	–	–
24	–	–	–	–	–	–	–	–
25	–	–	–	–	–	–	–	–
26	–	–	–	–	–	–	–	–
27	–	–	Non focal	–	–	–	–	–
28	–	–	Non focal	–	–	–	–	–
29	–	–	Non focal	–	–	–	–	–
30	–	–	Left parietal	–	–	–	–	Left temporal
31	Generalized	"General dysrhythmia"	Right temporal abnormalities	–	–	–	–	Right temporal
32	–	Right temporo-parietal	–	–	–	–	–	Right temporal
33	Generalized	–	–	–	–	–	–	Left precentral

34	Generalized	"General dysrhythmia"	Left pre- and post-central focus	–	–	–	–	Left pre/ post-central
35	–	–	Right temporal	–	–	–	–	Right temporal
36	–	–	Right temporal	–	–	–	–	Right temporal
37	–	Right mediobasal temporal	–	–	–	–	–	–
38	–	–	Right frontotemporal	–	–	–	–	Right frontotemporal
39	–	–	–	–	–	–	–	–
40	–	–	Left temporal	–	–	–	–	Left temporal
41	–	–	Right temporal	–	–	–	–	Right temporal
42	–	–	Right frontotemporal	–	–	–	–	Right frontotemporal
43	–	–	Right temporal	–	–	–	–	Right temporal
44	–	–	Left temporal	–	–	–	–	Left temporal
45	–	–	Left temporal	–	–	–	–	Left temporal
46	Complex partial; generalized	Left temporal slow waves	Generalized dysrhythmia	–	–	–	–	–
47	Generalized	Normal	Generalized rhythmic discharges	–	–	–	–	Temporal lobe
48	Complex partial	–	Right temporal	–	–	–	–	Right temporal
49	–	–	Normal	–	–	–	–	–

(continued)

Table 8.1 (continued)

ID	Seizure type	Interictal EEG	Ictal EEG	MRI/fMRI	PET	SPECT	MEG	Hypotised EZ
50	–	Normal	–	–	–	–	–	–
51	–	–	–	–	–	–	–	–
52	–	–	Right frontotemporal	–	–	–	–	Right frontotemporal
53	–	–	Right temporal	–	–	–	–	Right temporal
54	–	–	Right temporal	–	–	–	–	Right temporal
55	–	–	Bitemporal	–	–	–	–	–
56	–	–	–	–	–	–	–	–
57	–	–	Bitemporal	–	–	–	–	–
58	–	–	Right temporal	–	–	–	–	Right temporal
59	–	Normal	–	–	–	–	–	–
60	–	Small abnormalities	–	–	–	–	–	–
61	–	Temporal lobe spikes (unknown side)	–	–	–	–	–	–
62	Complex partial	Moderate theta activity in temporal regions	Left temporal	–	–	–	–	Left temporal
63	Complex partial	Recurrent bitemporal delta activity	Bi-temporal sharp activity (R > L)	–	–	–	–	Right temporal
64	–	–	Bitemporal anterior	–	–	–	–	Left temporal
65	–	–	–	–	–	–	–	–
66	–	Left fronto-temporal	–	–	–	–	–	–

67	–	–	Left temporal	–	–	–	–	Left temporal
68	–	–	Left temporal	–	–	–	–	Left temporal
69	Secondary generalized	Right temporal	Right temporal, with secondary generalization	–	–	–	–	–
70	–	–	Left temporal	–	–	–	–	Left temporal
71	–	–	Left temporal	–	–	–	–	Left temporal
72	–	Right temporo-occipital	–	–	–	–	–	–
73	Complex partial	–	Right temporal	–	–	–	–	Right temporal
74	–	–	Left temporo-parietal	–	–	–	–	Left temporo-parietal
75	–	Bitemporal abnormalities	–	–	–	–	–	–
76	–	–	Right temporal	–	–	–	–	Right temporal
77	–	–	Non focal	–	–	–	–	–
78	Complex partial	Intermittent bitemporal theta activity	Bitemporal theta activity (L > R)	–	–	–	–	Bilateral temporal
79	Simple partial	–	Right temporo-frontal	–	–	–	–	–
80	–	Right temporal abnormalities	–	–	–	–	–	–
81	–	–	Left temporal	–	–	–	–	Left temporal

(continued)

Table 8.1 (continued)

ID	Seizure type	Interictal EEG	Ictal EEG	MRI/fMRI	PET	SPECT	MEG	Hypotised EZ
82	Generalized	Normal	Bilateral, generalized	–	–	–	–	–
83	Simple partial	Normal	Left temporal	–	–	–	–	Left temporal
84	–	Left temporal abnormalities	–	–	–	–	–	–
85	Simple partial	–	Right mesial temporal	–	–	–	–	–
86	Complex partial	–	–	–	–	–	–	–
87		Fronto-temporal bilateral focal abnormalities	Right frontotemporal	Normal	Right temporal and frontal slight hypometabolism (interictal)	Right temporal hyperperfusion (interictal). Right temporal posterior hypoperfusion, increased right anterior temporopolar hyperperfusion (ictal)	–	Right temporal
88	Complex partial	–	Right temporal (11 Hz rhythmic epileptiform activities) and subsequent delta activities over the right hemisphere	Normal	–	–	–	Right temporal

89	–	–	Right temporal (subdural EEG)	Right temporal cortex tickening		–	–	Right temporal superior gyrus
90	Complex partial	Bitemporal sharp wave discharges, predominant on the right side	Right temporal (high voltage sharp and slow sharp waves and spikes), then became generalized	Normal	–	Normal (interictal). Right anterior and mesial temporal hyperperfusion (HMPAO, ictal)	–	Right temporal
91	Simple partial	Independent slow waves over the temporal regions	Right temporal	Normal	–	Right temporal hyperperfusion (HMPAO, ictal)	–	Right temporal
92	Simple partial, generalized	Normal	Left temporal	Normal	–	Left temporal hyperperfusion (ictal)	–	Left temporal
93	Complex partial	Normal	Left anterior	Normal (MRI). Right gyrus rectus, ventral frontal lobes, left temporal lobe increased activity (fMRI)	–	Left temporal hypoperfusion (interictal). Left temporal hyperperfusion (ictal)	–	Right gyrus rectus
94	–	–	Right temporal	–	–	–	–	Bilateral temporal
95	–	–	–	–	–	–	–	–
96	–	–	–	–	–	–	–	–
97	–	–	–	–	–	–	–	–
98	–	–	–	–	–	–	–	–

(continued)

Table 8.1 (continued)

ID	Seizure type	Interictal EEG	Ictal EEG	MRI/fMRI	PET	SPECT	MEG	Hypotised EZ
99	–	–	–	–	–	–	–	–
100	–	–	–	–	–	–	–	–
101	–	–	–	Normal	Normal (interictal)	–	Righ temporal	Right temporal
102	Complex partial	–	–	–	–	–	–	Temporal lobe
103	–	–	–	–	–	–	–	–
104	Simple partial	Intermittent theta activity and sharp wave like transients in the left fronto-temporal region	–	Left fronto-temporal astrocitoma	–	Left temporal hyperactivity (IMT, interictal)	–	–
105	Simple partial	Focal spikes in F8 and T4	Normal	Normal	–	Normal (interictal)	–	Right temporal
106	Simple partial	–	Right fronto-temporal activity (4-Hz sharp waves) evolving into high-frequency low-voltage fast activity (IC EEG)	T2 iperintense occipital lesion	Normal (interictal)	–	–	Right anterior lateral temporal

107	Simple partial	–	Right anteromesial temporal (rhythmic intermixed gamma/beta activity, IC EEG)	Normal	Right temporal mild hypometabolism (interictal)	Normal (interictal)	–	Right mesial temporal
108	Complex partial	–	Left mesial temporal; right mesial temporal lobe	Normal	Normal (interictal)	–	Left mesial temporal	Reft and right mesial temporal regions
109	Partial	Right temporal spike discharges	Right fronto-temporal sharp theta and alpha frequency discharges, with rapid spread to the left temporal region.	–	–	–	–	Right fronto-temporal
110	Complex partial	Sharp waves during sleep on the right temporal lobe	Right temporal (rhythmic theta activity)	Normal (MRI) right insula, anterior temporal lobe, amygdala, and hippocampal head BOLD activation (fMRI)	Right insula, amigdala and hippocampal head and anterior temporal hypometabolism (interictal)	Normal (interictal). Right anterior and mesial temporal hyperperfusion (SISCOM, ictal)	–	Right temporal

(continued)

Table 8.1 (continued)

ID	Seizure type	Interictal EEG	Ictal EEG	MRI/fMRI	PET	SPECT	MEG	Hypotised EZ
111	Simple partial	Epileptiform abnormalities over right temporal regions	Right temporal	Normal (MRI). Right fronto-temporo-occipital BOLD activation (fMRI)	–	–	–	Right temporal
112	Complex partial	Bilateral spiking	Right mesial temporal (subdural IC-EEG)	Normal	Right lateral temporal lobe hypometabolism (interictal). Right anteromesial temporal lobe hypermetabolism and right lateral temporal lobe hypometabolism (ictal).	–	–	–
113	Complex partial	–	Right temporal (short sequences of medium voltage theta waves)	Right frontal, right middle-posterior temporal BOLD activation (fMRI)	–	–	–	Right temporal
114	Complex partial, generalized	Left temporal, left frontal	Left frontotemporal	Normal	–	Left temporal and left mesial temporal hypoperfusion (interictal)	–	Left temporal lobe

115	Secondary generalized	–	Bitemporal sharp waves spreading to centrotemporal areas	–	–	–	–	–
116	Complex partial	Left temporal spikes	Left temporal	Normal (MRI). “Snowballing” bilateral BOLD activation (fMRI)	–	–	–	Left temporal
117	–	–	–	–	–	–	–	–
118	Generalized	Normal	Normal	Normal	–	–	–	–
119	Secondary generalized	–	Left temporal	–	–	–	–	Left temporal
120	Complex partial	–	Right ippocampus (musicogenic), left ippocampus (spontaneous seizure). Intracranial EEG	Mild atrophy of the left anterior temporal lobe	Right temporal hypometabolism (interictal)	–	–	Right hippocampus (intracranial EEG) for musicogenic seizure, left hippocampus (intracranial EEG) for spontaneous seizure

(continued)

Table 8.1 (continued)

ID	Seizure type	Interictal EEG	Ictal EEG	MRI/fMRI	PET	SPECT	MEG	Hypotised EZ
121	Complex partial	Intermittent left temporal slowing waves	Left temporal (intracranial EEG)	Normal	Left temporal hypometabolism (interictal)	Left lateral superior temporal gyrus and contiguous supratemporal plane hyperperfusion (ictal)	Left temporal	Left temporal
122	Secondary generalized	–	Right hippocampus with fast propagation to the mesial frontal depth electrode (intracranial EEG)	Normal (MRI). Right mesial temporal lobe (right hippocampus extending to the right insula and the right amygdala) BOLD activation (fMRI)	–	–	Right mesial frontal, bilateral mesial temporal	Right mesial temporal
123	Secondary generalized	Left frontotemporal sharp waves	Left frontotemporal	Normal	–	–	–	Left fronto-temporal
124	Partial	–	Right temporal	Normal	Normal (ictal)	–	Right fronto-temporo-insular	Right temporal
125	Complex partial	Normal	Left mesial temporal	Normal	–	–	–	Left mesial temporal

126	Simple partial	Normal	Left mesial temporal, neocortical temporal	Normal	–	–	–	Left mesial temporal
127	Complex partial	Fronto-temporal discharges	Left mesial temporal	Right anterior temporal encephalomalacia	–	–	–	Left mesial temporal
128	Complex partial	Normal	Right temporal	Normal	Right medial temporal hypometabolism (interictal)	–	–	Right temporal
129	Simple partial; complex partial	Left temporal discharges	–	Normal	Bilateral temporal and insular hypometabolism (interictal)	–	–	–
130	Complex partial	–	–	Normal	Right medial temporal hypometabolism (interictal)	–	–	Right temporal
131	Complex partial	Right temporal spikes	Right temporal and central (T4, C4). SEEG:Right amygdala and hippocampus	–	–	–	–	Right temporal
132	Complex partial	Left fronto-temporal spikes	–	Normal	–	–	–	Left fronto-temporal
133	Complex partial	Right fronto-temporal spikes	Right fronto-temporal	Normal	–	–	–	Right fronto-temporal

(continued)

Table 8.1 (continued)

ID	Seizure type	Interictal EEG	Ictal EEG	MRI/fMRI	PET	SPECT	MEG	Hypotised EZ
134	Simple partial	Normal	Normal	Right temporal lesion	–	–	–	Right temporal
135	Complex partial	Bitemporal abnormalities	Right temporal	Normal	–	–	–	Right temporal
136	Simple partial	Bitemporal abnormalities	–	Normal	–	–	–	Left temporal
137	Complex partial	Right temporal	–	Normal	–	–	–	Right temporal
138	Simple partial	Right temporal	–	Normal	–	–	–	Right temporal
139	Complex partial	Bitemporal abnormalities	Right temporal	Normal	–	–	–	Right temporal
140	Complex partial	Normal	Left temporal	Normal	–	–	–	Left temporal
141	Complex partial	Bitemporal abnormalities	–	Normal	–	–	–	Right temporal
142	Complex partial	Normal	Right temporal	Normal	–	–	–	Right temporal
143	Complex partial	Bitemporal abnormalities	–	Right mesial temporal sclerosis	–	–	–	Right temporal
144	Complex partial; generalized	–	Left temporal	Normal	–	–	–	Left temporal
145	–	–	Right temporal	–	–	–	–	Right temporal
146	Simple partial	–	Right temporal	Bilateral tempo-mesial abnormalities	–	–	–	Bilateral temporal

EEG electroencephalogram; *EZ* epileptogenic zone; *fMRI* functional magnetic resonance imaging; *IC-EEG* intracranial EEG; *MEG* magnetoencephalography; *MRI* magnetic resonance imaging; *PET* positron emission tomography; *SPECT* single-photon emission computed tomography

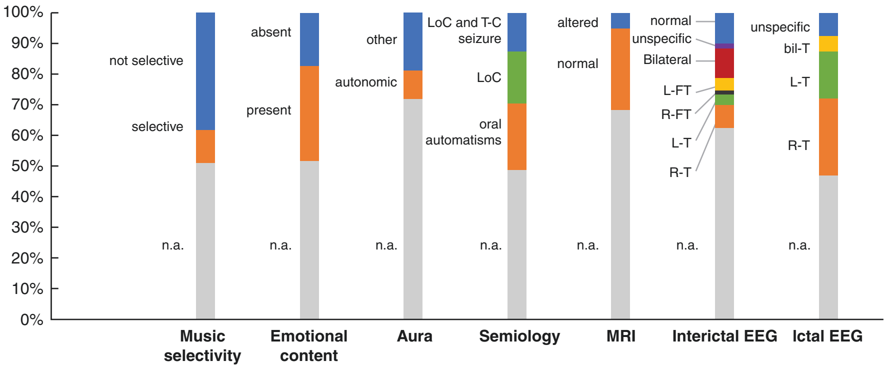

Fig. 8.1 Graphical representation of the reviewed cases of musicogenic epilepsy. Bars include percentage representation of the following findings: selectivity of music in provoking seizures, emotional charge of epileptogenic stimulus, aura's features, seizure's semiology, structural magnetic resonance imaging (MRI) features, and interictal and ictal electroencephalographic (EEG) findings (*n.a.* not available; *LoC* loss of consciousness; *T-C* tonic clonic; *L-T* left temporal; *R-T* right temporal; *L-FT* left frontotemporal; *R-FT* right frontotemporal; *bil-T* bilateral temporal)

8.2 Clinical Features of People with Musicolepsia

The demographical picture of people suffering from musicolepsia displays a mean age at observation (reported in 125 cases) of 38 ± 14 years, with mean seizure onset (reported in 69 cases) at 26 ± 13 years, without significant unbalancing in terms of gender (specified in 137 cases, 55% F, 45% M). Musical stimuli are not selective as seizures trigger in most cases ($n = 87$). In the remaining observations, only 16 cases (27%) reported seizures provoked exclusively by music listening. Other kinds of seizures coexisting with musicolepsia span from spontaneous seizures ($n = 23$, 39%) to non-musicogenic reflex seizures ($n = 4$, 3%) and other not detailed seizures ($n = 17$, 29%).

Since extensive musical training is known to induce long-lasting changes in cortical excitability [78], it would be speculated that music expertise may affect the probability of undergoing musicogenic seizures. However, the low prevalence of trained musicians among people with musicolepsia (only 13 cases, 9% of total) makes this hypothesis unlikely.

Feelings prodromal to the musicogenic seizures (i.e., aura, reported in 41 patients) is often autonomic (14 patients), but other symptoms ranging from auditory, olfactory, visual to somatosensory phenomena are also described. In some cases, an intense sense of fear starts at music onset and precedes the seizure: this would be the literary case reported in the manuscript *"fear of music"* by the Russian writer B. Nikonov and subsequently reported by Bekhterev [79].

Supporting the ictogenic involvement of temporal lobe, seizure semiology (reported in 83 cases) displays oroalimentary automatism (chewing, swallowing, smacking lips) in about one-fourth of observations (23 patients). Loss of consciousness represents a common event, being reported in 49 cases (59%), 16 of them (19%) including tonic-clonic seizures.

In most cases, musicolepsia is not secondary to morphological brain alterations. In fact, when performed (46 cases), structural MRI is usually unremarkable (90%).

The rare structural abnormalities usually involve the temporal lobes (7 cases; [46, 53, 65, 70, 73, 74, 77]), in a single case extending to frontal areas [53]. Finally, in one patient, unspecific occipital abnormalities were described [55].

8.3 Is the *Emotional Glow* to Light the Fire?

One of the main reasons why humans are looking for musical experience is for its natural vocation to arouse emotions: the obsessive rhythms of tribal rituals provoke emotional bursts and *trance* experiences [80]; ragas belonging to Indian classical music are prescribed to evoke a precise emotional effect [81]; the administration of music linked to specific memories can resurface their affective burden (see the effects of Sam's playing *"As time goes by"* in the movie *Casablanca*, 1942).

Despite its key role in musical experience, the presence/absence of emotional content of musical stimulus triggering seizures has not been methodically investigated. Among the 71 cases where it has been enquired, 46 (65%) reported a salient emotional charge related to the musical stimulus. Of note, the presence of such an affective component is not clearly inferable in about half of cases, leading to a potential underestimation of the presence of emotional factors. Besides incomplete case-history collections, also patients' difficulties in remembering seizure events [13] as well as reluctance to expose personal anamnestic details [82] may have sometimes hindered the access to this kind of information.

But, how to determine the association between such an emotional component and seizure ignition?

A first way could be investigating if the epileptogenic zones associated with "emotionally charged" seizures are more frequently situated in the right hemisphere, this latter traditionally acknowledged as "dominant" for emotional processing.

Selecting data of cases in which both emotional content and epileptogenic zone are defined ($n = 41$, 3 bilateral Ictal EEG excluded), patients with an emotional component ($n = 30$) showed a higher prevalence of right-sided epileptic zone (22 vs 7). However, a chi-square test performed to detect if epileptogenic-zone laterality is biased by the presence/absence of such an emotional component did not return any significant result (chi = 0.016, $p > 0.05$); in other words, also people whose seizures are elicited by *"cold"* music showed a predominance of right-hemisphere epileptogenic zones.

These findings are consistent with the view that the processing of emotional content of music, as well as the mapping of basic—potentially ictogenic—sound features (e.g., pitch, timbre, and melodic contour) are prerogative (although not exclusive) functions of the right hemisphere. This view is supported by a huge amount of behavioral studies [83, 84], neuroimaging investigations [85, 86], and clinical data from patients with brain lesions [87, 88] and music-related disturbances [89].

Music, however, it's not a mere matter of pitch, rhythm, and—when present—"emotional glow". Indeed, in order to be noticed as *musical*, sequences of discrete elements need to be endowed with a hierarchical structure [90], i.e., with a *syntax* [91]. This prerequisite extends to multiple musical cultures: from the complex rhythmic organization of traditional sub-Saharan music to the choice of the proper *svara* within Indian *ragas*, as well as in the *armonic* structure of western musical pieces. As in spoken language, neural processing of music syntax predominantly involves the left hemisphere [92–94], which is strongly recruited during the perception of sounds associated with spoken words [95].

Investigations on patients with musicolepsia can indirectly support such hemispherical bias: Tseng et al. [70] administered different versions of epileptogenic songs (i.e., with/without lyrics) to three patients suffering from left-temporal musicogenic epilepsy, demonstrating that only vocal versions of songs were able to provoke seizures. These experimental findings are consistent with the previous musicolepsia literature: music containing lyrics provokes seizures in the left-temporal epileptogenic zone twofold more frequently than the right temporal region, thus indicating that language-associated elements may represent a key triggering factor for left-temporal musicogenic seizures.

However, the generalization of such an observation needs to be considered with caution: even music with lyrics may conceal epileptogenic triggers within non-linguistic elements, spanning from rhythmic riffs to instrumental solos. Exemplary in this regard is the case described by Bekhterev [79] about the Russian writer B. Nikonov, who experienced a seizure at the theatre while listening “The Prophet” by Meyerbeer. Although this opera is composed by wide lyrical segments along all its five acts, the seizure—preceded by an intense fear feeling—just occurred during the listening of an instrumental part (i.e., the ballet introducing the third act).

Another element that supports the presence of multiple stages of high-order processes during music listening is the long latency between the epileptogenic stimulus and seizure onset. This aspect represents a typical feature distinguishing musicogenic seizures from other reflex seizures [3, 11]. Noteworthy, patients with an epileptogenic zone in the right hemisphere show higher latencies from stimulus onset (279 ± 236 s vs 82.2 ± 43.3 s, Mann-Whitney $U = 6$; $p = 0.023$), possibly reflecting the functional predominancy of the right hemisphere in the emotional processing of music [10].

Even if it is informative about the “emotional” and “linguistic” domains of music, the mere hemispheric laterality of the epileptogenic zone is not sufficient to detail the neural substrates of music processing. For this purpose, the integration of neurophysiological (e.g., electroencephalography—EEG) and functional neuroimaging (fMRI, PET, SPECT) data give the opportunity to associate clinical symptoms of people with musicolepsia with brain topographies, thus providing insights into the functional role of brain regions involved in music processing.

8.4 Neurophysiological and Functional-Neuroimaging Findings of Musicolepsia

The introduction in the first half of twentieth century of the clinical electroencephalography (EEG) represented a milestone for epileptology. In addition to providing temporal and spatial information about the brain substrates of seizures, the possibility to demonstrate neurophysiological abnormalities during fits gave the opportunity to enclose in the neurological realm paroxysmal events (e.g., musicolepsia), which until then were often classified as “hysterical” manifestations [13].

From the first EEG recording of a seizure evoked by mean of a gramophone [13], 84 ictal EEG have been performed to date in people with musicolepsia, of which 40 (48%) displayed right-temporal alterations, 24 (29%) left temporal, 7 (8%) bitemporal, and 11 (13%) showed not focal or unspecific alterations. Intracranial EEG, performed on 10 subjects, found an epileptogenic zone in the temporal lobe (8 right, 1 left, 1 bilateral), involving temporo-mesial structures in 6 cases. Moving to neuroimaging techniques, the ictal SPECT study (7 cases) displayed 4 right temporal (of which two included mesial structures) and 3 left temporal alterations. Ictal fMRI (6 cases) showed right-sided increased activation in 5 cases, of which 2 limited to temporal regions and 3 involving also frontal or insular regions. Finally, one case [63] showed bilateral activation in a “snowballing-like” pattern (see Fig. 8.1). Seizure latency from music onset was indicated in 18 cases (210 ± 210 s).

The long latency between musical stimulus and seizure onset makes musicogenic seizures as a use case to investigate the brain mechanisms responsible for the ignition of the ictal phases. In this regard, the study of interictal EEG findings may help identify epileptic focus. Moreover, additional information about their morphology, rate, time delay, spread etc. may help to differentiate areas of origin from areas of propagation of interictal discharges [96].

Interictal EEG abnormalities have been reported in 55 cases of musicolepsia (see Fig. 8.1). Among them, 13 showed right-temporal, 11 left-temporal, 13 bi-temporal, and 1 case reported “temporal spikes” without side specification. The detection of neurophysiological alterations was extended to frontal electrodes in 9 cases (6 left, 2 right, 1 bilateral). Finally, 3 cases displayed unspecific EEG alterations, and 11 recordings were unremarkable. The morphology of interictal alterations (reported in 15 cases) included sharp waves ($n = 5$), slow waves ($n = 2$), and spikes ($n = 8$). In one case [54], the detailed study of interictal spikes resulted in determinants to define the epileptogenic zone since no ictal data were available.

The relationship between interictal spiking and epileptogenesis is still a matter of debate [96]. On the one hand, it has been demonstrated that an increased cortical excitability favors epileptic spikes, whose spatiotemporal density may reach a critical threshold able to provoke seizures [97–99], so that there would be a direct association between the sustained presence of interictal abnormalities and “epileptogenity” [100]. On the other side, several studies demonstrated a reduction in the interictal discharge rate before seizure onset, suggesting that—at least in some cases—spikes may exert a “protective” role toward seizure onset [96, 101, 102]. This view is supported by animal experimental models in which interictal activity is able to reduce the ability of the entorhinal cortex to generate ictal events [103], as well as by pharmacological investigations that evidenced an opposite dynamic between interictal and ictal spike rates following the administration of $GABA_B$ agonists [104].

These findings are consistent with a recent high-density EEG report of a patient with musicolepsia, in which seizures were evoked by listening to epileptogenic music [11]. Here, independent component analysis (ICA) was applied to identify epileptiform markers and to detect putative epileptogenic sources: Ictal and

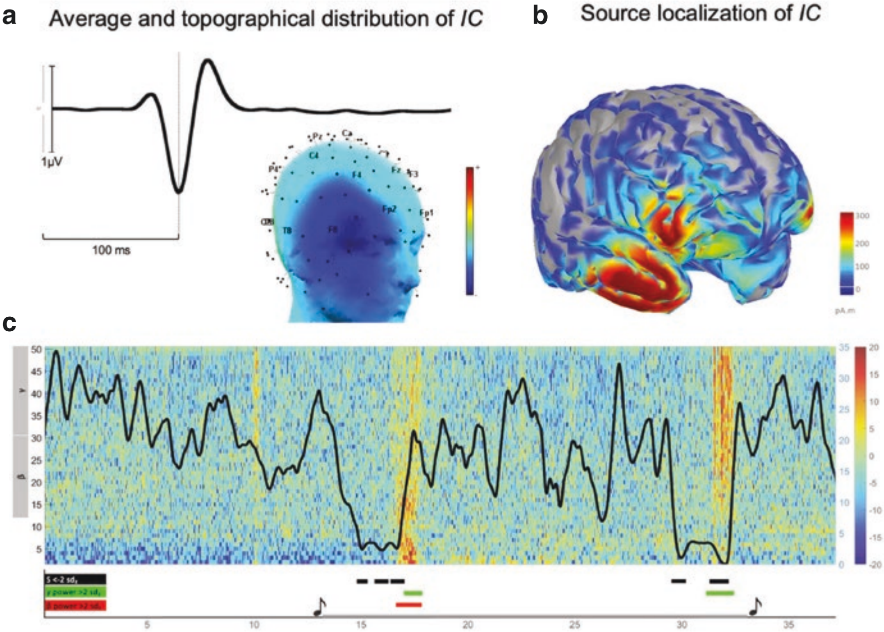

Fig. 8.2 Neurophysiological features of interictal spikes and temporal dynamic of their density during EEG recording, patient R.C., adapted from Nuara et al., Clinical Neurophysiology, 2020, 131 (10), 2393–2401 with permission **Panel A:** Average spike of the independent component and its topography. **Panel B**: Source localization of IC is displayed onto a cortical sheet template. Note the right frontotemporal localization. **Panel C**: Temporal dynamic (minutes) of spike density (black line) overlapped to time-frequency plot of EEG recording. The first spike-density negative peaks (indicated by the first three black rectangles on the bottom panel) just precede seizure onset, this latter associated with the expected increase of beta and gamma power (respectively, red and green rectangles). The second spike-density negative peak precedes an increase in gamma power, without overt clinical seizure correlates. The musical notes in the timeline indicate the start and the end of the music-listening period

interictal discharges highlighted a right frontotemporal localization and a suppression of spike density preceding the seizure onset (see Fig. 8.2).

The involvement of extra-auditory domains as potential sources in musicogenic seizures is consistent with the complex architecture of neural substrates of music listening. Indeed, from the primary auditory cortices involved in tonal mapping, distinct—but interacting—pathways spread along two main streams: the dorsal-posterior one interfaces with the inferior parietal cortex, while the ventral-anterior goes toward the anterior part of the temporal lobe [105]. Both streams interact with distinct frontal areas, forming frontotemporal cortical loops that play a key role in maintaining musical information in working memory, controlling musical expectancy [7].

When, during music listening, we experience an emotional peak (i.e., the *“music chills”*), bursts in autonomic activity (e.g., increase of heart rate) are associated with an increased activity in anterior frontal regions, ventral striatum, mesolimbic regions, and other key subcortical structures involved in reward and emotion [10]. Moreover, the functional connectivity between auditory and frontal areas increases as a function of increasing pleasure component during music listening ([106], see also for a review [7]).

These findings suggest that the “emotional glow” of perceived music—especially when reported by patients—may represent an independent trigger for musicogenic seizures, possibly involving extra-auditory regions.

8.5 Conclusions

Eighty-five years have passed since Critchley first adopted the term “musicolepsia” to describe seizures induced by music listening. Since then, the growing knowledge in the field of neuroscience and the technological advances in neuroimaging allowed us to rethink musicogenic seizures from a simple *“operation of a conditioned reflex in a Pavlovian sense”* [1], to a complex phenomenon involving multiple aspects of music processing. Among them, the “emotional glow” of music is endowed with a peculiar faculty to ignite seizures.

Indeed, more than a nosological class in the wide realm of epilepsy, musicolepsia represents a unique window on the neural substrates of human music experience.

References

1. Critchley M. Musicogenic epilepsy. Brain. 1937;60(1):13–27. https://doi.org/10.1093/brain/60.1.13.
2. Critchley M, Henson RA. Music and the brain: studies in the neurology of music. Berlin: Elsevier Science; 2014. http://qut.eblib.com.au/patron/FullRecord.aspx?p=1655618
3. Avanzini G. Musicogenic seizures. Ann N Y Acad Sci. 2003;999:95–102.
4. Fujinawa A, Kawai I, Ohashi H, Kimura S. A case of musicogenic epilepsy. Folia Psychiatr Neurol Jpn. 1977;31(3):463–72.
5. Genç BO, Genç E, Taştekin G, Iihan N. Musicogenic epilepsy with ictal single photon emission computed tomography (SPECT): could these cases contribute to our knowledge of music processing? Eur J Neurol. 2001;8(2):191–4.
6. Poskanzer DC, Brown AE, Miller H. Musicogenic epilepsy caused only by a discrete frequency band of church bells. Brain. 1962;85:77–92.
7. Zatorre RJ, Salimpoor VN. From perception to pleasure: music and its neural substrates. Proc Natl Acad Sci U S A. 2013;110(Suppl 2):10430–7. https://doi.org/10.1073/pnas.1301228110.
8. Kunert R, Willems RM, Casasanto D, Patel AD, Hagoort P. Music and language syntax interact in Broca’s area: an fMRI study. PLoS One. 2015;10(11):e0141069. https://doi.org/10.1371/journal.pone.0141069.
9. Gordon CL, Cobb PR, Balasubramaniam R. Recruitment of the motor system during music listening: an ALE meta-analysis of fMRI data. PLoS One. 2018;13(11):e0207213. https://doi.org/10.1371/journal.pone.0207213.
10. Blood AJ, Zatorre RJ. Intensely pleasurable responses to music correlate with activity in brain regions implicated in reward and emotion. Proc Natl Acad Sci. 2001;98(20):11818–23. https://doi.org/10.1073/pnas.191355898.
11. Nuara A, Mirandola L, Fabbri-Destro M, Giovannini G, Vecchiato G, Vaudano AE, Tassinari CA, Avanzini P, Meletti S. Spatio-temporal dynamics of interictal activity in musicogenic

epilepsy: two case reports and a systematic review of the literature. Clin Neurophysiol. 2020;131(10):2393–401. https://doi.org/10.1016/j.clinph.2020.06.028.
12. Vanelle JM. Contribution a l'etude de l'epilepsie musicogenique. These, Paris, University. 1982.
13. Shaw D, Hill D. A case of musicogenic epilepsy. J Neurol Neurosurg Psychiatry. 1947;10(3):107–17. https://doi.org/10.1136/jnnp.10.3.107.
14. Joynt RJ, Green D, Green R. Musicogenic epilepsy. JAMA. 1962 Feb 17;179(7):501–4.
15. Stubbe-Teglbjaerg H. On musciogenic epilepsy. Acta Psychiatrica Scandinavica. 1949 Dec;24(3-4):679–90.
16. Arellano AP, Schwab RS, Casby JU. Sonic activation. Electroencephalogr Clin Neurophysiol. 1950;2(1-4):215–7.
17. Dow RS. Electroencephalographic findings in a case of musicogenic epilepsy. In: Electroencephalogr Clin Neurophysiol 1951 (Vol. 3, No. 3, pp. 384-384).
18. Vercelletto P. A propos d'un cas d'épilepsie musicogénique. Présentation d'une crise temporale, discussion sur son point de départ. Rev Neurol. 1953;88:379–82.
19. Hoheisel HP, Walch R. Ein Fall von akustischer Reflexepilepsie. Psychiatr Neurol Med Psychol. 1953 May;1:194–200.
20. Levi PG. Su un caso di epilessia musicogena. Neuropsichiatria. 1954;10:119–28.
21. Bickford RG. Musicogenic epilepsy. Electroencephalogr Clin Neurophysiol. 1956;8(1):152–3.
22. Weber R. Musikogene epilepsie. Nervenarzt. 1956;27:337–40.
23. Daly DD, Barry MJ Jr. Musicogenic epilepsy: report of three cases. Psychosom Med. 1957 Sep 1;19(5):399–408.
24. Reifenberg E. Beitrag zur Kasuistik der musikogenen Epilepsie. Psychiatr Neurol Med Psychol. 1958 Mar;1:88–91.
25. Barrios Del Risco P, Esslen E. Epilepsia musicógena. Acta Neurol Latinoamer. 1958;4:130–44.
26. Titeca J. Lepilepsie musicogenique: Revue generale a propos d'un cas personnel suivi pendant quatorze ans. Acta Neurol Belg. 1965;65:598–648.
27. Piotrowski A. A case of musicogenic epilepsy-clinical and EEG study. Electroencephalogr Clin Neurophysiol 1959 (Vol. 11, No. 1, pp. 176-176).
28. Bash KW, Bash-Liechti J. Die Psychotherapie eines Falles von musikogener Epilepsie. Schweiz Arch Neurol Psychiatr. 1959;83:196–221.
29. Yvonneau M, de Barros-Ferreira M. A propos de l'épilepsie audiogénique. Presse Med. 1963:71–616.
30. Gornik VM. Apropos of musicogenic epilepsy. Zh Nevropatol Psikhiatr Im S S Korsakova. 1952;1964(64):1227–31.
31. Perpiniotis D. A propos d'un cas d'épilepsie musicogénique pure, influencé par la méthylphényléthylhydantoıne. Rev Neurol. 1964;110:226–31.
32. Forster FM, Klove H, Peterson WG, Bengzon AR. Modification of musicogenic epilepsy extinction technique. Trans Am Neurol Assoc. 1965;90:179–82.
33. Toivakka E, Lehtinen LO. Musicogenic epilepsy: a case report.
34. Dearman HB, Smith BM. A case of musicogenic epilepsy. JAMA. 1965 Sep 27;193(13):1123–5.
35. Gastaut H, Tassinari CA. Triggering mechanisms in epilepsy the electroclinical point of view. Epilepsia. 1966 Jun;7(2):85–138.
36. Vizioli R, Simone F, Felici F. L'epilessia musicogena: contributo clinico. Riv Neurol. 1974;44:448–70.
37. Newman P, Saunders M. A unique case of musicogenic epilepsy. Arch Neurol. 1980 Apr 1;37(4):244–5.
38. Sutherling WW, Hershman LM, Miller JQ, Lee SI. Seizures induced by playing music. Neurology. 1980 Sep 1;30(9):1001–4.
39. Brien SE, Murray TJ. Musicogenic epilepsy. Can Med Assoc J. 1984 Nov 11;131(10):1255.
40. Byun YJ, Hah JS, Park CS. A case of musicogenic epilepsy. J Korean Neurol Assoc. 1989:123–30.
41. Jallon P, Heraut LA, Vanelle JM, Beaumanoir A, Gastaut H, Naquet R, editors. Reflex seizures and reflex epilepsies. Geneva: Éditions Médecine & Hygiène; 1989. p. 269–74.

42. Smeijsters H, van Den Berk P. Music therapy with a client suffering from musicogenic epilepsy: a naturalistic qualitative single-case research. Arts Psychother. 1995;
43. Ackerman RJ, Banks ME. A neuropsychological case study of musicogenic epilepsy. Arch Clin Neuropsychol. 1995;4(10):286–7.
44. Wieser HG, Hungerböhler H, Siegel AM, Buck A. Musicogenic epilepsy: review of the literature and case report with ictal single photon emission computed tomography. Epilepsia. 1997 Feb;38(2):200–7.
45. Nakano M, Takase Y, Tatsumi C. A case of musicogenic epilepsy induced by listening to an American pop music. Rinsho Shinkeigaku. 1998 Dec 1;38(12):1067–9.
46. Trevathan E, Gewirtz RJ, Cibula JE, Schmitt FA. Musicogenic seizures of right superior temporal gyrus origin precipitated by the theme song from 'The X-files'. Epilepsia. 1999;40:23.
47. Gelisse P, Thomas P, Padovani R, Hassan-Sebbag N, Pasquier J, Genton P. Ictal SPECT in a case of pure musicogenic epilepsy. Epileptic Disord. 2003 Sep 1;5(3):133–7.
48. Lin KL, Wang HS, Kao PF. A young infant with musicogenic epilepsy. Pediatr Neurol. 2003 May 1;28(5):379–81.
49. Mórocz IÁ, Karni A, Haut S, Lantos G, Liu G. fMRI of triggerable aurae in musicogenic epilepsy. Neurology. 2003 Feb 25;60(4):705–9.
50. Wieser HG. Musicogenic seizures and findings on the anatomy of musical perception. Reflex epilepsies: progress in understanding. 2004 Apr;13:79–91.
51. Stern JM, Tripathi M, Akhtari M, Korb A, Engel J, Cohen MS. Musicogenic seizure localization with simultaneous EEG and functional MRI (SEM). Neurology 2006 Mar 14 (Vol. 66, No. 5, pp. A90-A90).
52. Sacks O. The power of music. Brain. 2006 Oct 1;129(10):2528–32.
53. Anneken K, Fischera M, Kolska S, Evers S. An unusual case of musicogenic epilepsy in a patient with a left fronto-temporal tumour. J Neurol. 2006;253(11):1502–4. https://doi.org/10.1007/s00415-006-0257-1.
54. Shibata N, Kubota F, Kikuchi S. The origin of the focal spike in musicogenic epilepsy. Epileptic Disord. 2006;8(2):131–5.
55. Tayah TF, Abou-Khalil B, Gilliam FG, Knowlton RC, Wushensky CA, Gallagher MJ. Musicogenic seizures can Arise from multiple temporal lobe foci: intracranial EEG analyses of three patients. Epilepsia. 2006;47(8):1402–6. https://doi.org/10.1111/j.1528-1167.2006.00609.x.
56. Claassen DO, Walting PJ, Tan KM, Pittock PJ, So EL. Elvis and epilepsy; A case of musicogenic epilepsy treated with music. Epilepsia 2007 Oct 1 (Vol. 48, pp. 22-22).
57. Cho JW, Seo DW, Joo EY, Tae WS, Lee J, Hong SB. Neural correlates of musicogenic epilepsy: SISCOM and FDG-PET. Epilepsy Res. 2007 Dec;77(2-3):169–73.
58. Pittau F, Tinuper P, Bisulli F, Naldi I, Cortelli P, Bisulli A, Stipa C, Cevolani D, Agati R, Leonardi M, Baruzzi A. Videopolygraphic and functional MRI study of musicogenic epilepsy. A case report and literature review. Epilepsy Behav. 2008 Nov;13(4):685–92.
59. Mehta AD, Ettinger AB, Perrine K, Dhawan V, Patil A, Jain SK, Klein G, Schneider SJ, Eidelberg D. Seizure propagation in a patient with musicogenic epilepsy. Epilepsy Behav. 2009 Feb;14(2):421–4.
60. Marrosu F, Barberini L, Puligheddu M, Bortolato M, Mascia M, Tuveri A, Muroni A, Mallarini G, Avanzini G. Combined EEG/fMRI recording in musicogenic epilepsy. Epilepsy Res. 2009 Mar;84(1):77–81.
61. Duanyu N, Yongjie L, Guojun Z, Lixin C, Liang Q. Surgical treatment for musicogenic epilepsy. J Clin Neurosci. 2010 Jan;17(1):127–9.
62. Sanchez-Carpintero R, Patiño-Garcia A, Urrestarazu E. Musicogenic seizures in Dravet syndrome. Dev Med Child Neurol. 2013 Jul;55(7):668–70.
63. Diekmann V, Hoppner AC. Cortical network dysfunction in musicogenic epilepsy reflecting the role of snowballing emotional processes in seizure generation: an fMRI-EEG study. Epileptic Disord. 2014;1:31–44. https://doi.org/10.1684/epd.2014.0636.
64. Seidi O, El Sadig S, Ahmed A, et al. J Neurol Sci. 2015;357(Supplement 1):e32.

65. Tezer FI, Bilginer B, Oguz KK, Saygi S. Musicogenic and spontaneous seizures: EEG analyses with hippocampal depth electrodes. Epileptic Disord. 2014;16(4):500–5. https://doi.org/10.1684/epd.2014.0706.
66. Wang ZI, Jin K, Kakisaka Y, Burgess RC, Gonzalez-Martinez JA, Wang S, Ito S, Mosher JC, Hantus S, Alexopoulos AV. Interconnections in superior temporal cortex revealed by musicogenic seizure propagation. J Neurol. 2012 Oct;259(10):2251–4.
67. Klamer S, Rona S, Elshahabi A, Lerche H, Braun C, Honegger J, Erb M, Focke NK. Multimodal effective connectivity analysis reveals seizure focus and propagation in musicogenic epilepsy. Neuroimage. 2015 Jun;113:70–7.
68. Cheng JY. Musicogenic epilepsy and treatment of affective disorders: case report and review of pathogenesis. Cogn Behav Neurol. 2016 Dec;29(4):212–6.
69. Nagahama Y, Kovach CK, Ciliberto M, Joshi C, Rhone AE, Vesole A, Gander PE, Nourski KV, Oya H, Howard MA, Kawasaki H, Dlouhy BJ. Localization of musicogenic epilepsy to Heschl's gyrus and superior temporal plane: case report. J Neurosurg. 2018 Jul;129(1):157–64.
70. Tseng WEJ, Lim SN, Chen LA, Jou SB, Hsieh HY, Cheng MY, Chang CW, Li HT, Chiang HI, Wu T. Correlation of vocals and lyrics with left temporal musicogenic epilepsy. Ann N Y Acad Sci. 2018; https://doi.org/10.1111/nyas.13594.
71. Falip M, Rodriguez-Bel L, Castañer S, Miro J, Jaraba S, Mora J, Bas J, Carreño M. Musicogenic reflex seizures in epilepsy with glutamic acid decarbocylase antibodies. Acta Neurol Scand. 2018 Feb;137(2):272–6.
72. Pelliccia V, Villani F, Gozzo F, Gnatkovsky V, Cardinale F, Tassi L. Musicogenic epilepsy: a stereo-electroencephalography study. Cortex. 2019 Nov;120:582–7.
73. Bass DI, Shurtleff H, Warner M, Knott D, Poliakov A, Friedman S, Collins MJ, Lopez J, Lockrow JP, Novotny EJ, Ojemann JG, Hauptman JS. Awake mapping of the auditory cortex during tumor resection in an aspiring musical performer: A case report. Pediatr Neurosurg. 2020;55(6):351–8. https://doi.org/10.1159/000509328.
74. Smith KM, Zalewski NL, Budhram A, Britton JW, So E, Cascino GD, Ritaccio AL, McKeon A, Pittock SJ, Dubey D. Musicogenic epilepsy: expanding the spectrum of glutamic acid decarboxylase 65 neurological autoimmunity. Epilepsia. 2021;62(5) https://doi.org/10.1111/epi.16888.
75. Al-Attas AA, Al Anazi RF, Swailem SK. Musicogenic reflex seizure with positive antiglutamic decarboxylase antibody: a case report. Epilepsia Open. 2021;6(3):607–10.
76. Benoit J, Martin F, Thomas P. Musicogenic epilepsy with ictal asystole: a video-EEG case report. Epileptic Disord. 2021;23(4):649–54.
77. Morano A, Orlando B, Fanella M, Irelli EC, Colonnese C, Quarato P, Giallonardo AT, Di Bonaventura C. Musicogenic epilepsy in paraneoplastic limbic encephalitis: a video-EEG case report. Epileptic Disord. 2021;23(5):754–9. https://doi.org/10.1684/epd.2021.1322.
78. Schlaug G. Musicians and music making as a model for the study of brain plasticity. Prog Brain Res. 2015;217:37–55. https://doi.org/10.1016/bs.pbr.2014.11.020.
79. Bekhterev V. O reflektornoi epilepsi pod oliyaniem evyookovic razdrazheniye;1914. p. 513.
80. Rouget G. Music and trance: a theory of the relations between music and possession. Chicago: University of Chicago Press; 1985.
81. Valla JM, Alappatt JA, Mathur A, Singh NC. Music and emotion—a case for north Indian classical music. Front Psychol. 2017;8:2115. https://doi.org/10.3389/fpsyg.2017.02115.
82. Gastaut H, Tassinari CA. Triggering mechanisms in epilepsy the electroclinical point of view. Epilepsia. 2010;7(2):85–138. https://doi.org/10.1111/j.1528-1167.1966.tb06262.x.
83. Kallman HJ, Corballis MC. Ear asymmetry in reaction time to musical sounds. Percept Psychophys. 1975;17(4):368–70. https://doi.org/10.3758/BF03199348.
84. Taub JM, Tanguay PE, Doubleday CN, Clarkson D, Remington R. Hemisphere and ear asymmetry in the auditory evoked response to musical chord stimuli. Physiol Psychol. 1976;4(1):11–7. https://doi.org/10.3758/BF03326537.
85. Gaab N, Gaser C, Zaehle T, Jancke L, Schlaug G. Functional anatomy of pitch memory—an fMRI study with sparse temporal sampling. NeuroImage. 2003;19(4):1417–26. https://doi.org/10.1016/S1053-8119(03)00224-6.

86. Zatorre R, Evans A, Meyer E. Neural mechanisms underlying melodic perception and memory for pitch. J Neurosci. 1994;14(4):1908–19. https://doi.org/10.1523/JNEUROSCI.14-04-01908.1994.
87. Berlin CI, Lowe-Bell SS, Jannetta PJ, Kline DG. Central auditory deficits after temporal lobectomy. Arch Otolaryngol Head Neck Surg. 1972;96(1):4–10. https://doi.org/10.1001/archotol.1972.00770090042003.
88. Gordon MC. Reception and retention factors in tone duration discriminations by brain-damaged and control patients. Cortex. 1967;3(2):233–49. https://doi.org/10.1016/S0010-9452(67)80014-5.
89. Stewart L, von Kriegstein K, Warren JD, Griffiths TD. Music and the brain: disorders of musical listening. Brain. 2006;129(10):2533–53. https://doi.org/10.1093/brain/awl171.
90. Schoenberg A. Theory of harmony. New York: Philosophical Library; 1948.
91. Lerdahl F, Jackendoff R. A generative theory of tonal music. Cambridge: MIT Press; 1983.
92. Koelsch S, Gunter TC, Cramon D Yv, Zysset S, Lohmann G, Friederici AD. Bach speaks: a cortical 'language-network' serves the processing of music. NeuroImage. 2002;17(2):956–66.
93. Maess B, Koelsch S, Gunter TC, Friederici AD. Musical syntax is processed in Broca's area: an MEG study. Nat Neurosci. 2001;4(5):540–5. https://doi.org/10.1038/87502.
94. Patel AD. Language, music, syntax and the brain. Nat Neurosci. 2003;6(7):674–81. https://doi.org/10.1038/nn1082.
95. Norman-Haignere S, Kanwisher NG, McDermott JH. Distinct cortical pathways for music and speech revealed by hypothesis-free voxel decomposition. Neuron. 2015;88(6):1281–96. https://doi.org/10.1016/j.neuron.2015.11.035.
96. Chvojka J, Kudlacek J, Chang W-C, Novak O, Tomaska F, Otahal J, Jefferys JGR, Jiruska P. The role of interictal discharges in ictogenesis—a dynamical perspective. Epilepsy Behav. 2019;106:591. https://doi.org/10.1016/j.yebeh.2019.106591.
97. de Curtis M, Avanzini G. Interictal spikes in focal epileptogenesis. Prog Neurobiol. 2001;63(5):541–67. https://doi.org/10.1016/S0301-0082(00)00026-5.
98. Dichter M, Ayala G. Cellular mechanisms of epilepsy: a status report. Science. 1987;237(4811):157–64. https://doi.org/10.1126/science.3037700.
99. Jensen MS, Yaari Y. The relationship between interictal and ictal paroxysms in an in vitro model of focal hippocampal epilepsy. Ann Neurol. 1988;24(5):591–8. https://doi.org/10.1002/ana.410240502.
100. Wada JA, Sato M, Corcoran ME. Persistent seizure susceptibility and recurrent spontaneous seizures in kindled cats. Epilepsia. 1974;15(4):465–78. https://doi.org/10.1111/j.1528-1157.1974.tb04022.x.
101. Goncharova II, Alkawadri R, Gaspard N, Duckrow RB, Spencer DD, Hirsch LJ, Spencer SS, Zaveri HP. The relationship between seizures, interictal spikes and antiepileptic drugs. Clin Neurophysiol. 2016;127(9):3180–6. https://doi.org/10.1016/j.clinph.2016.05.014.
102. Karoly PJ, Freestone DR, Boston R, Grayden DB, Himes D, Leyde K, Seneviratne U, Berkovic S, O'Brien T, Cook MJ. Interictal spikes and epileptic seizures: their relationship and underlying rhythmicity. Brain. 2016;139(4):1066–78. https://doi.org/10.1093/brain/aww019.
103. Barbarosie M, Avoli M. CA3-driven hippocampal-entorhinal loop controls rather than sustains in vitro limbic seizures. J Neurosci. 1997;17(23):9308–14. https://doi.org/10.1523/JNEUROSCI.17-23-09308.1997.
104. Motalli R, Louvel J, Tancredi V, Kurcewicz I, Wan-Chow-Wah D, Pumain R, Avoli M. $GABA_B$ receptor activation promotes seizure activity in the juvenile rat hippocampus. J Neurophysiol. 1999;82(2):638–47. https://doi.org/10.1152/jn.1999.82.2.638.
105. Rauschecker JP, Scott SK. Maps and streams in the auditory cortex: nonhuman primates illuminate human speech processing. Nat Neurosci. 2009;12(6):718–24. https://doi.org/10.1038/nn.2331.
106. Sachs ME, Ellis RJ, Schlaug G, Loui P. Brain connectivity reflects human aesthetic responses to music. Soc Cogn Affect Neurosci. 2016;11(6):884–91. https://doi.org/10.1093/scan/nsw009.