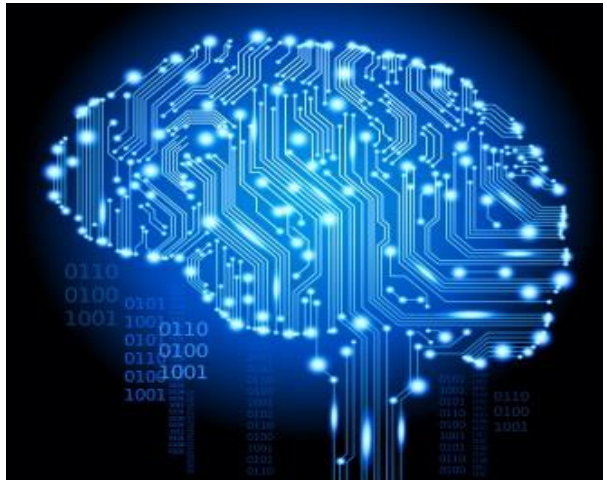
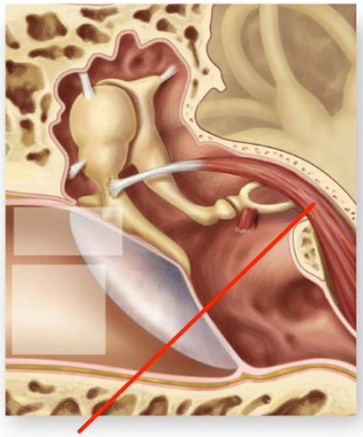
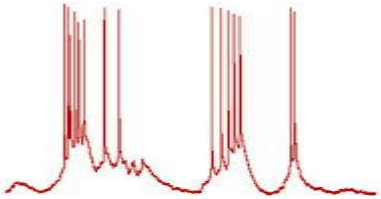
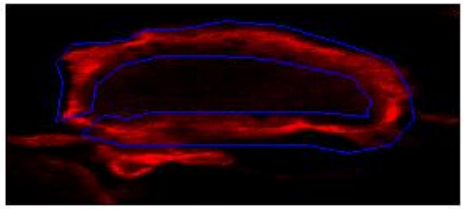
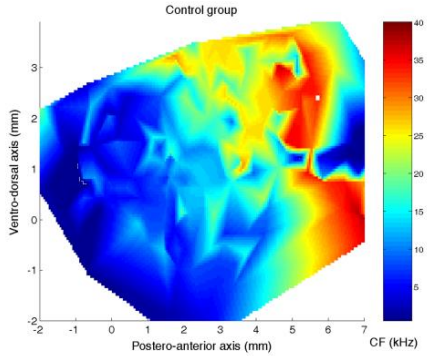


Les acouphènes







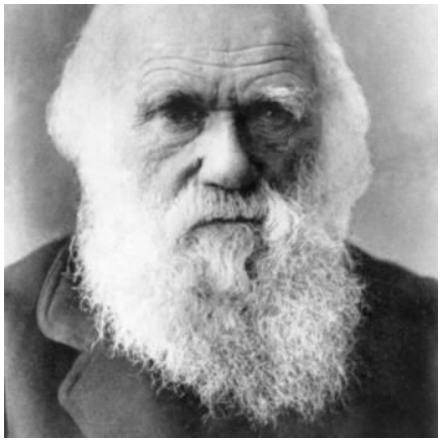


Arnaud Norena

Aix*Marseille université

Fédération 3C
COMPORTEMENT · CERVEAU · COGNITION

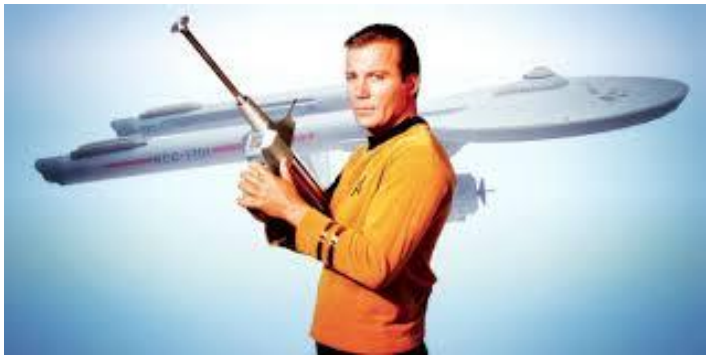
LNIA
LABORATOIRE de NEUROSCIENCES INTEGRATIVES et ADAPTATIVES





METALLICA.COM

IN SILENTIO
FORTITVDO
ET SPE ERIT
VESTRA .


Definition

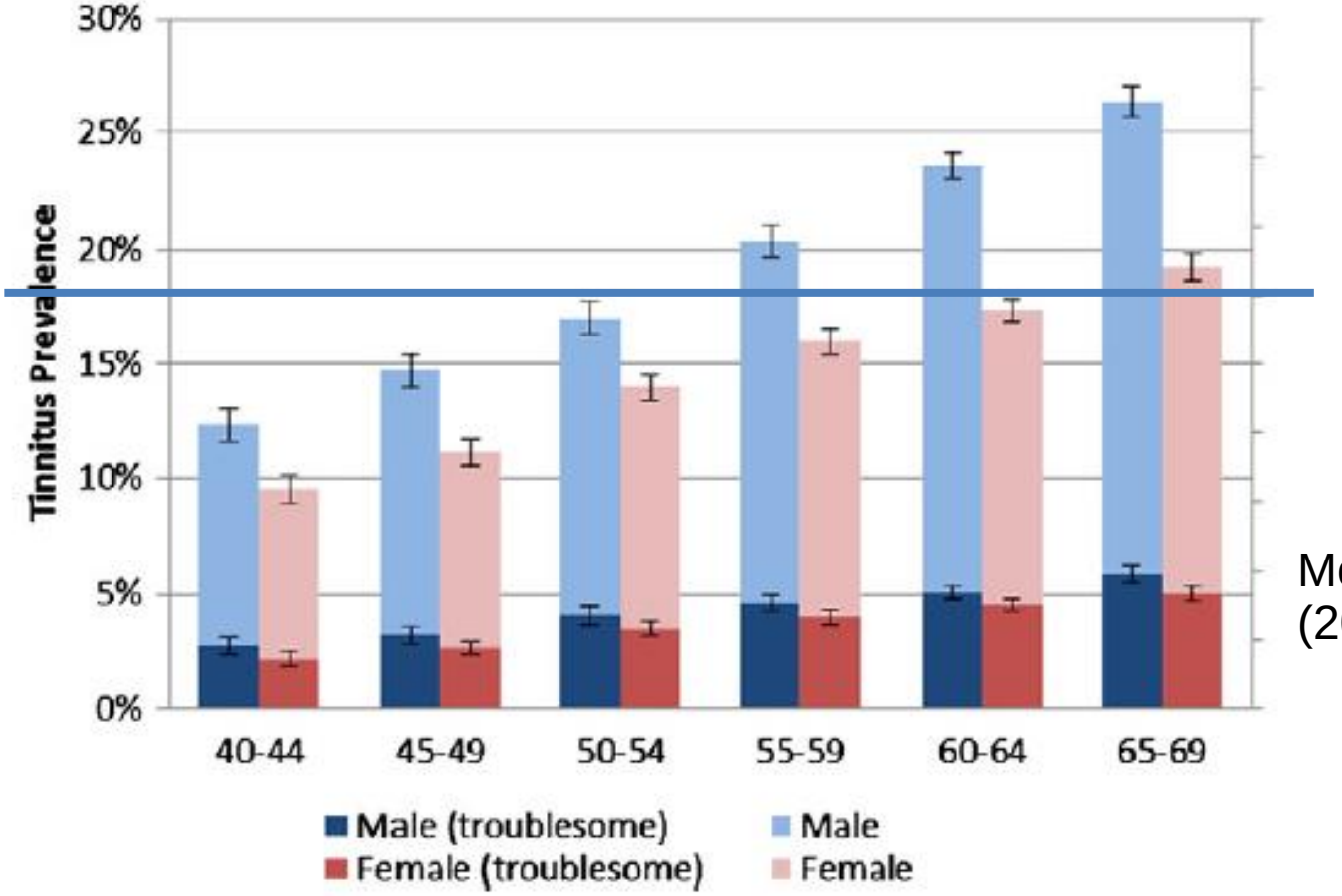
- Les acouphènes sont une perception auditive au contenu très simple (≠ hallucination) qui n'est pas produite par une stimulation acoustique dans l'*environnement*:
  - Acouphènes objectifs (5%): sources acoustiques provenant du corps (SOAEs, oreille moyenne, problèmes vasculaires, muscles de l'oreille moyenne…)
  - Acouphènes subjectifs: les causes sont « silencieuses » (mais produisant une activité neuronale « aberrante »)

Prevalence

- Large in the general population, larger in the ederly:

~18% of the general population

~20% of troublesome tinnitus



McCormack et al. (2014)

Fig. 2. Prevalence estimates for self-report of current tinnitus (light shade) and current bothersome tinnitus (dark shade) among males and females (N = 172,621), 95% CI shown.

Analogies acouphènes & douleur

Nociception
Information sur une lésion du corps

Audition
Information sur les sources sonores de l'environnement

Douleur
Expérience vécue

Perception auditive
Expérience vécue

Souffrance
Etape réflexive (capacité de penser sur quelque chose de senti ou vécu), interprétation de la douleur par le sujet, à connotation existentielle

Souffrance
Etape réflexive (capacité de penser sur quelque chose de senti ou vécu), interprétation des acouphènes par le sujet, à connotation existentielle

Fondras, 2007

Analogies acouphènes & douleur

Problème de Neurosciences

Nociception
Information sur une lésion du corps

Audition
Information sur les sources sonores de l'environnement

Douleur
Expérience vécue

Perception auditive
Expérience vécue

Souffrance
Etape réflexive (capacité de penser sur quelque chose de senti ou vécu), interprétation de la douleur par le sujet, à connotation existentielle

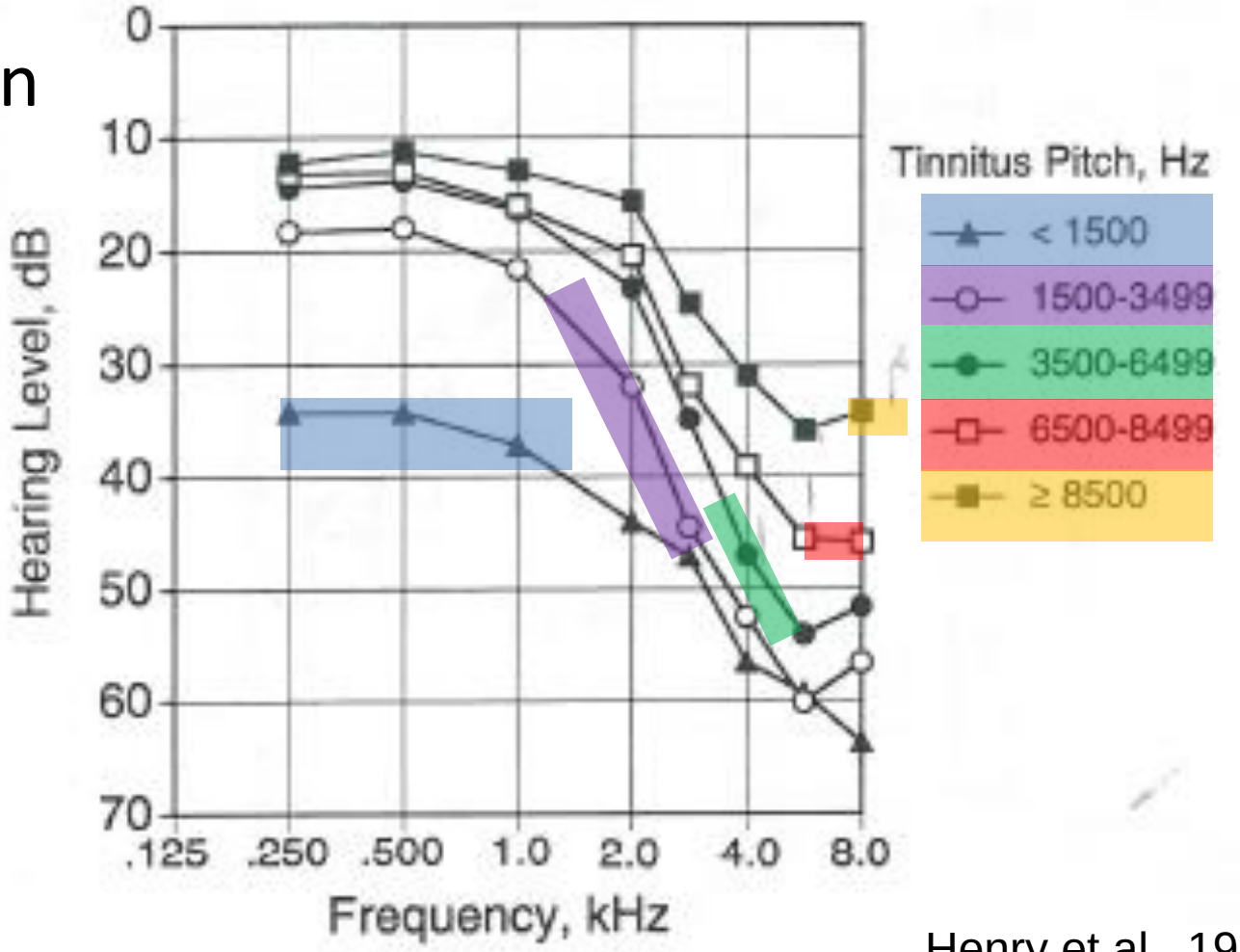
Souffrance
Etape réflexive (capacité de penser sur quelque chose de senti ou vécu), interprétation des acouphènes par le sujet, à connotation existentielle

Problème Clinique

Fondras, 2007

Psychoacoustic characteristics

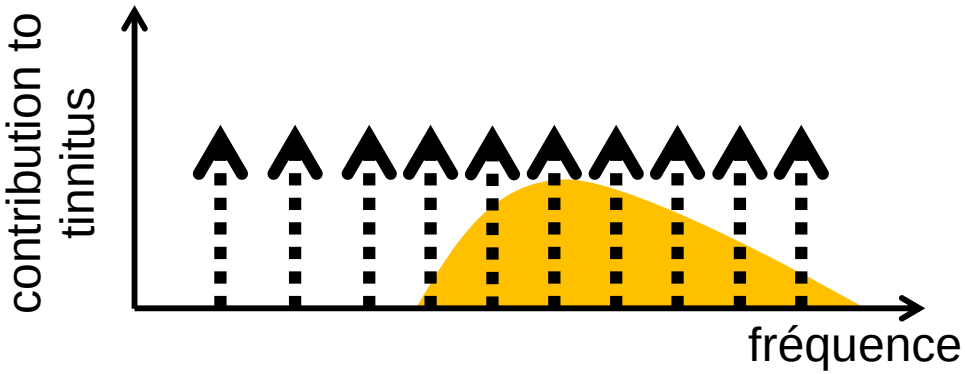
- Audiogram & pitch
  - Tinnitus is associated to HL in the majority of subjects (but not all)
  - Tinnitus has often a measurable dominant pitch
  - Pitch is function of the audiogram

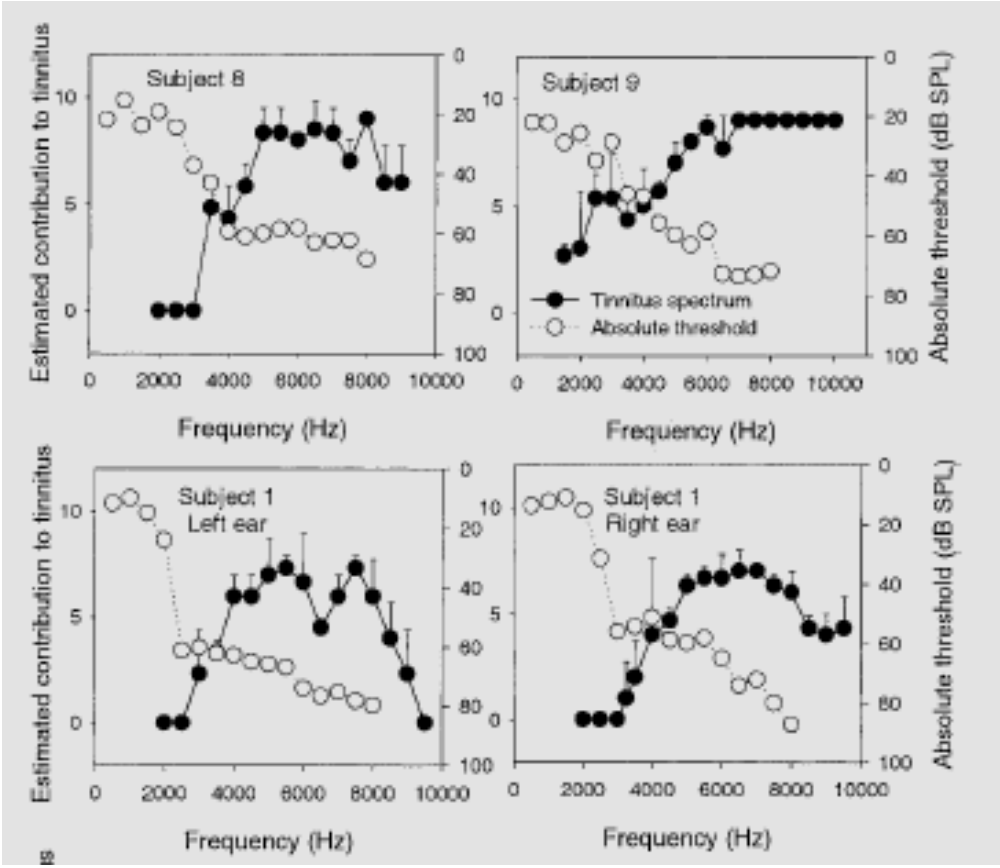


Henry et al., 1999

Psychoacoustic characteristics

- Pitch/timbre
  - The dominant pitch is usually in the HL region
  - The timbre is variable





Norena et al., 2002

Psychoacoustic characteristics

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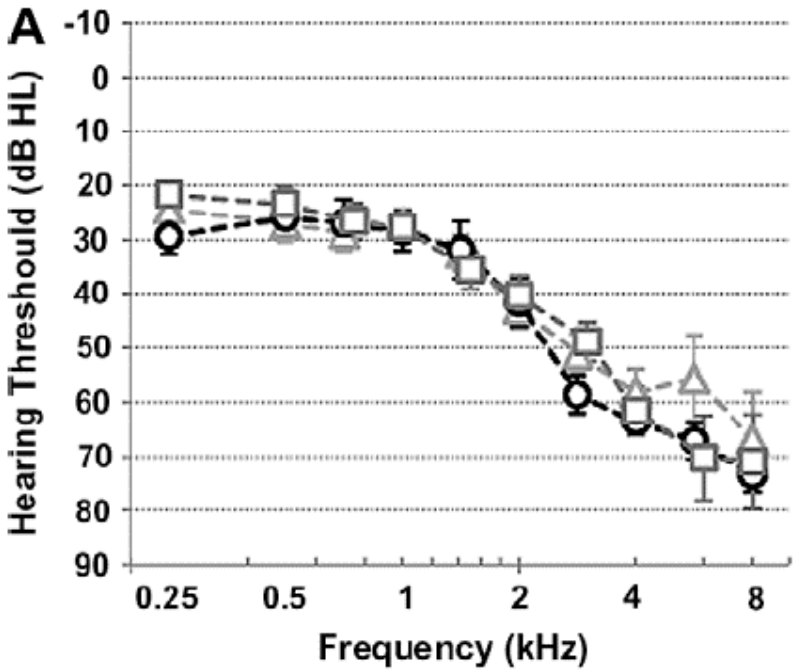
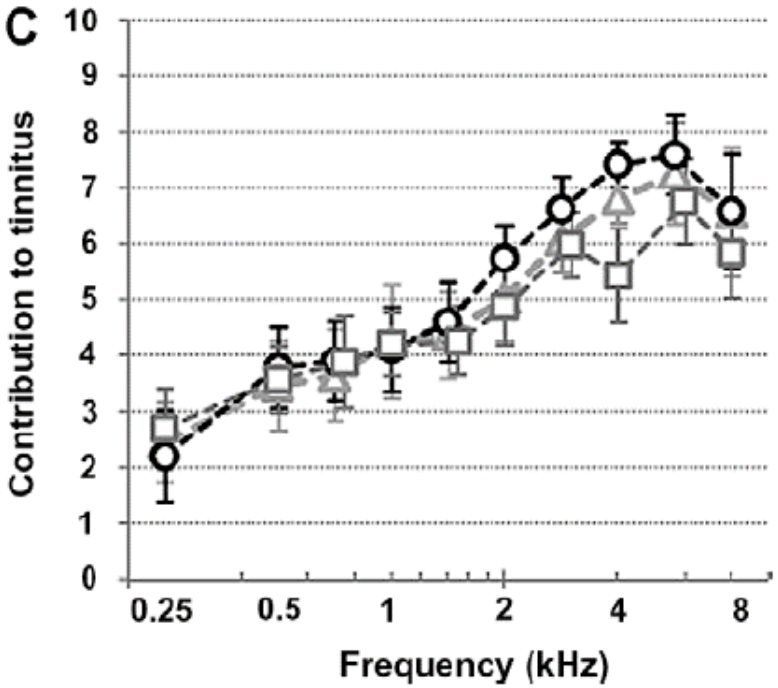
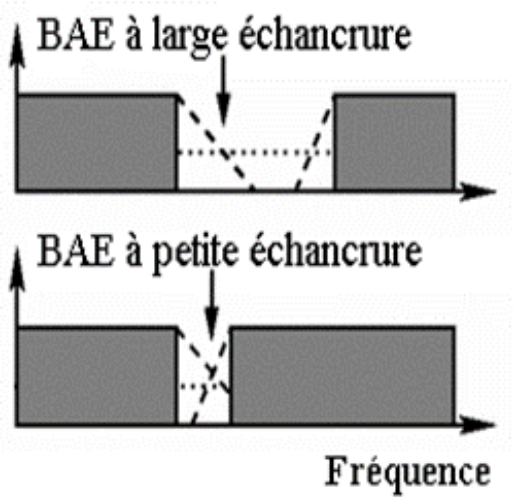


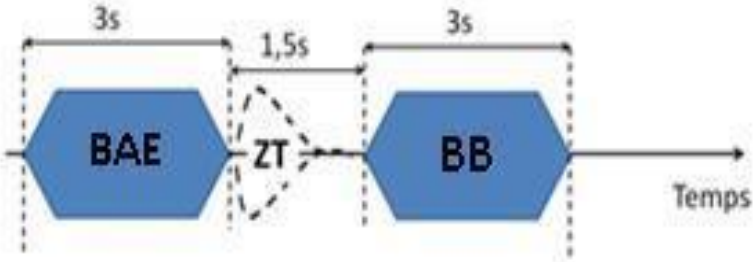


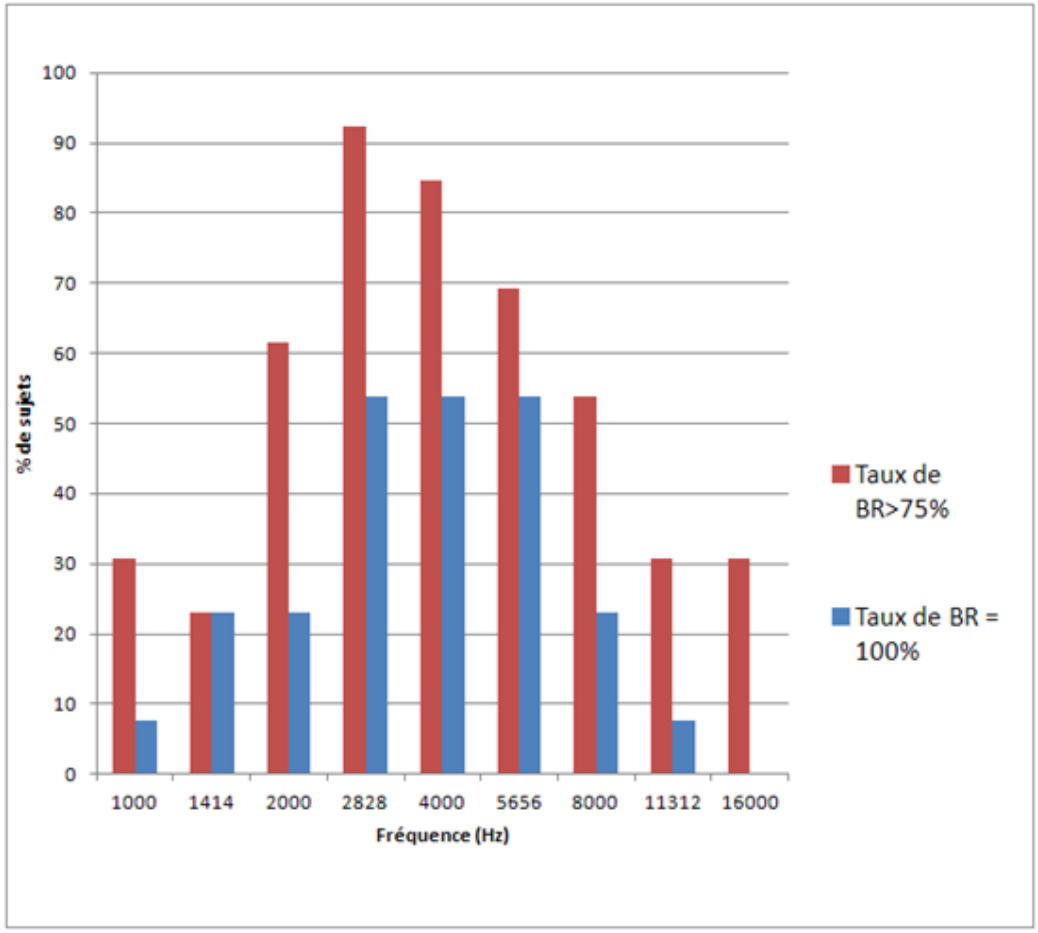
Moffat et al., 2009

Digression 1 Zwicker tone

Perte auditive « simulée »

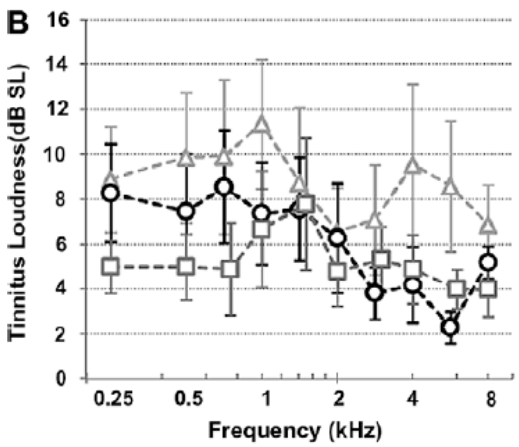






Psychoacoustic characteristics

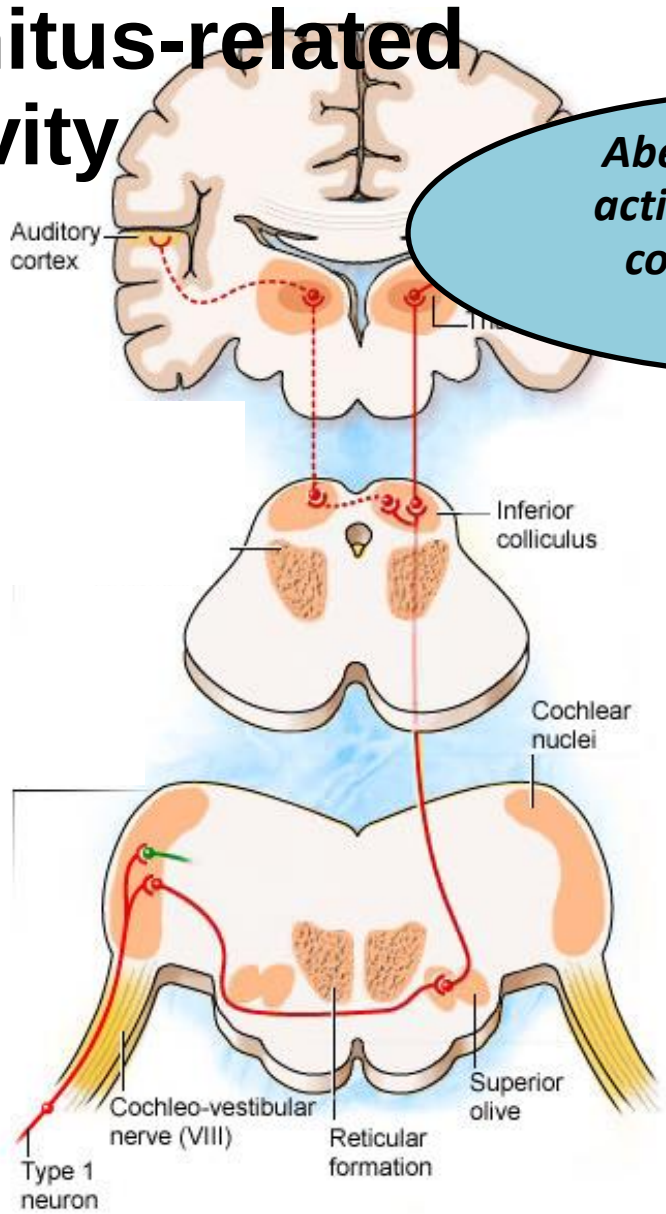
- Loudness
  - Matching to tinnitus or « normal » frequency (Goodwin and Johnson, 1980):
    - Tinnitus frequency: 1-20 dB SL, mean=6.6 dB SL
    - Normal frequency: 8-50 dB SL, mean=33.4 dB SL



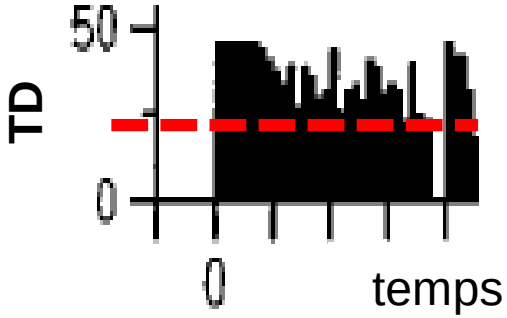
Moffat et al., 2009

  - No relationship between loudness and distress

Tinnitus Mechanisms → Tinnitus-related activity



Aberrant spontaneous activity underpinning a continuous auditory percept



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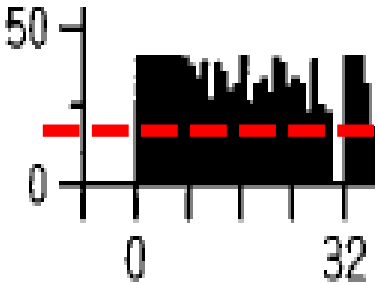
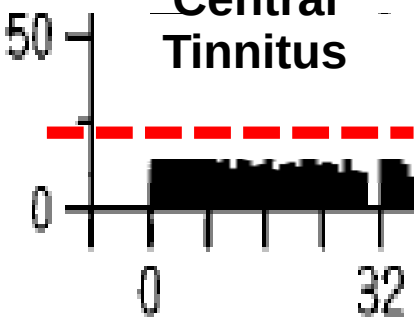
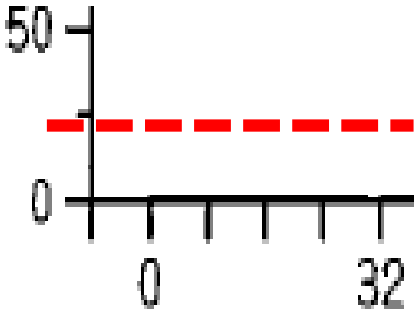
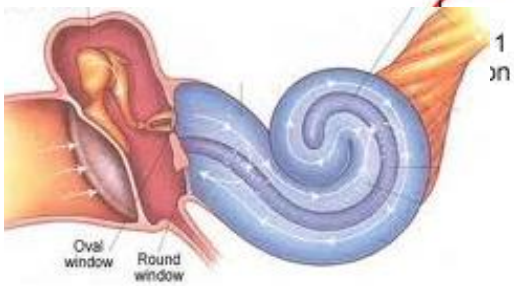
Cochlear Tinnitus

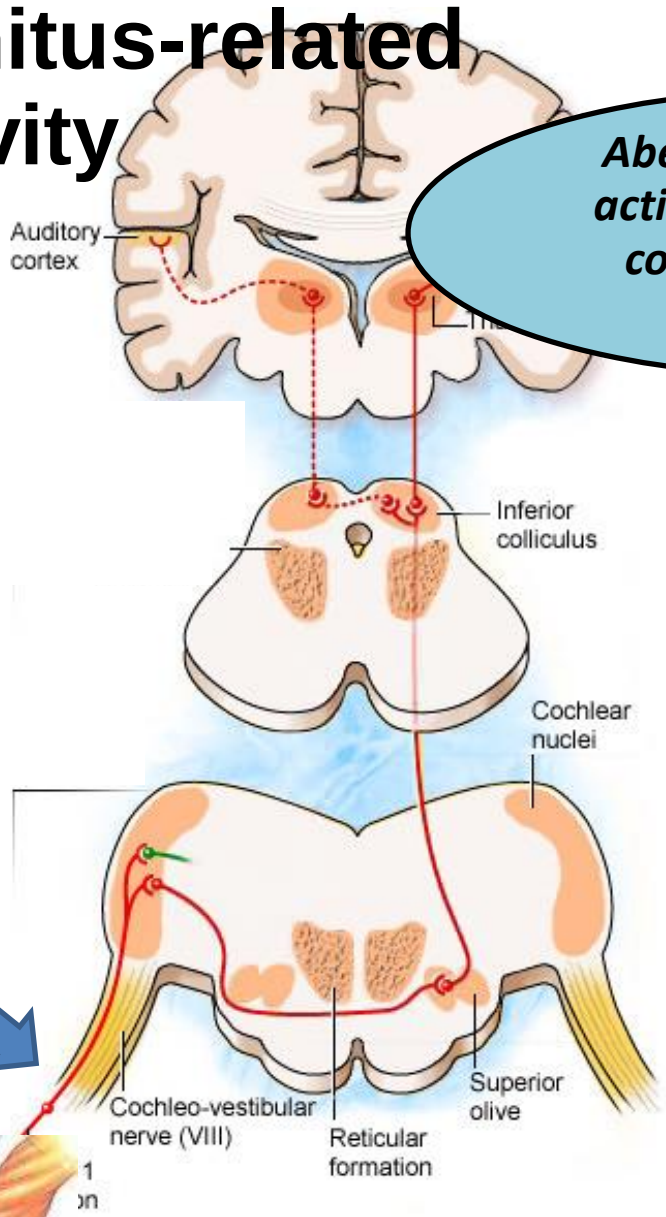


Central Tinnitus









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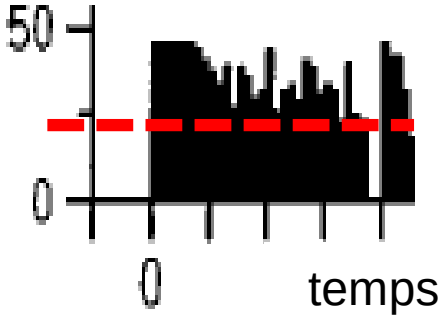

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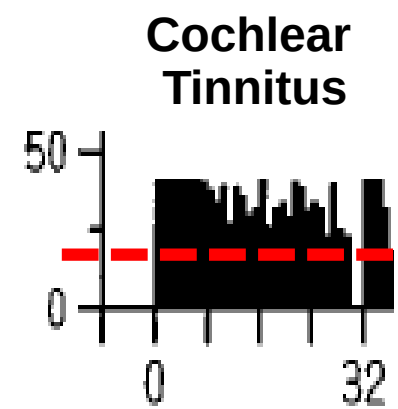
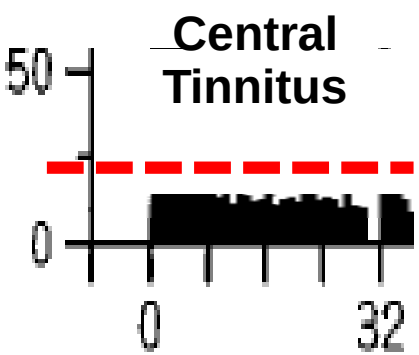
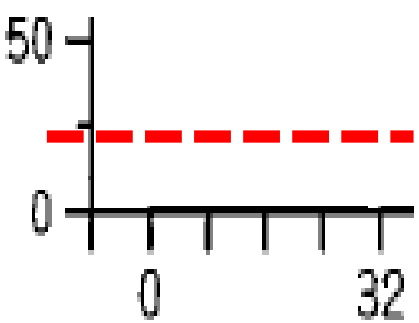
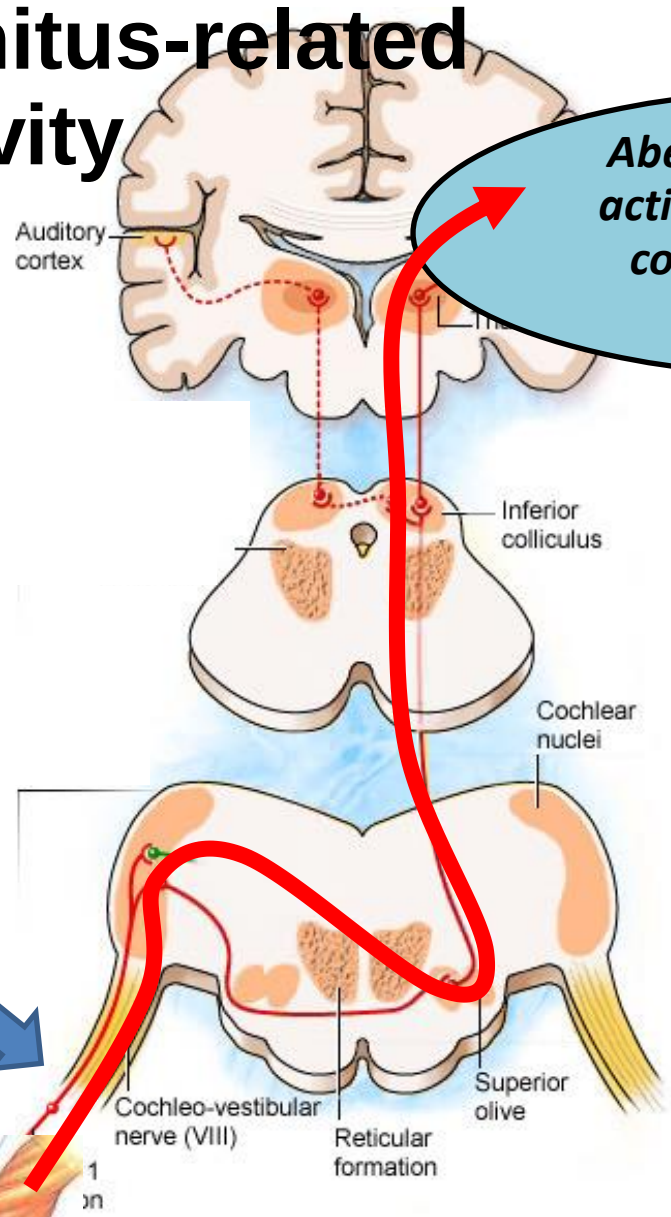
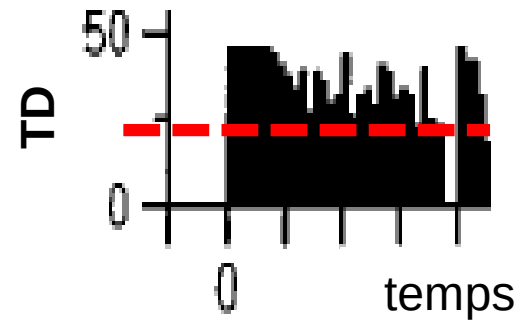








Aberrant spontaneous activity underpinning a continuous auditory percept



Acouphènes

Aberrant spontaneous activity underpinning a continuous auditory percept

Cochlear tinnitus

Centres are passive

- Pre-synaptic
  - Stereocilia lesions (rootlets)
  - OHC operating point
  - Strie vasculaire
- Post-synaptic
  - NMDA receptors

Central tinnitus

Centres are active

- Dependent from the periphery
- Independent from the periphery
  - Homeostatic plasticity
  - Tonotopic map reorganization
  - Multi-modal plasticity
  - Thalamo-cortical dysrythmia

Norena, 2015

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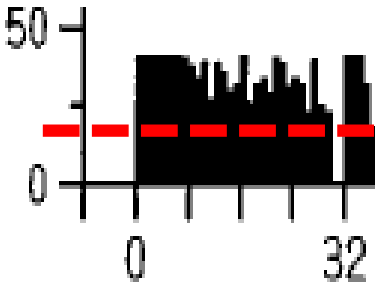
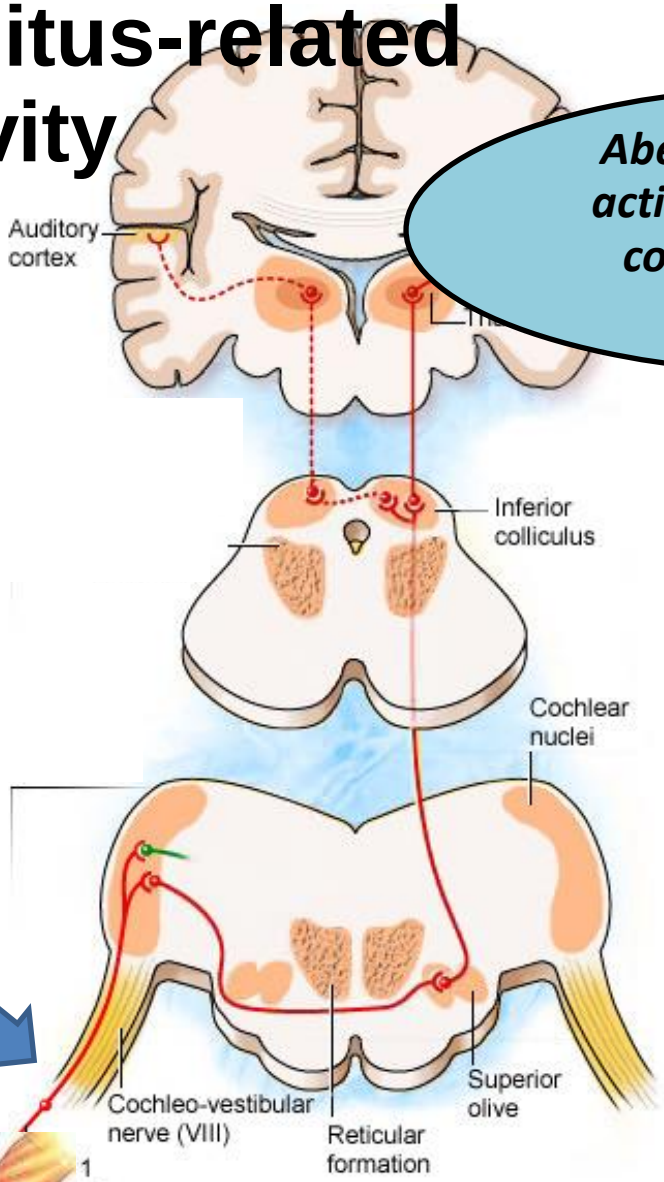
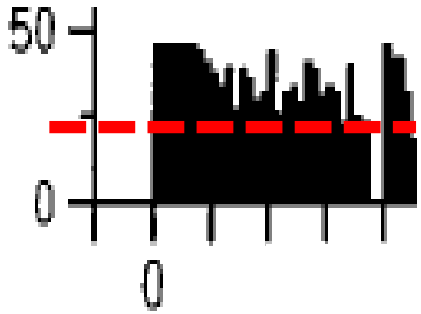
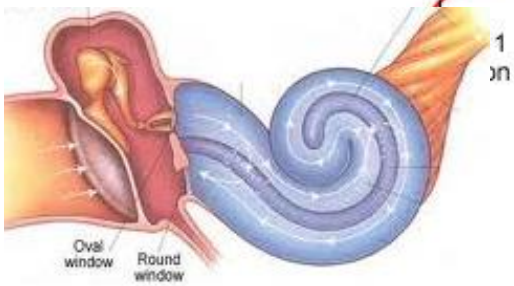


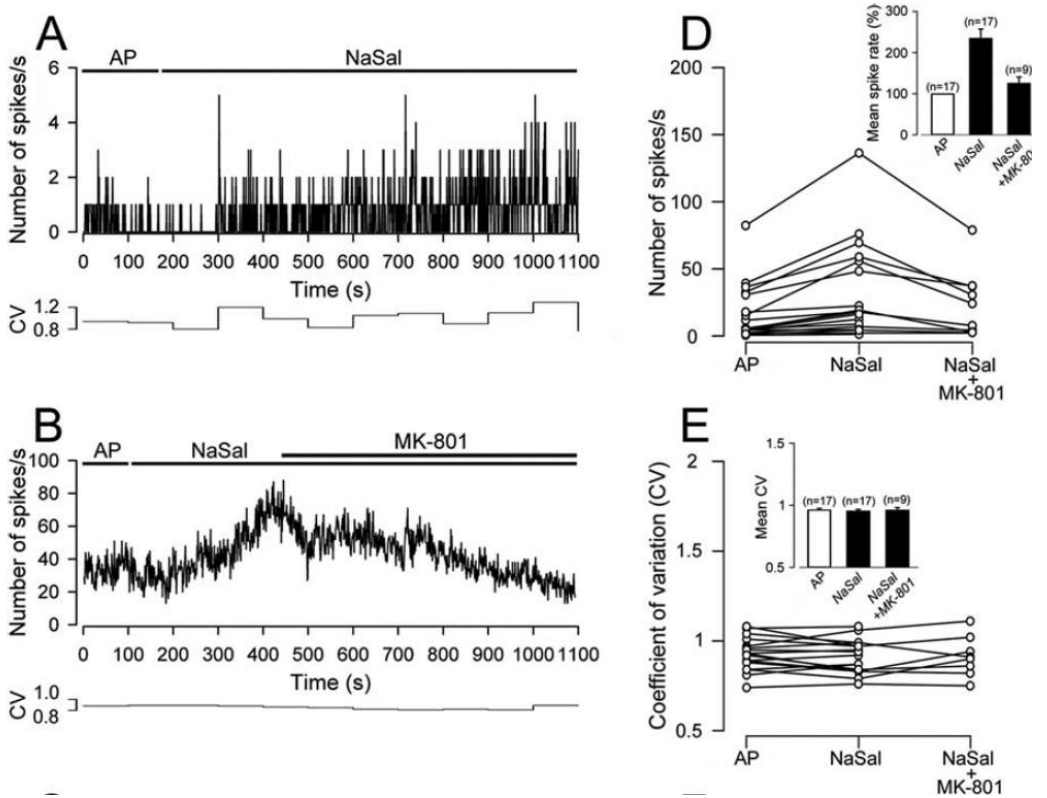


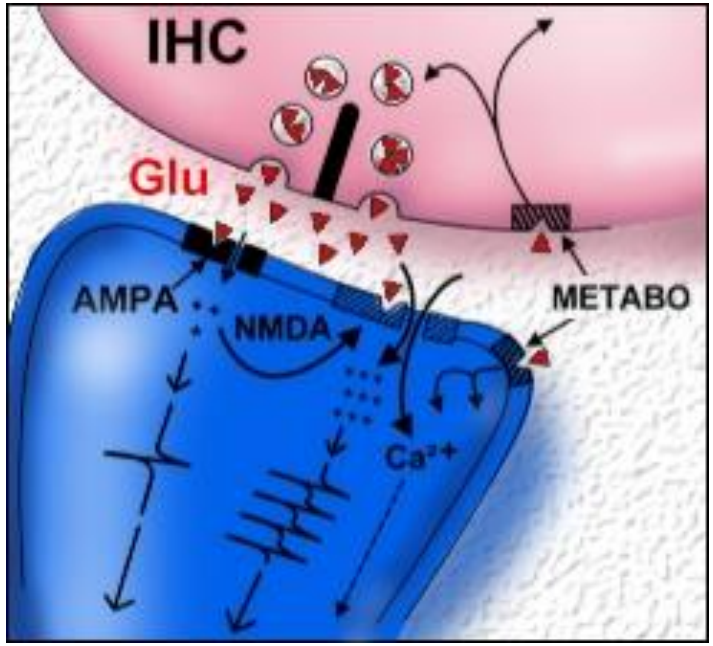




Cochlear tinnitus

- Salicylate: activation of NMDA receptors





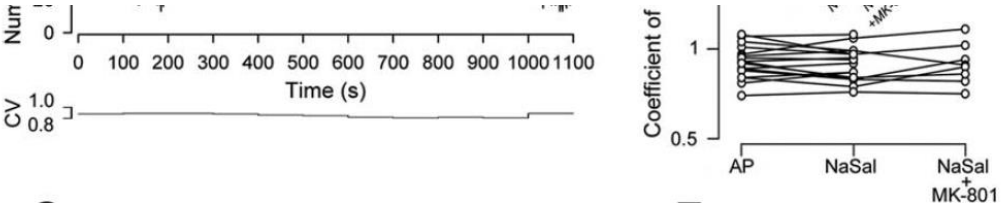
…But see Muller et al., 2003

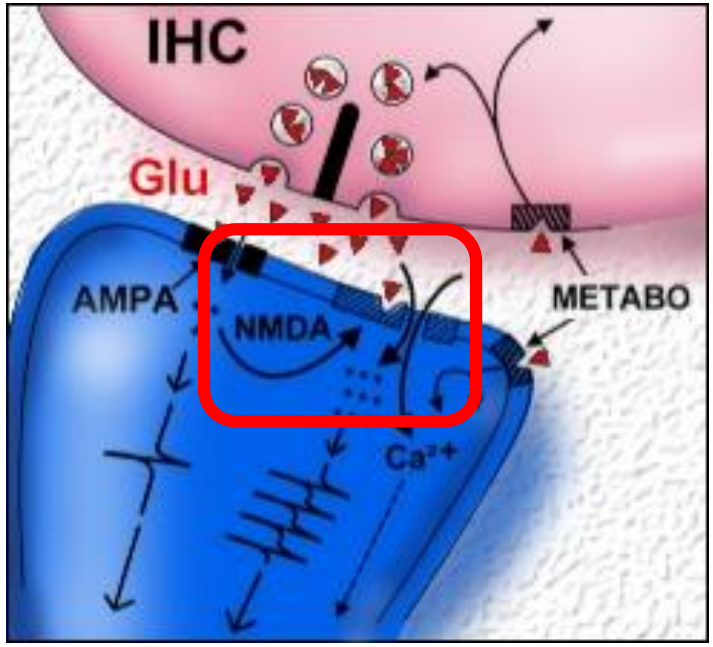
Ruel et al., 2008

Cochlear tinnitus

- Salicylate: activation of NMDA receptors

Acouphènes après traumatisme auditif





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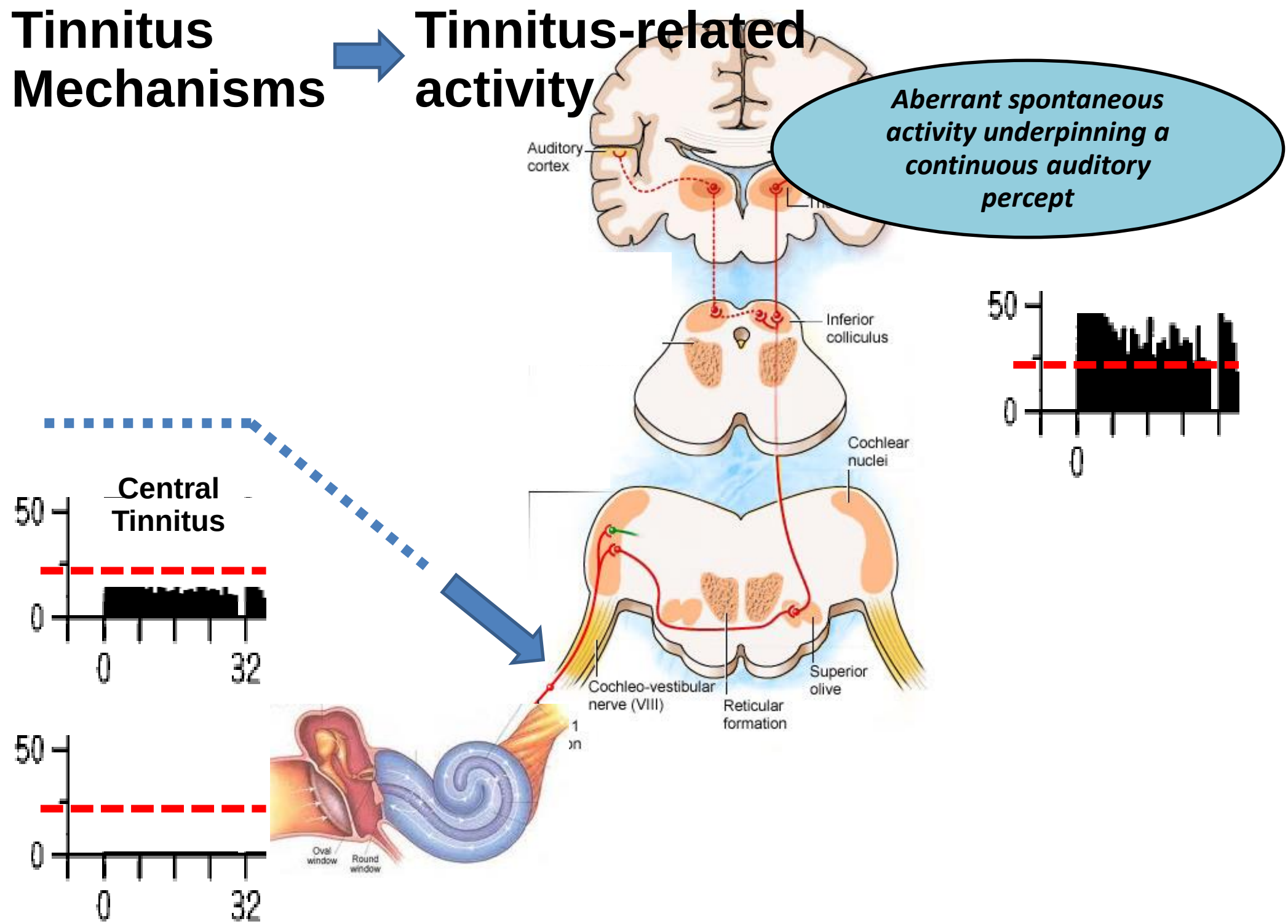
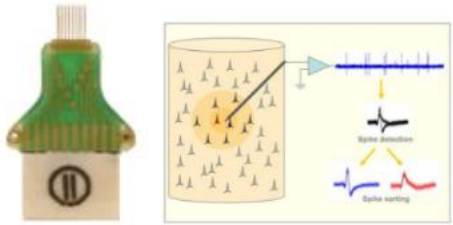
Norena, 2015

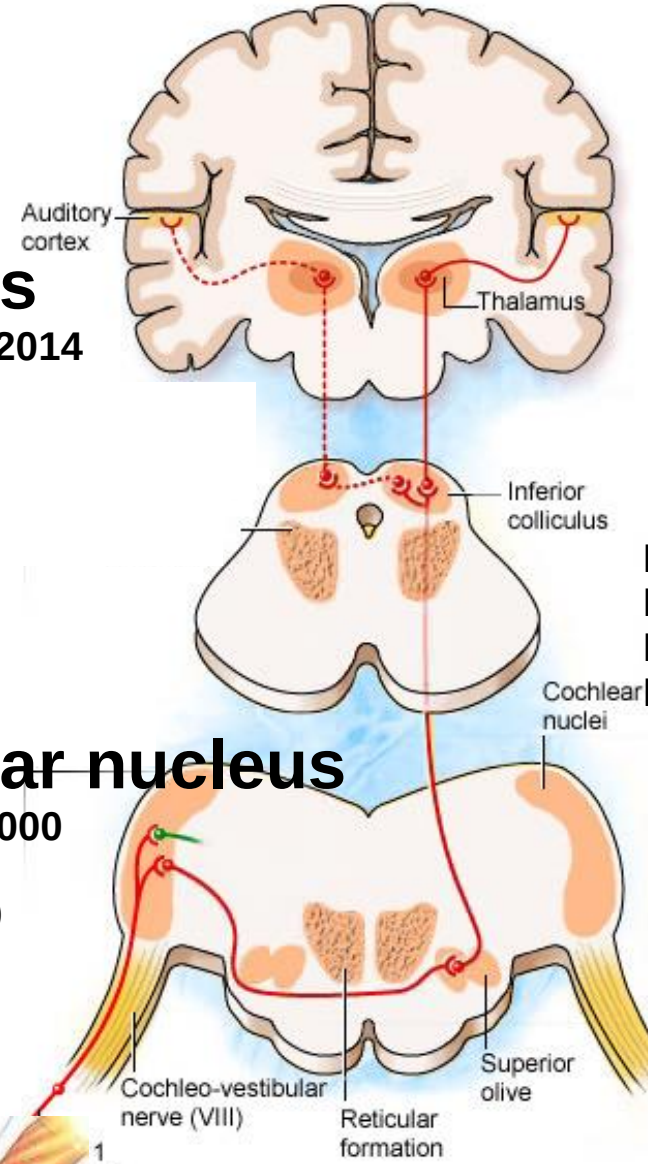
Tinnitus Mechanisms → Tinnitus-related activity





Thalamus

Kalappa et al., 2014

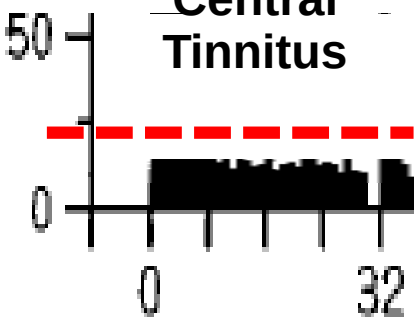


Auditory cortex

Komiya & Eggermont, 2000
Seki & Eggermont, 2003
Norena & Eggermont, 2003, 2005, 2006

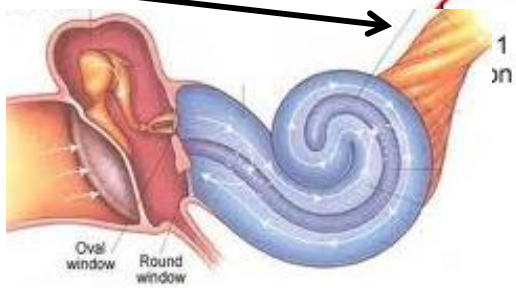
Inferior colliculus

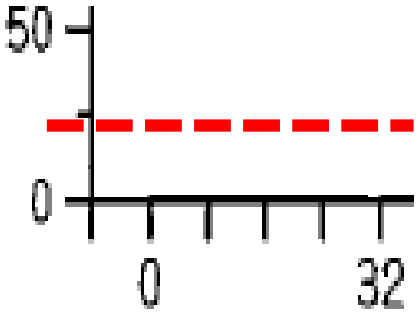
Bauer et al., 2008
Mulders & Robertson, 2009
Ropp et al, 2014
Norena et al., 2015

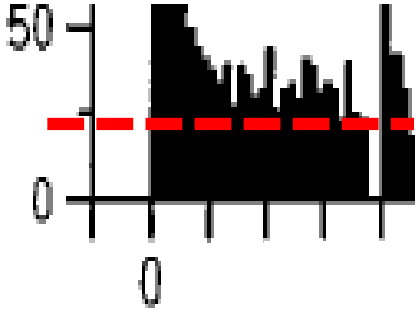


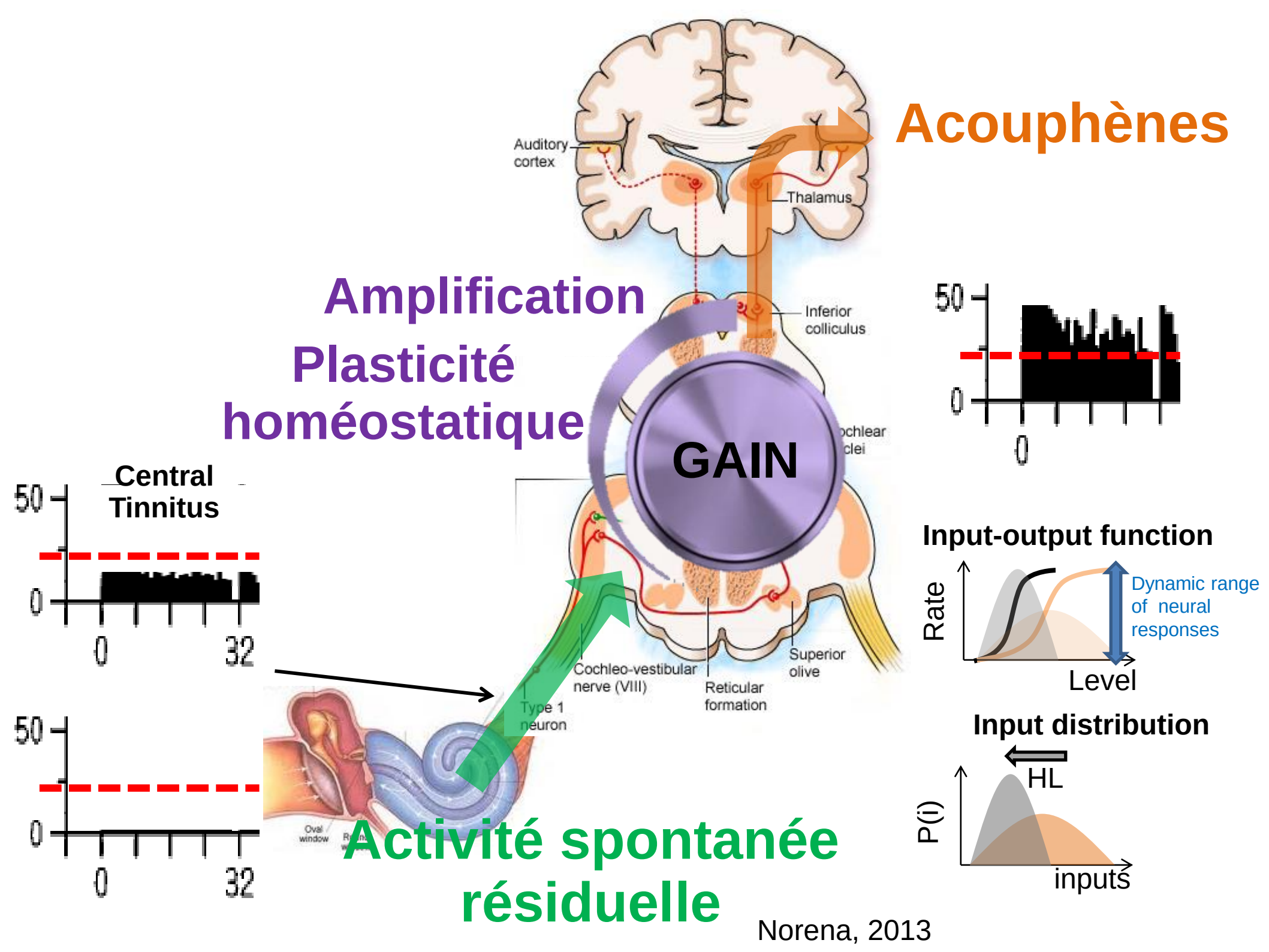
V/D Cochlear nucleus

Kaltenbach et al., 2000
Sumner et al., 2005
Bledsoe et al., 2009
Sumner et al., 2005
Vogler et al., 2011



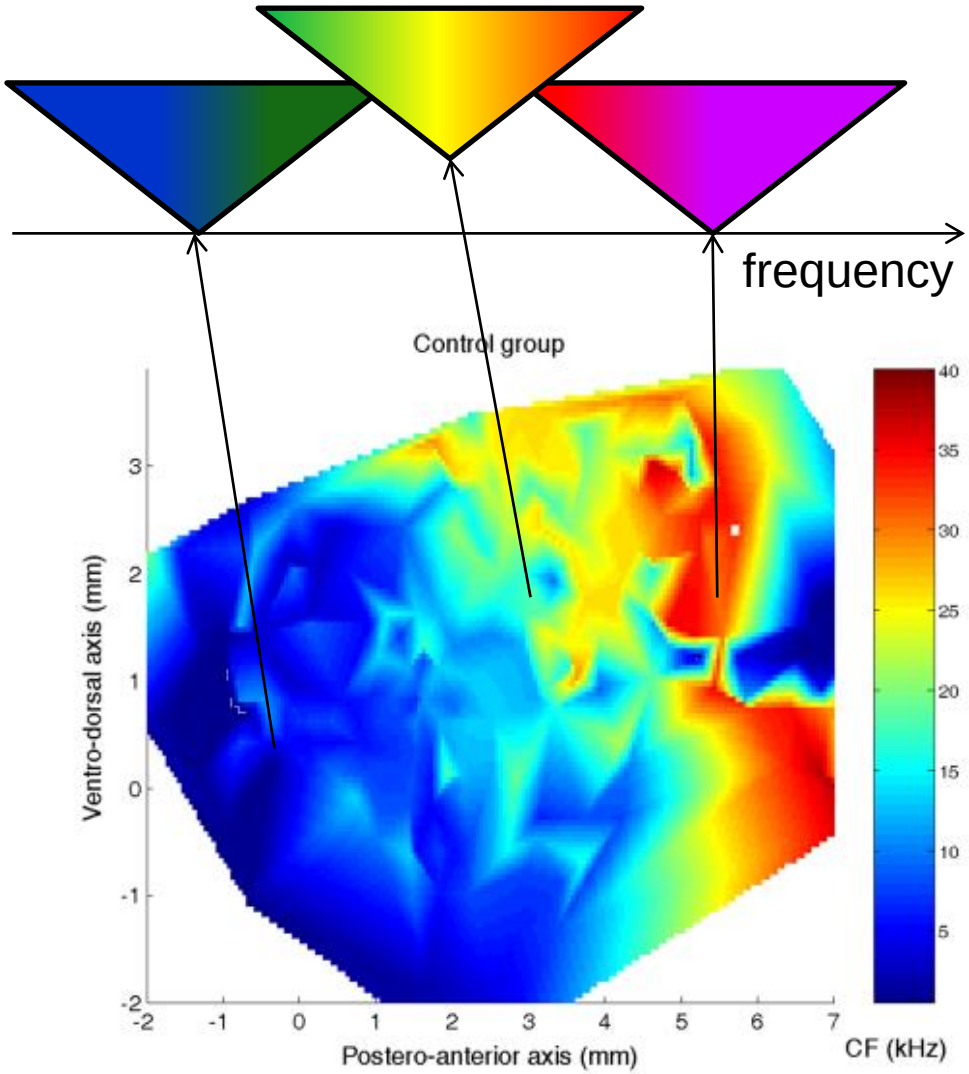




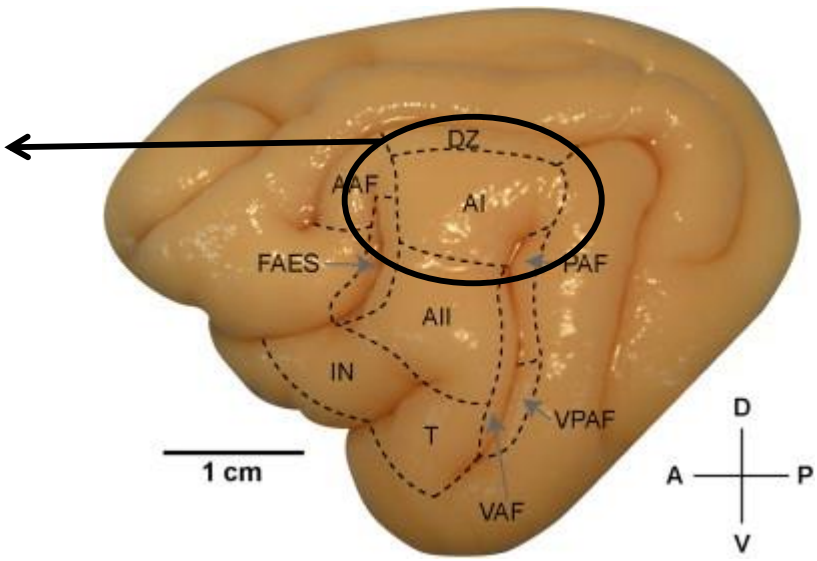

Acouphènes
Auditory cortex
Thalamus
Inferior colliculus
Amplification
Plasticité homéostatique
GAIN
Central Tinnitus
50
0
0
32
Cochleo-vestibular nerve (VIII)
Reticular formation
Superior olive
Type 1 neuron
Oval window
Input-output function
Rate
Level
Dynamic range of neural responses
Input distribution
HL
P(i)
inputs
Activité spontanée résiduelle

Norena, 2013

- Reorganization of the cortical tonotopic map

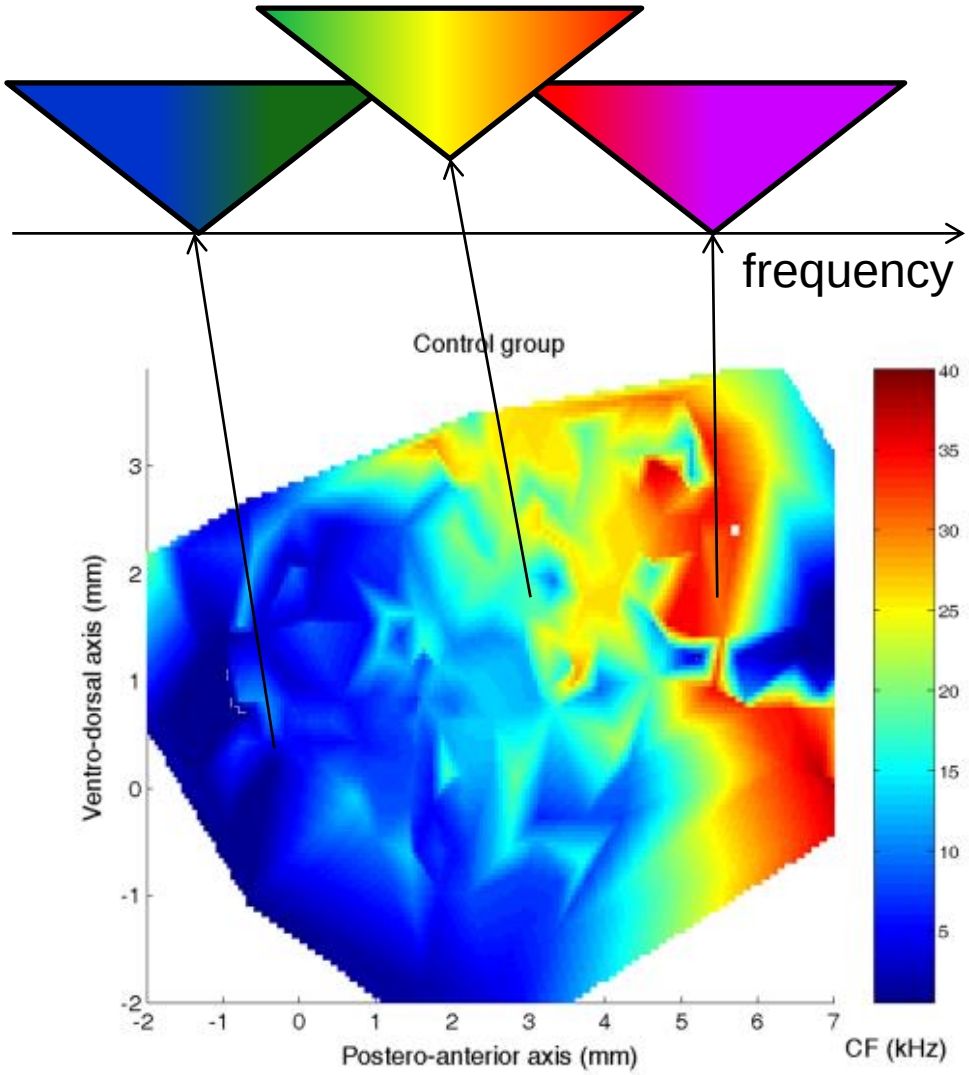


Normal



Norena and Eggermont, 2005

- Reorganization of the cortical tonotopic map



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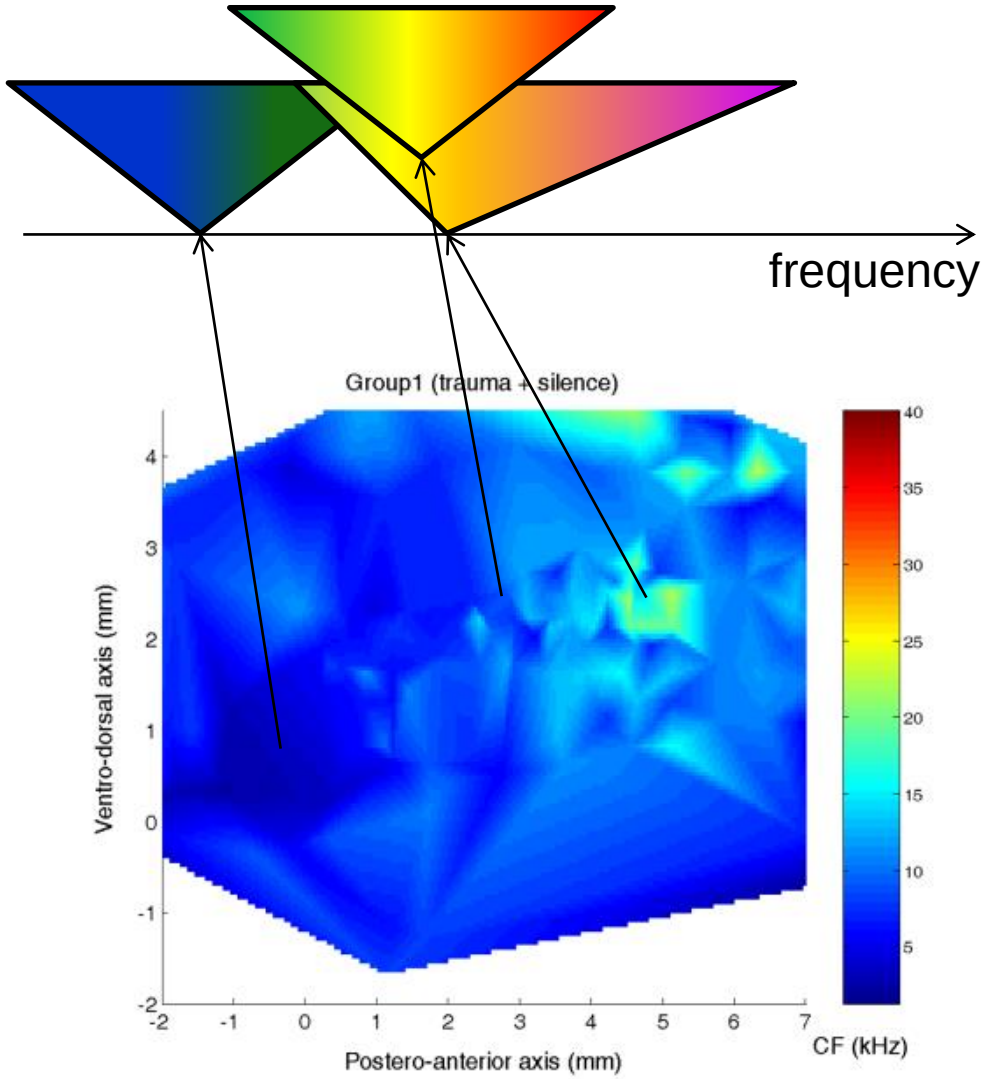
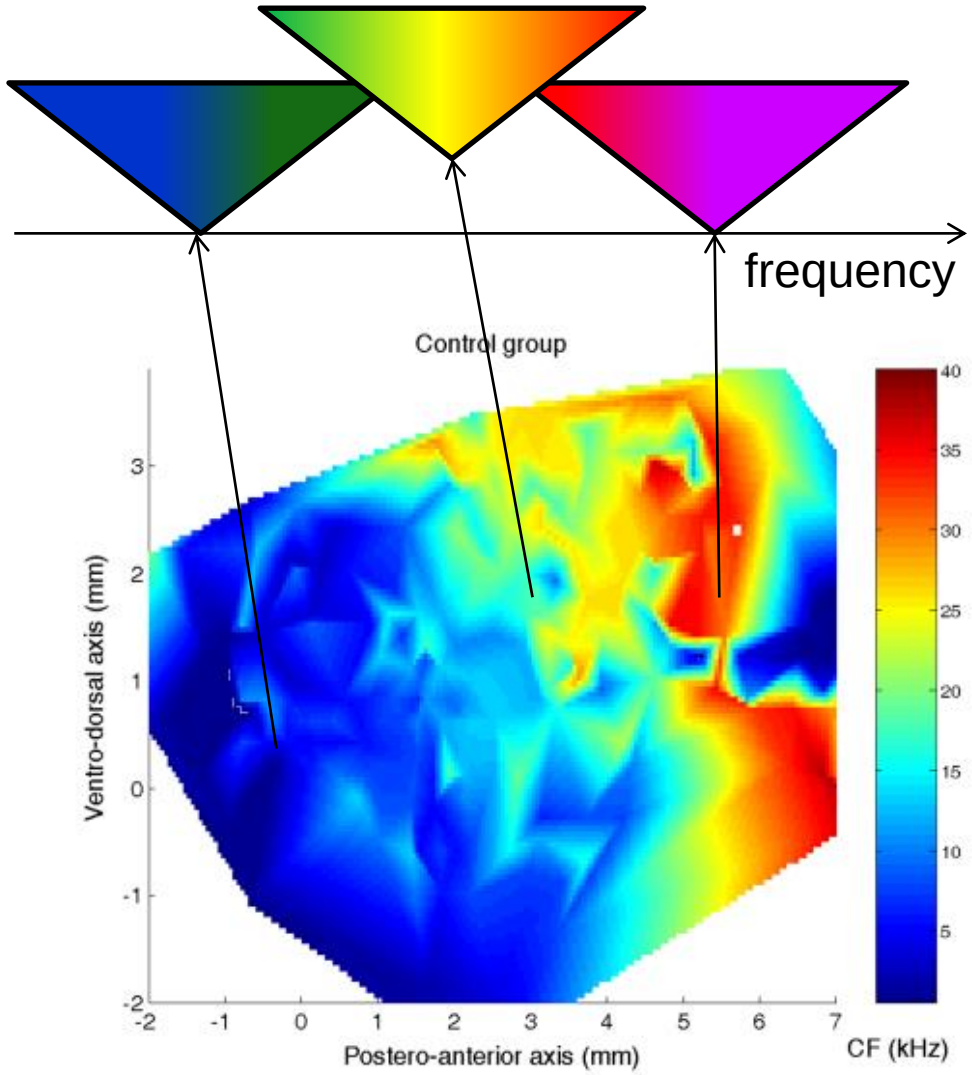


High-frequency loss

Norena and Eggermont, 2005, 2006

- Reorganization of the cortical tonotopic map



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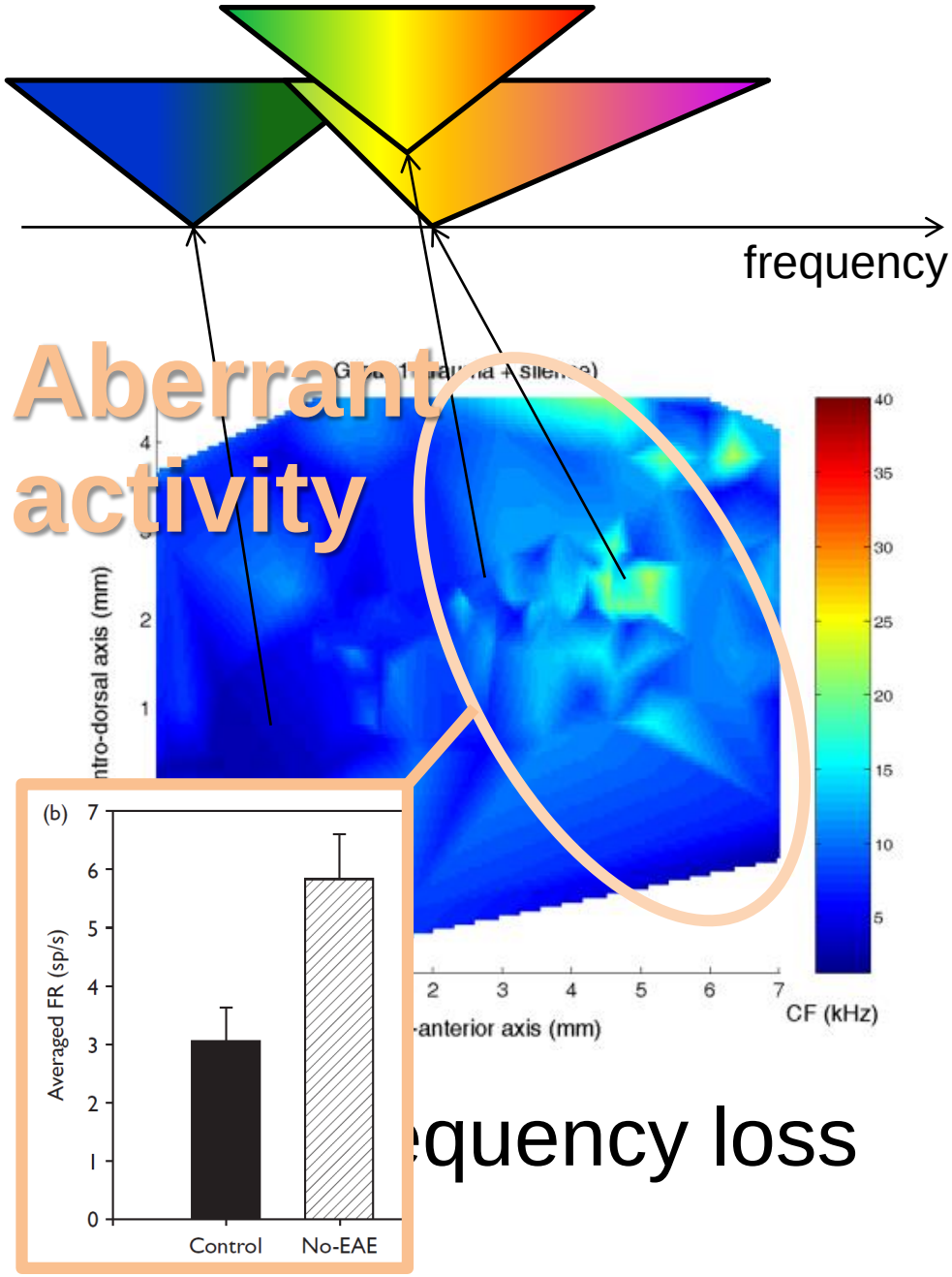
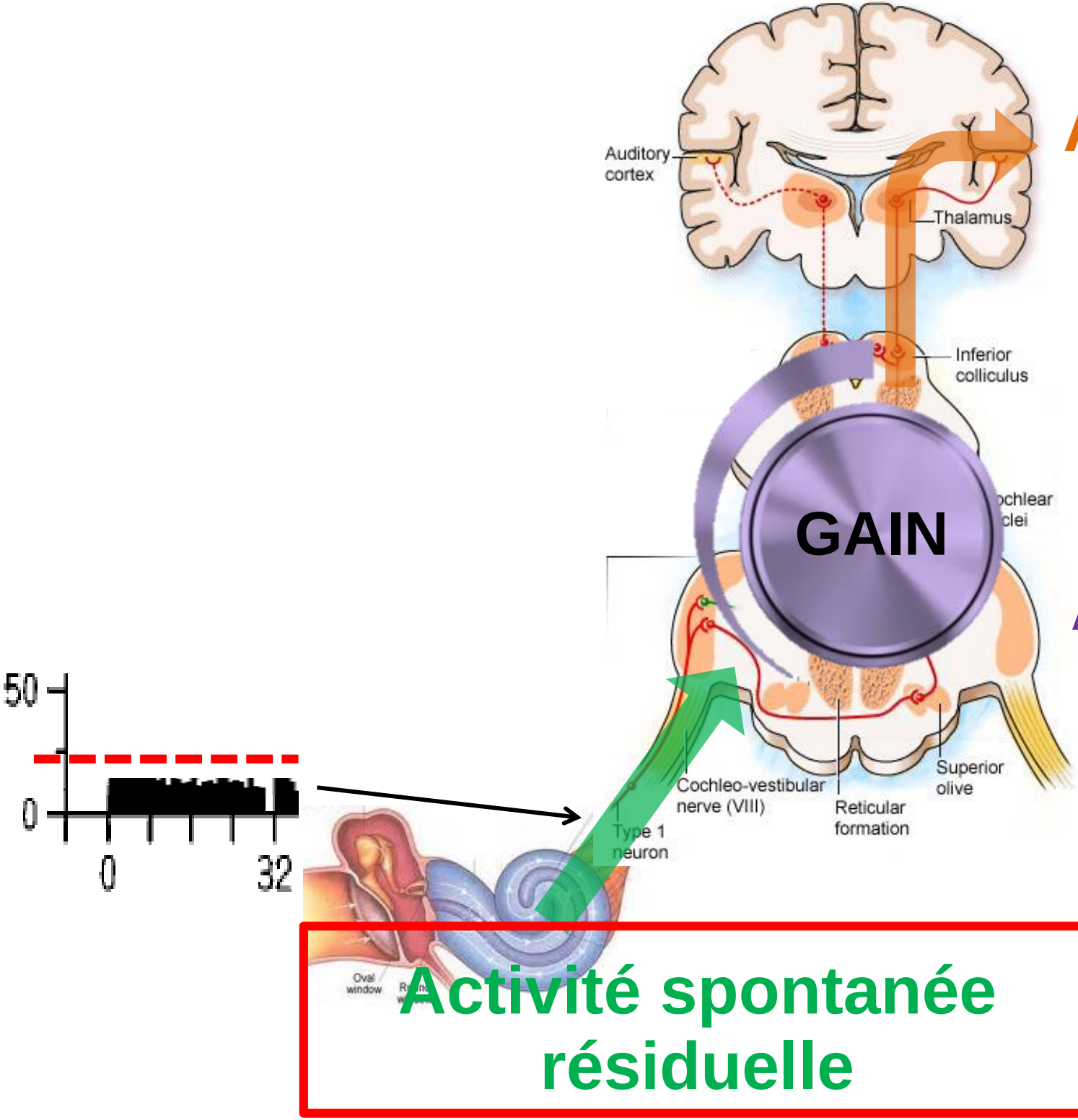


equency loss

Norena and Eggermont, 2005, 2006



Acouphènes

Amplification

Activité spontanée résiduelle

Digression 2

Acouphènes (dans le silence) chez sujets sans acouphènes

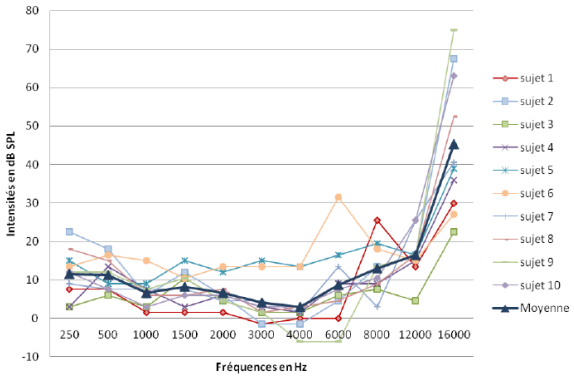
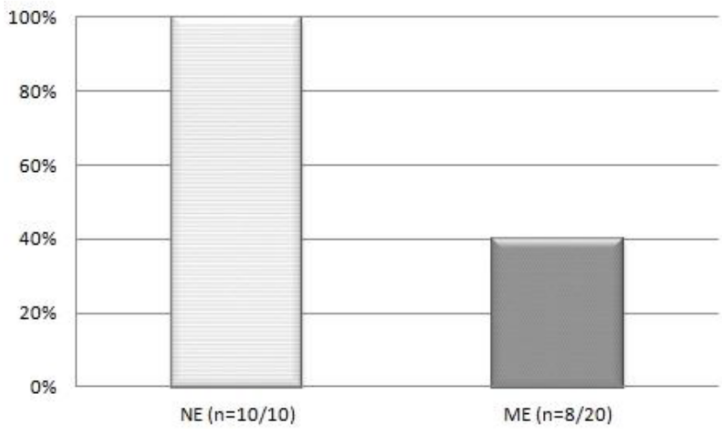


Figure 3 : Audiogramme reprenant l'ensemble des courbes audiométriques des sujets normoentendants (sujet 1 à 10) ainsi que la courbe moyenne du groupe (—▲—).



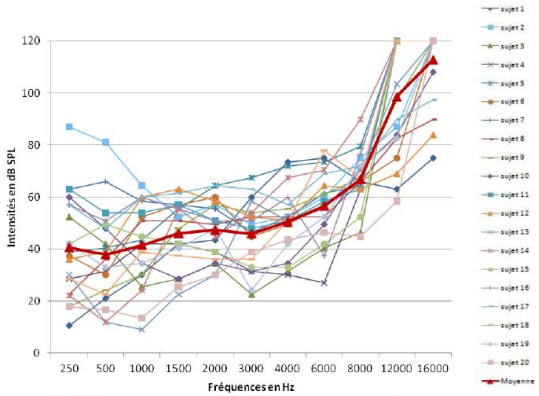
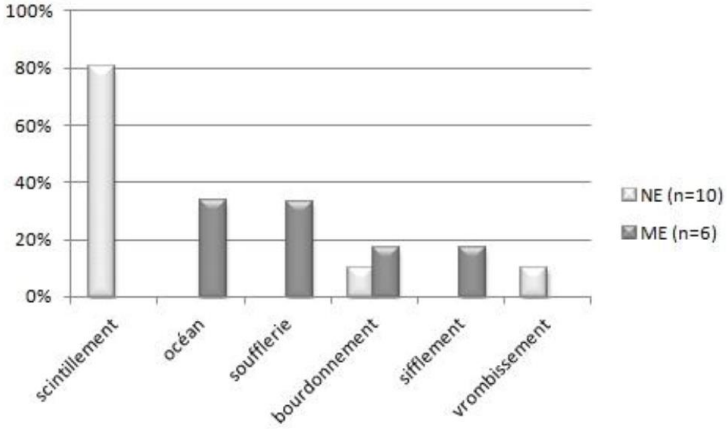
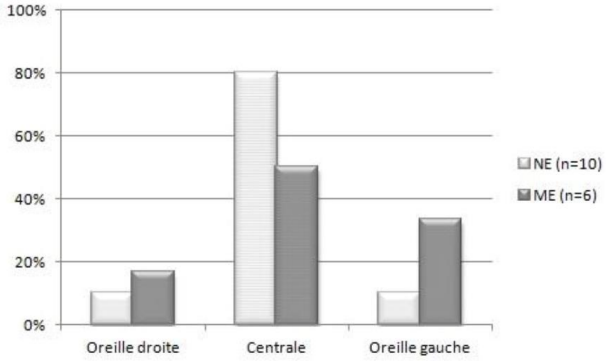
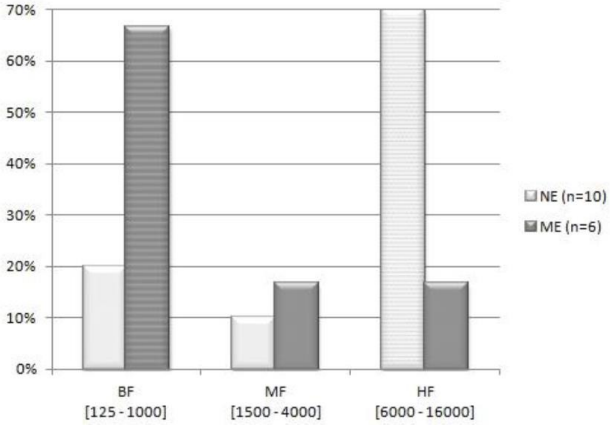


Figure 4 : Audiogramme reprenant l'ensemble des courbes audiométriques des sujets malentendants (sujet 1 à 20) ainsi que la courbe moyenne (—▲—).

Figure 5 : Comparaison du pourcentage de sujets ayant perçu une sensation auditive en chambre insonorisée entre le groupe des normoentendants (NE) et des malentendants (ME).

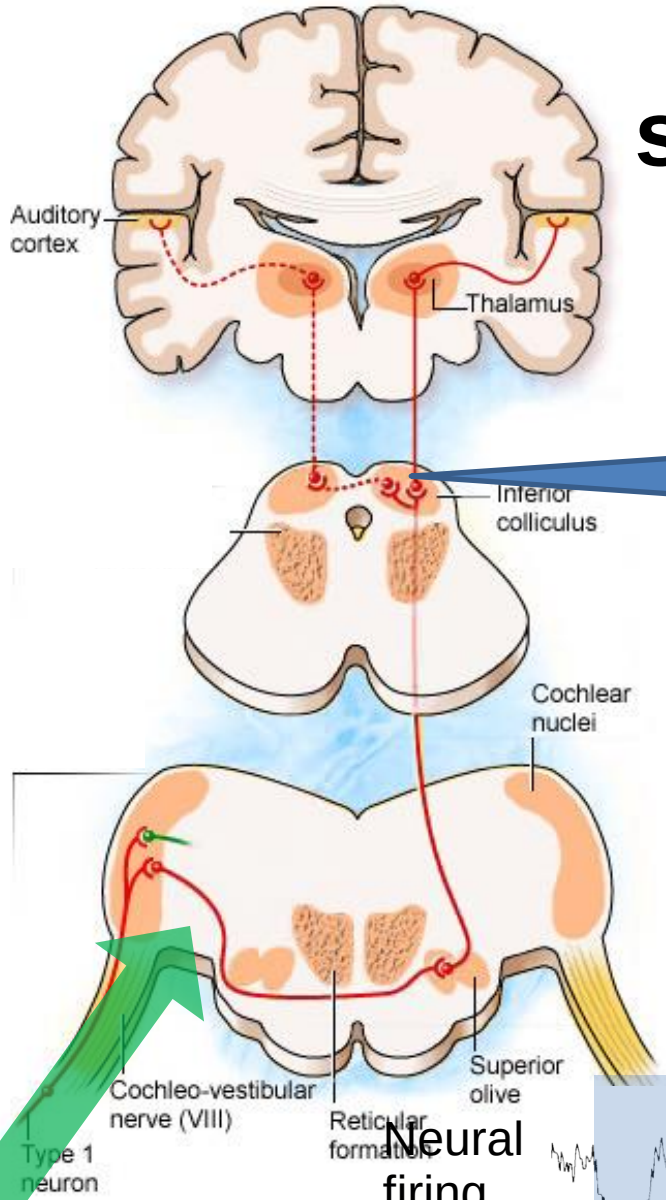






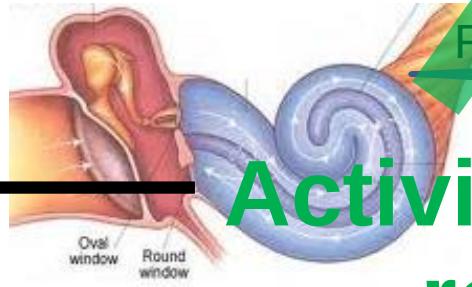
Tinnitus suppression

Cazals et al., 1978
Portman et al., 1979



SA in central nucleus of IC?
After trauma

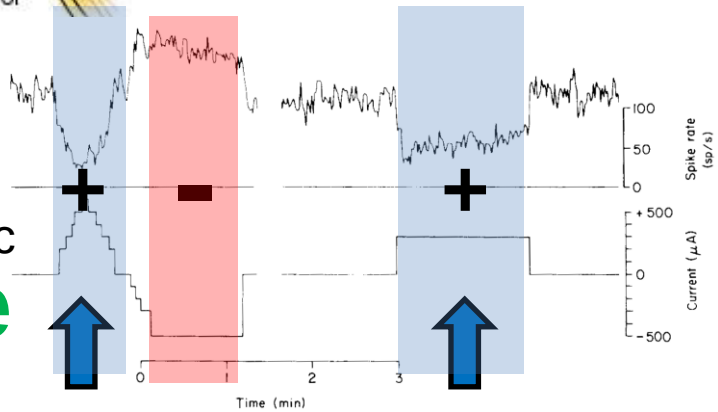
- Electric stimulation



Recording SUA in cochlear nerve

Neural firing

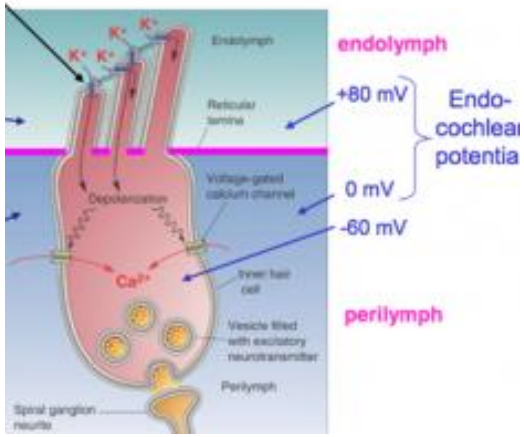
Electric stim

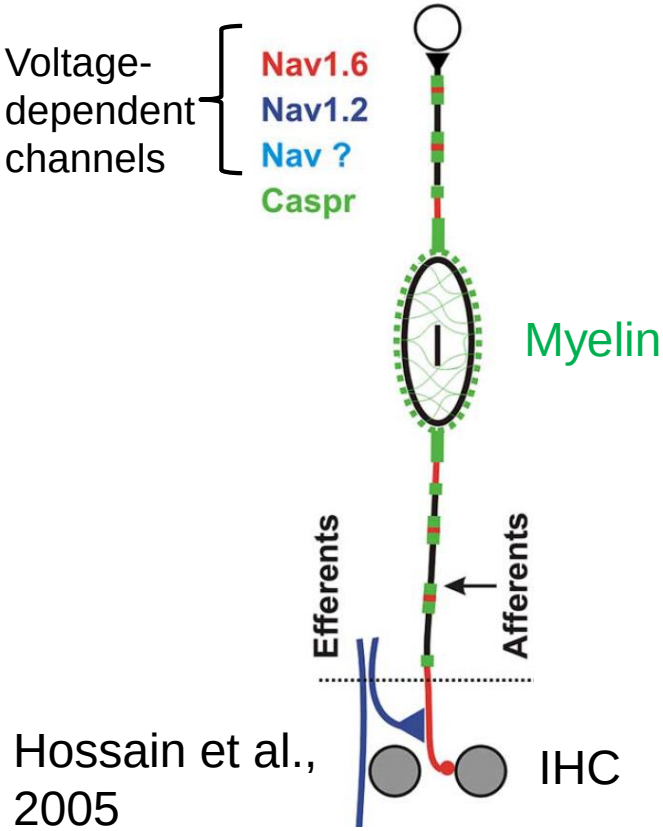


Evans & Borerwe, 1982

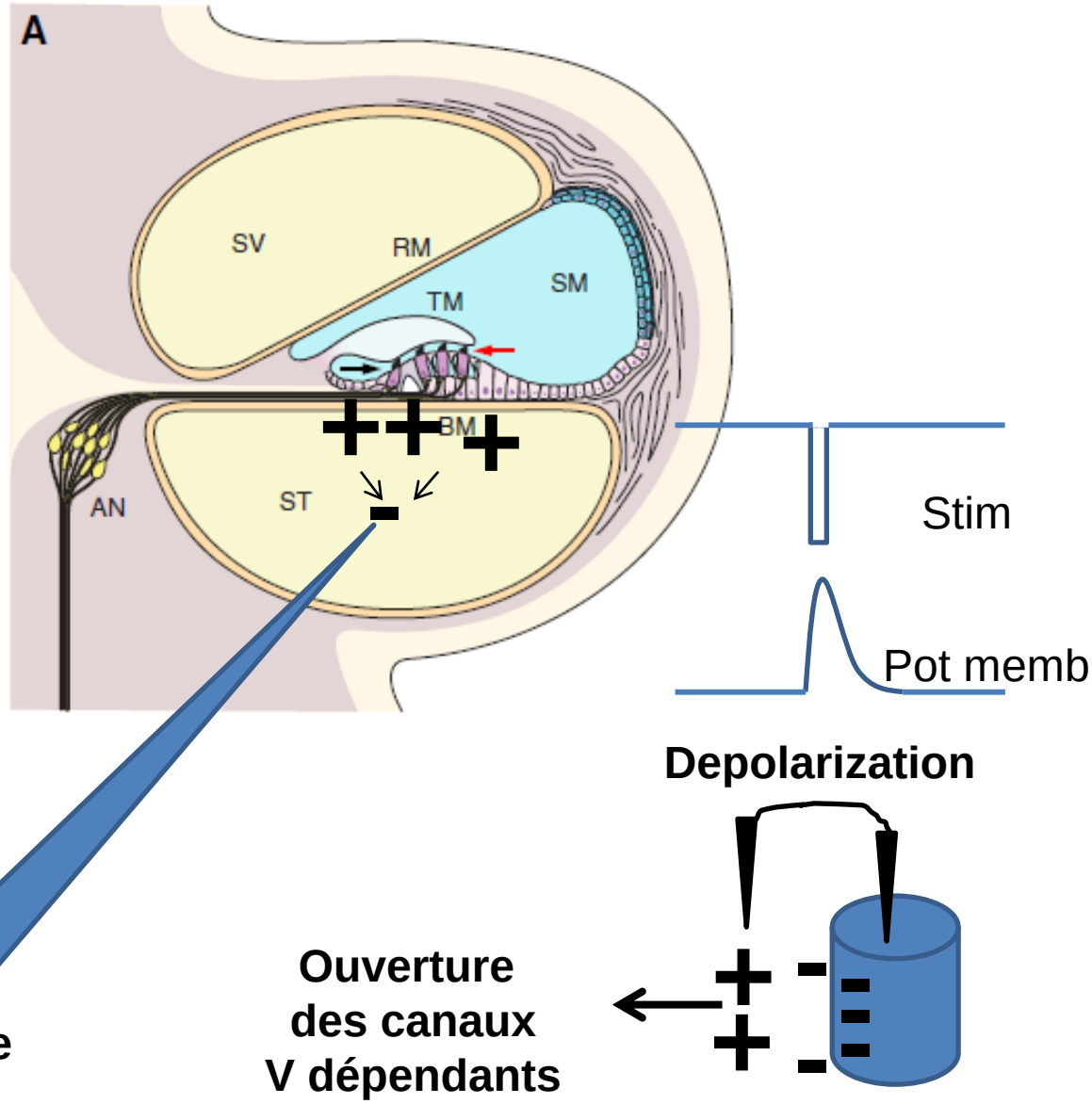
Activité spontanée résiduelle

Stimulation électrique

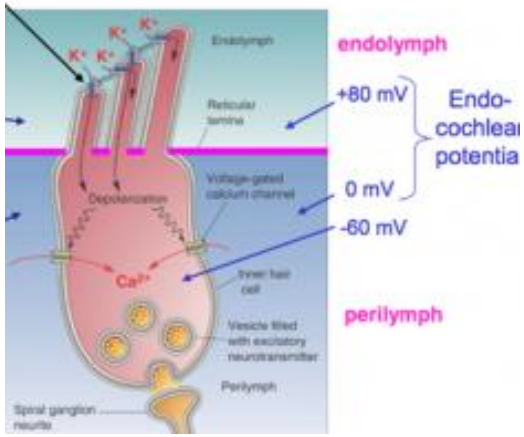


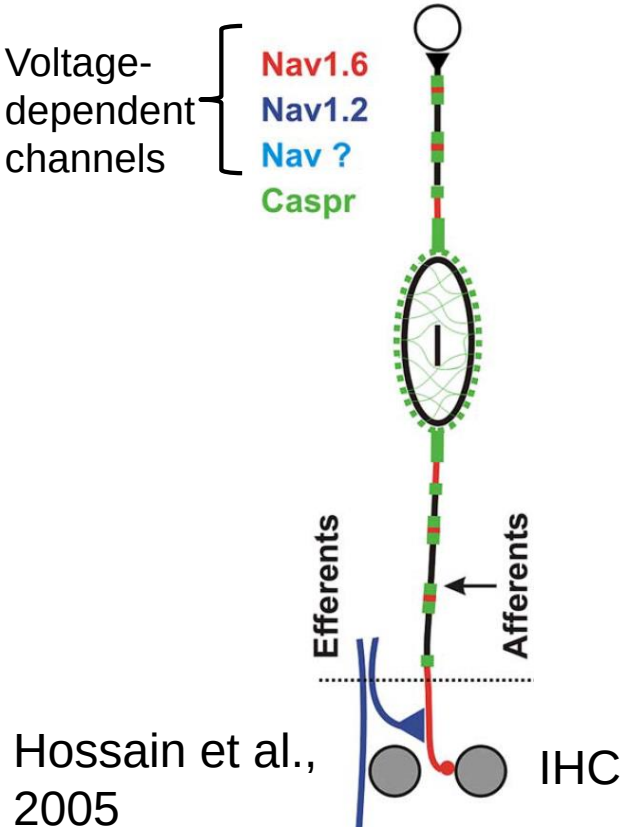


Hossain et al., 2005

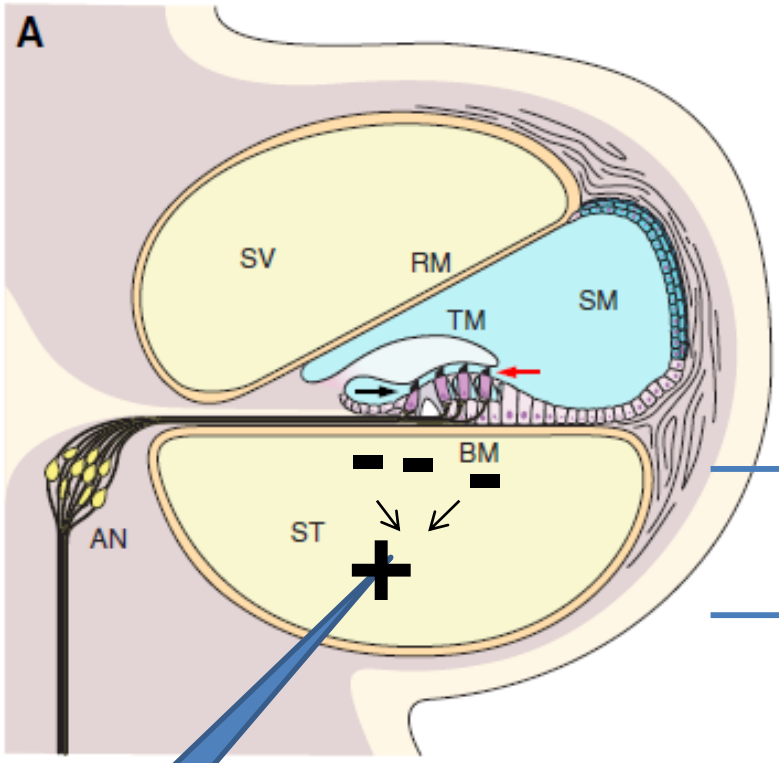


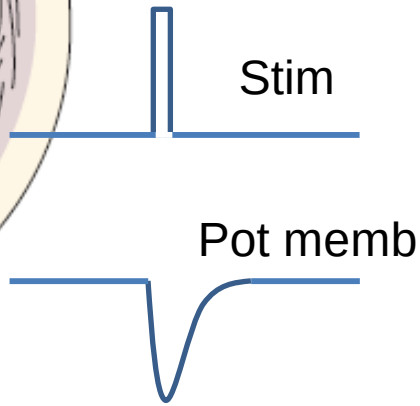
Stimulation électrique





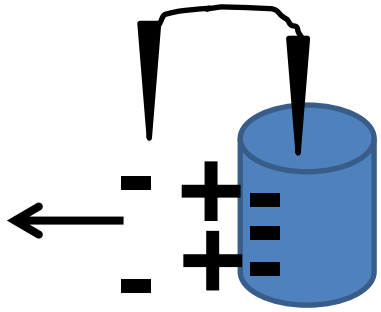
Hossain et al., 2005





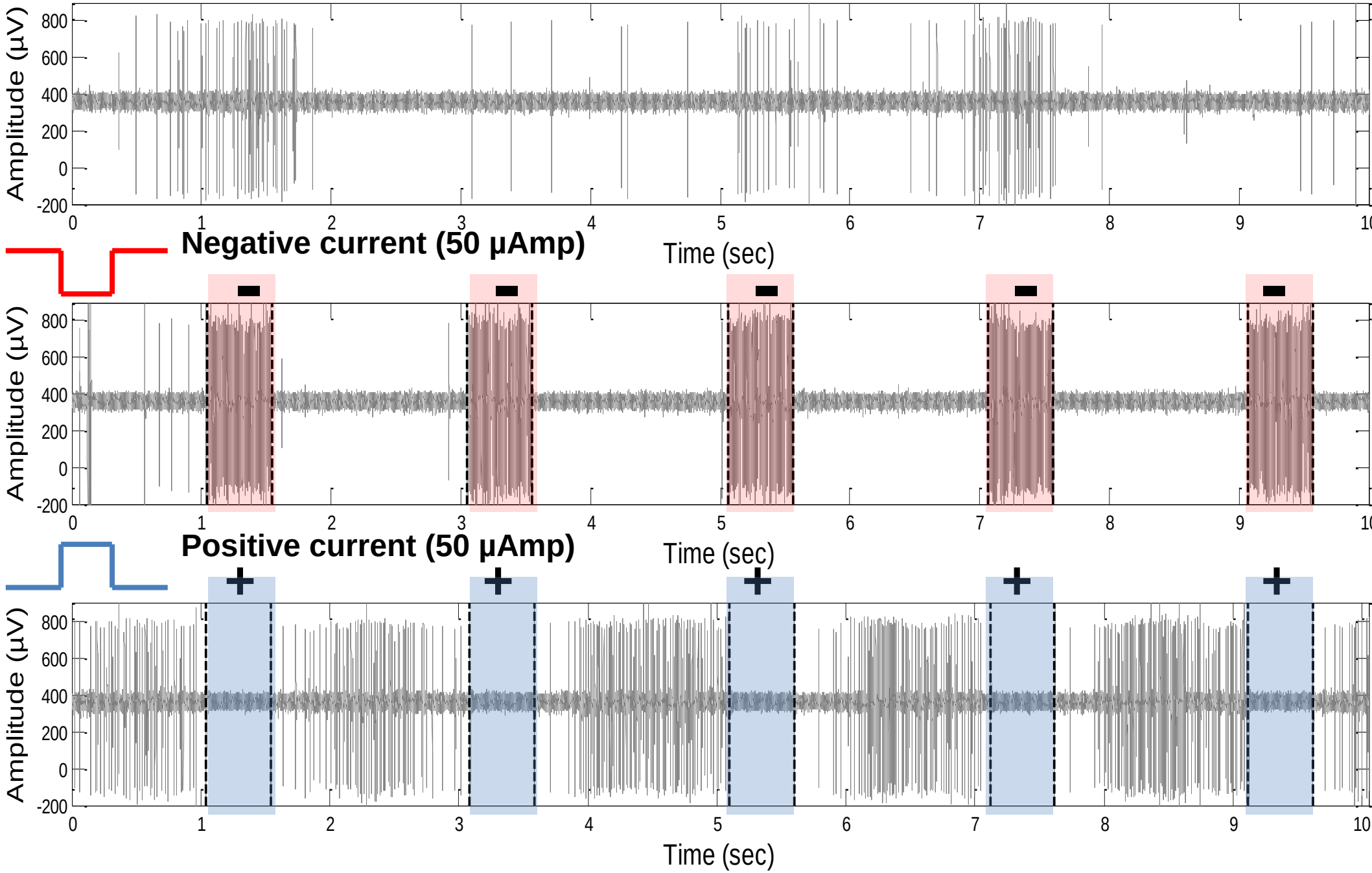
Anode

Hyperpolarization

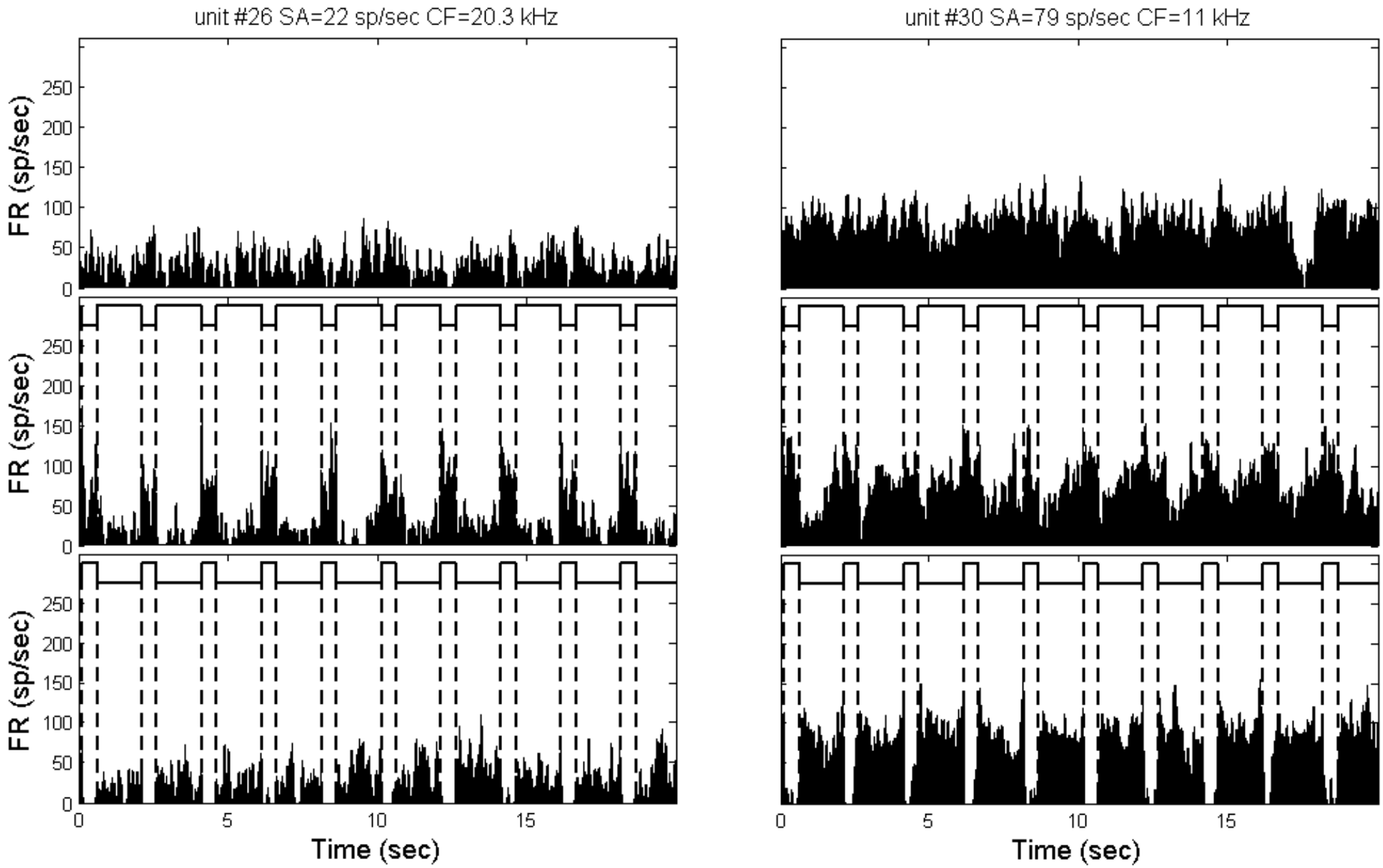


Fermeture des canaux V dépendants

Spontaneous activity (after trauma) CF=21.7 kHz

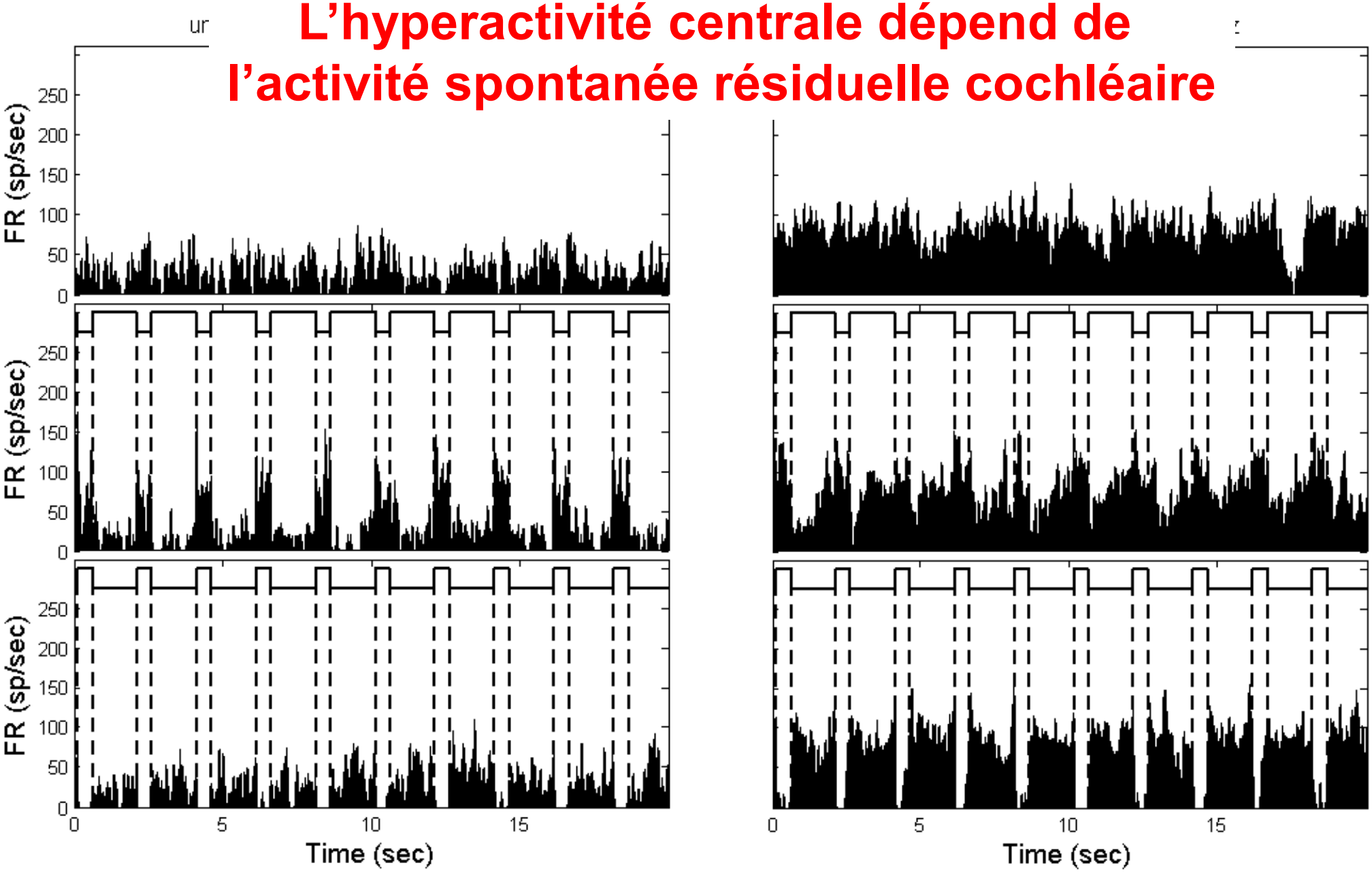


Norena et al., 2015

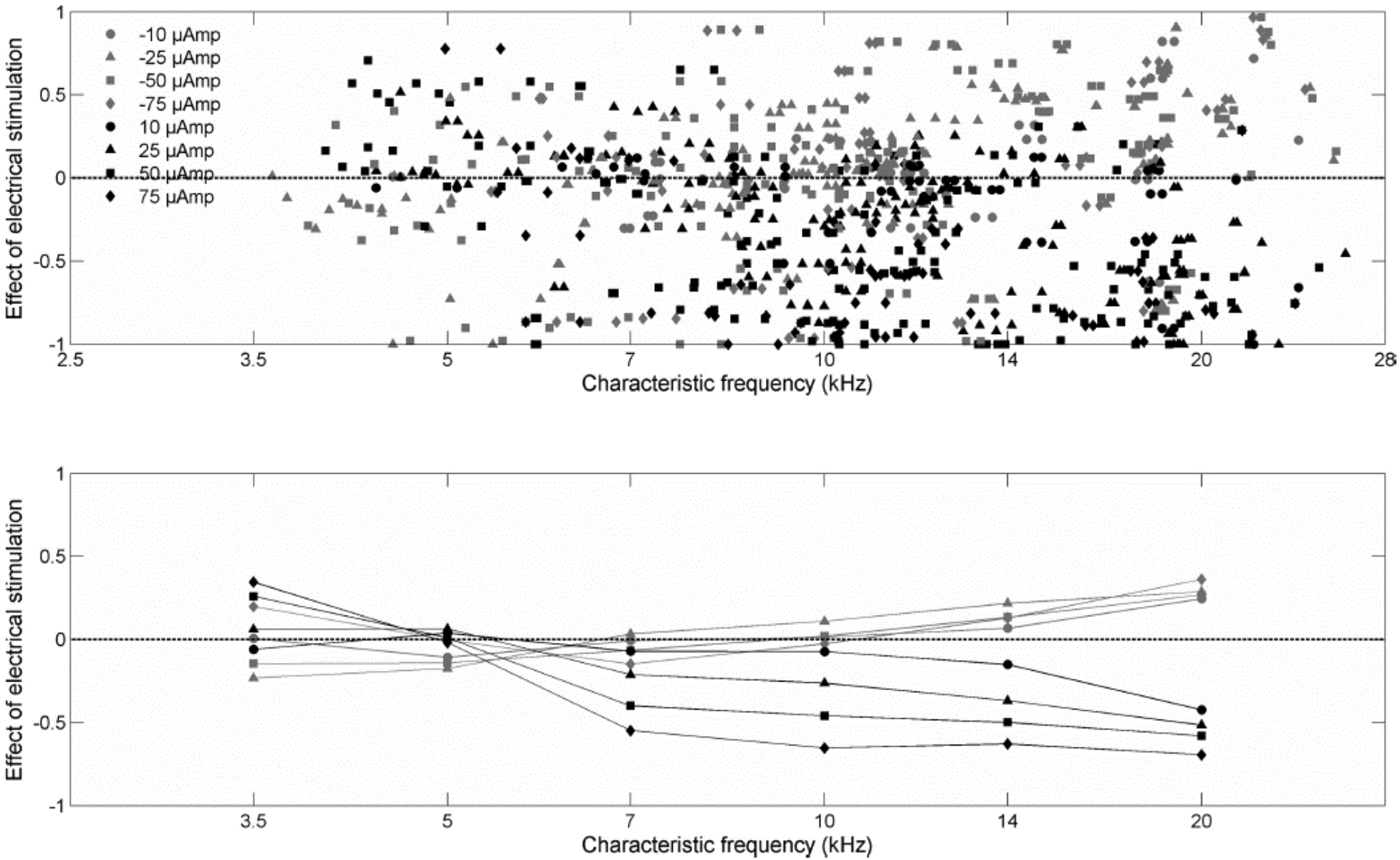


Norena et al., 2015

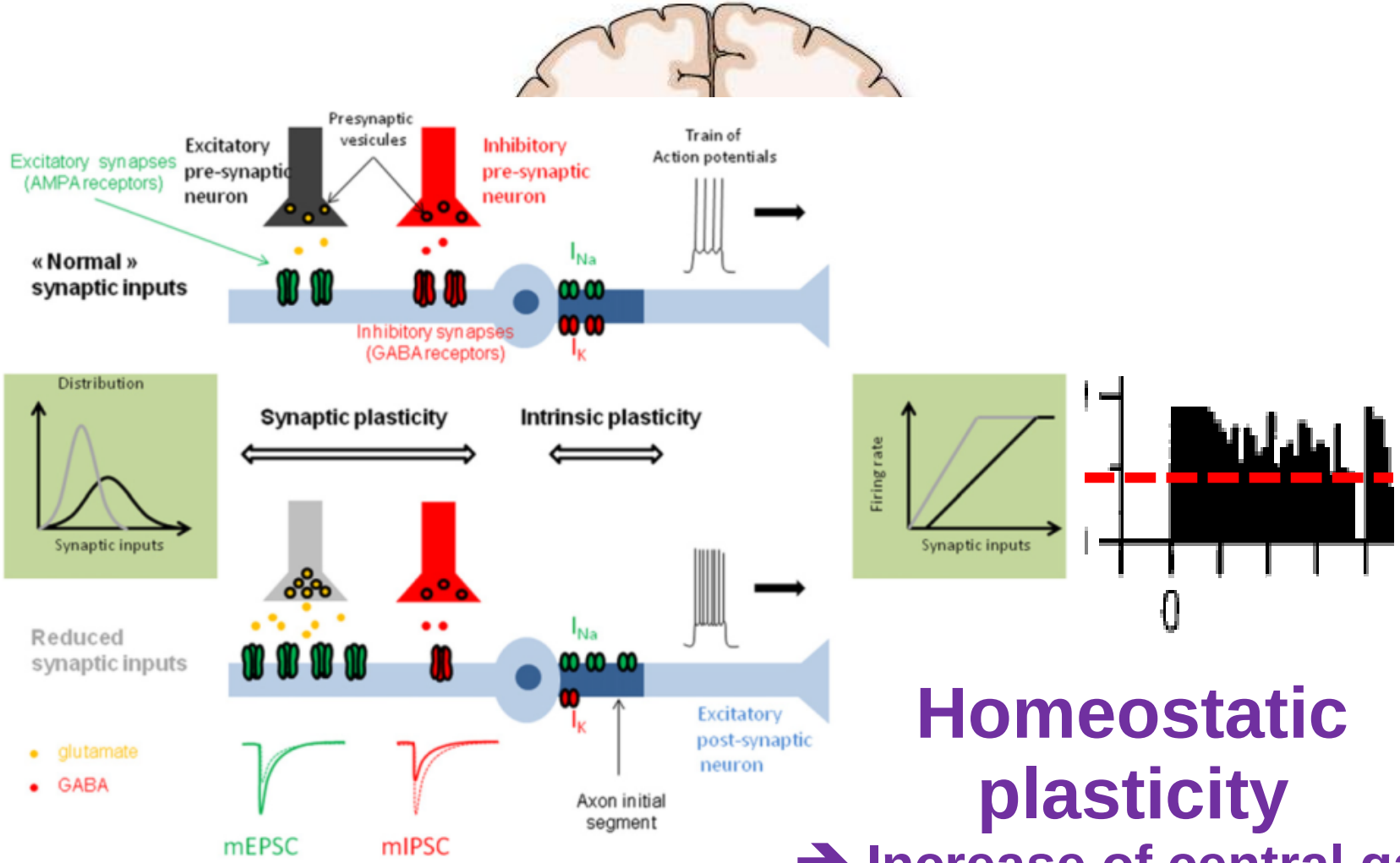
L'hyperactivité centrale dépend de l'activité spontanée résiduelle cochléaire

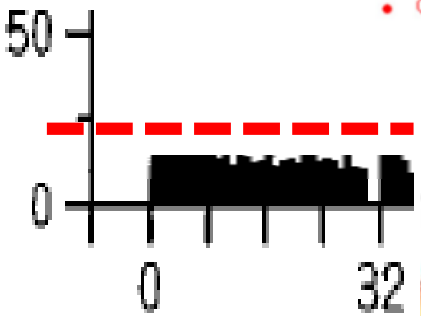


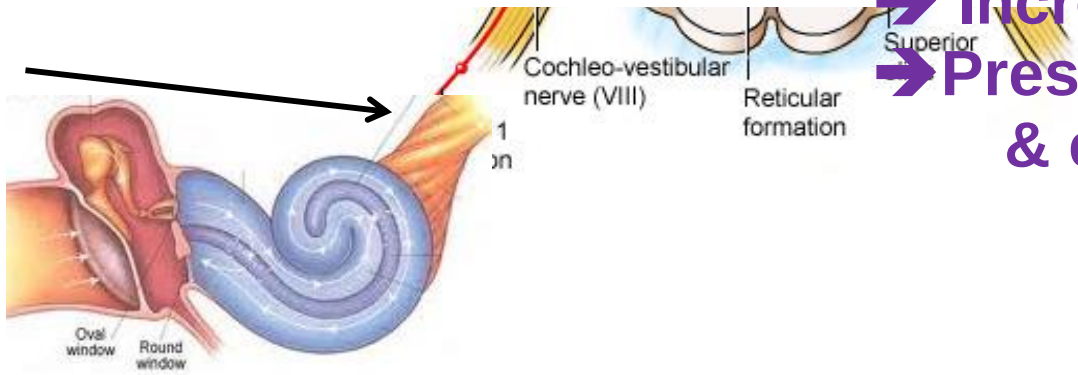
Norena et al., 2015


-10 µAmp
-25 µAmp
-50 µAmp
-75 µAmp
10 µAmp
25 µAmp
50 µAmp
75 µAmp
Effect of electrical stimulation
Characteristic frequency (kHz)
1
0.5
0
-0.5
-1
2.5
3.5
5
7
10
14
20
28

Mécanismes de la plasticité centrale







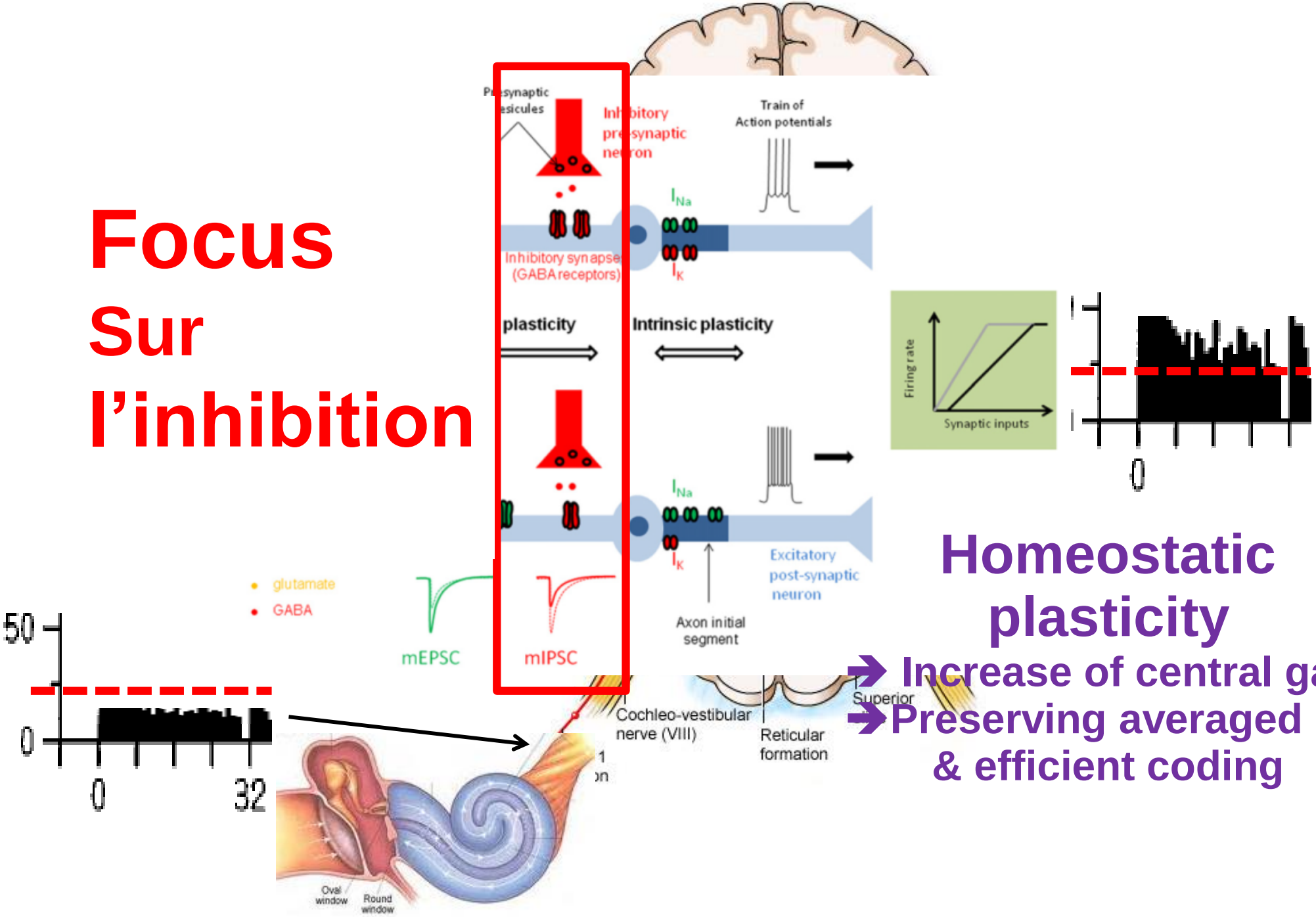
Homeostatic plasticity

➔ Increase of central gain

➔ Preserving averaged SA & efficient coding

Norena and Farley, 2013

Focus Sur l'inhibition



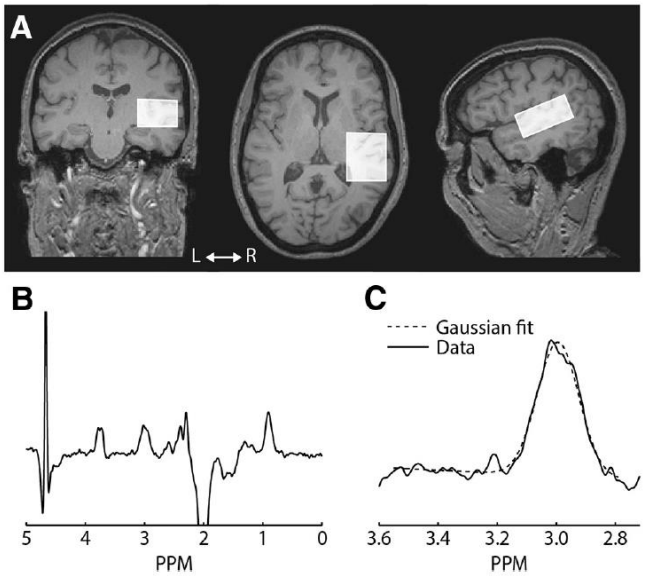
Homeostatic plasticity

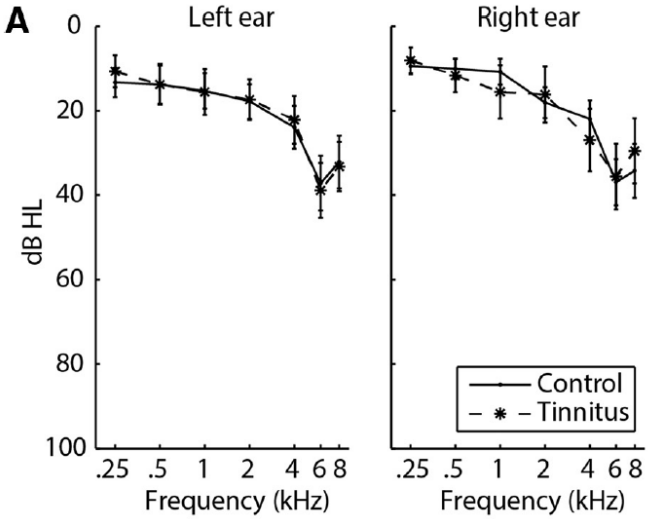
- ➔ Increase of central gain
- ➔ Preserving averaged SA & efficient coding

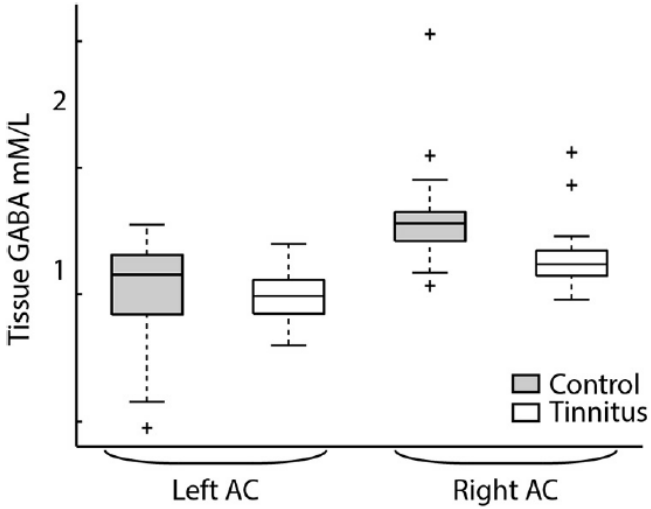
Norena and Farley, 2013

Central inhibition

- GABA concentration in AI (MR spectroscopy, Sedley et al., 2015)



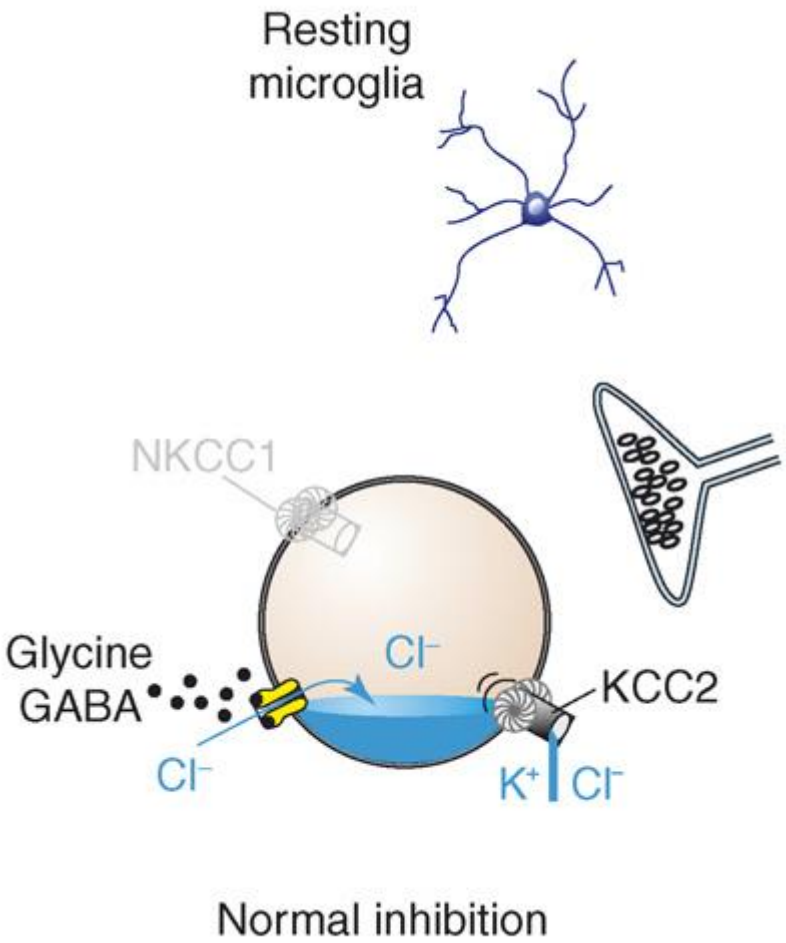




Reduction of GABA = Reduction of inhibition

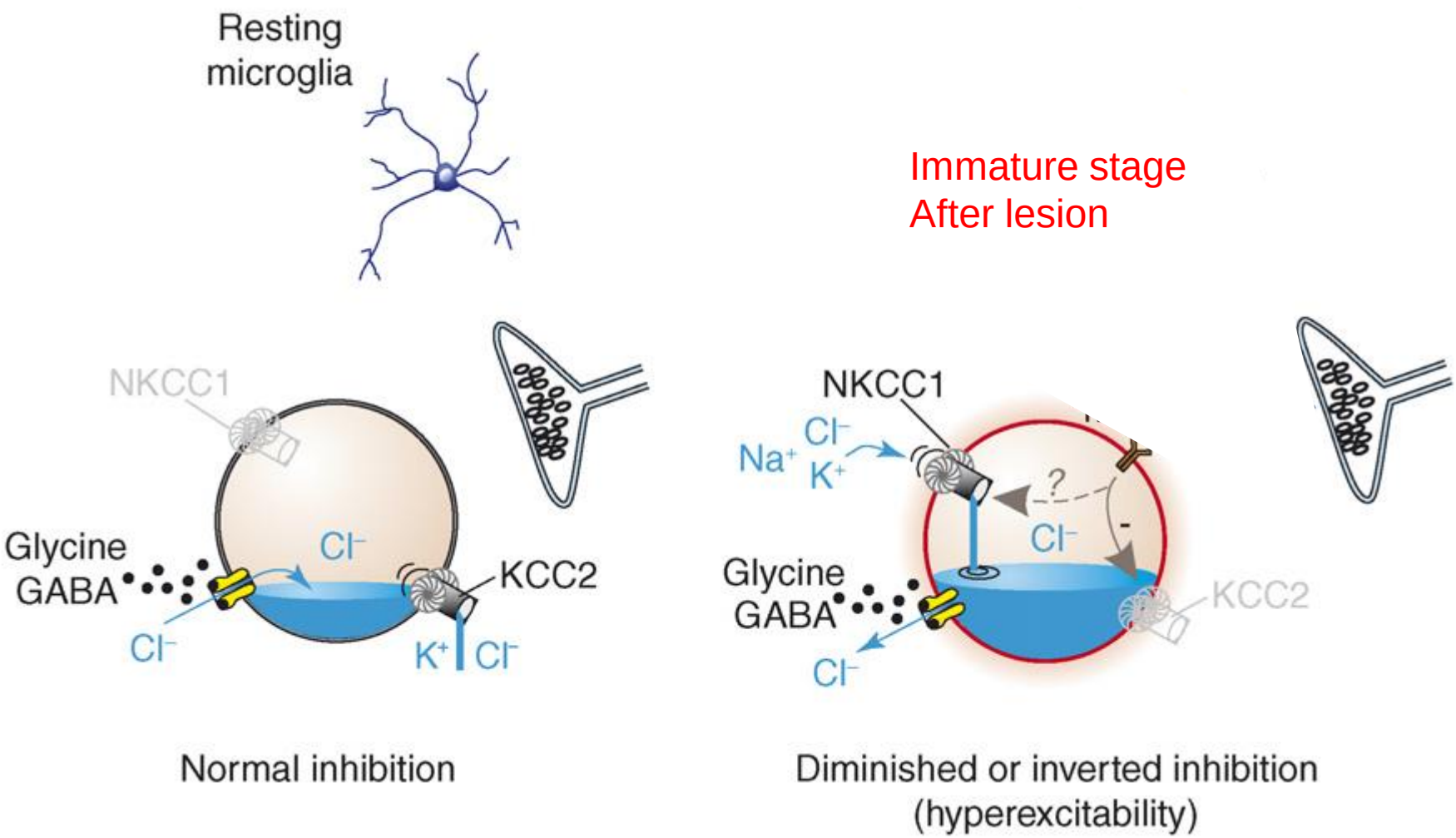
Central inhibition

- GABA and the intracellular concentration of Cl^-



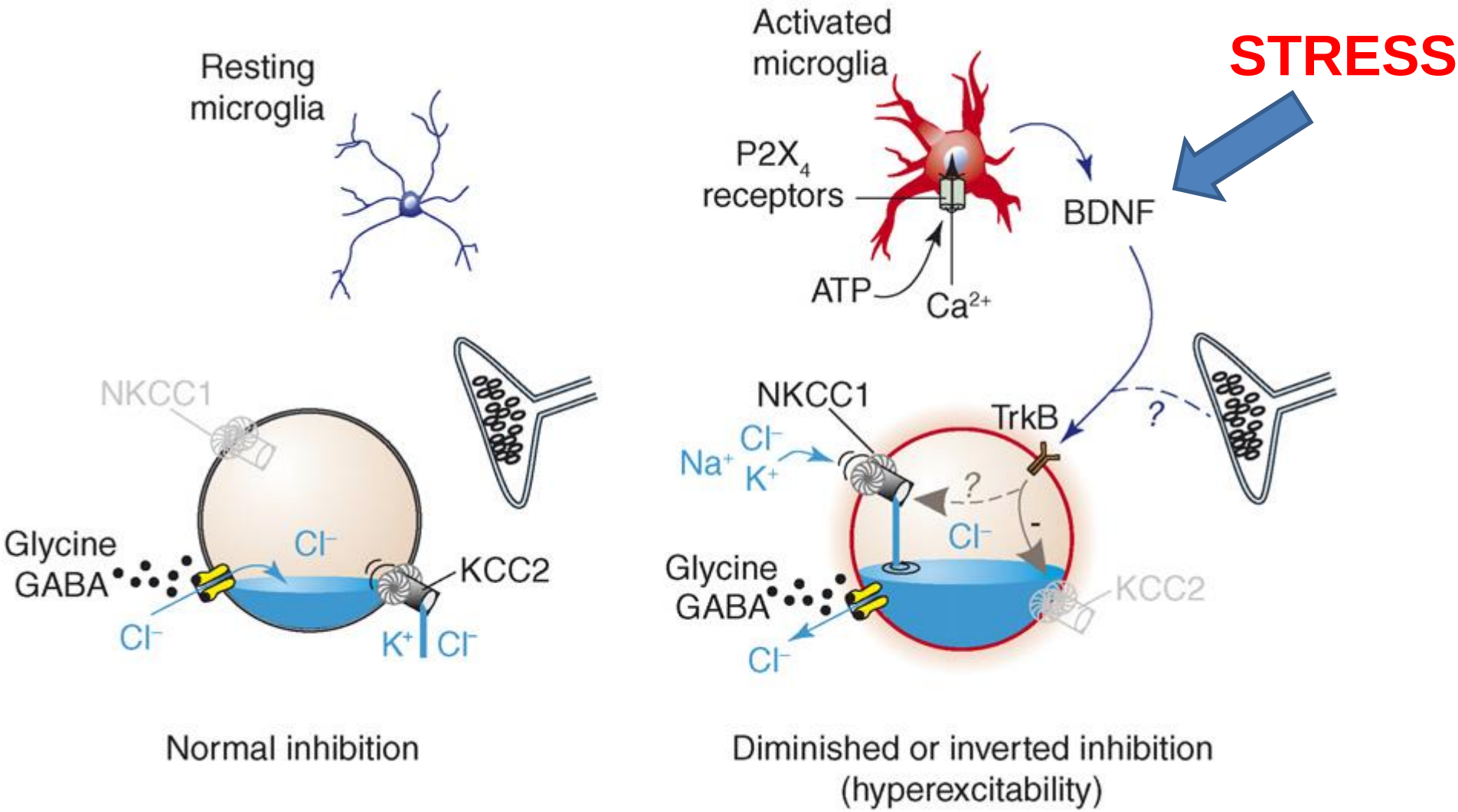
Central inhibition

- GABA and the intracellular concentration of Cl^-

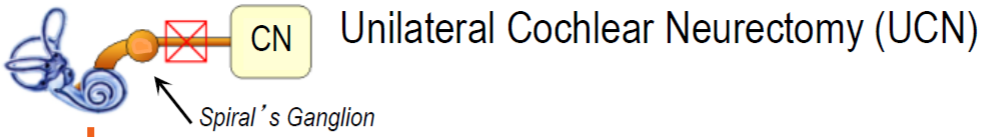


Central inhibition

- GABA and the intracellular concentration of Cl^-



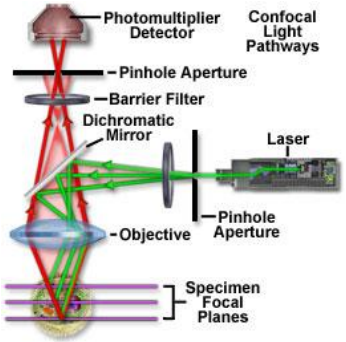
Co-transporter KCC2



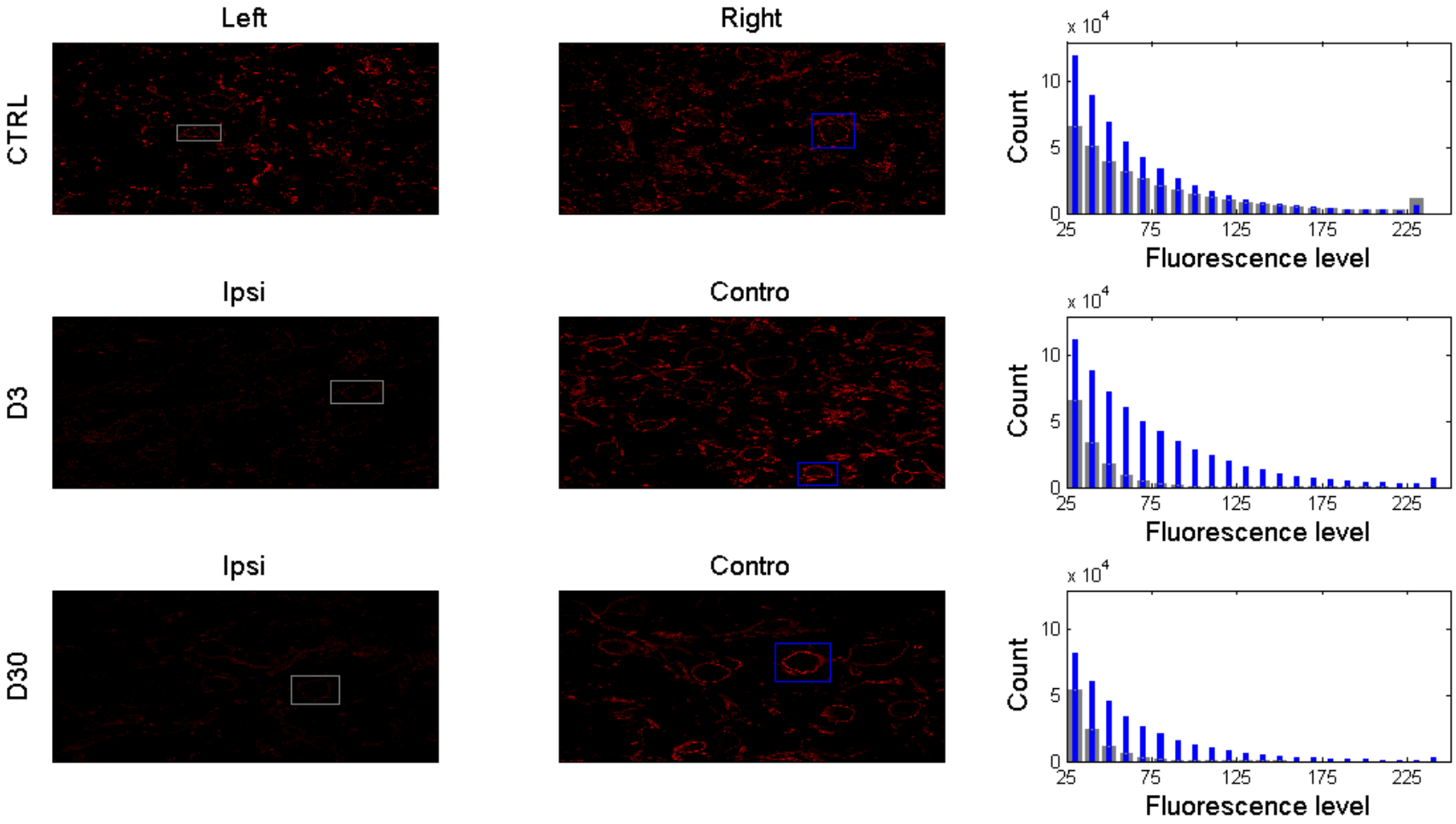
Unilateral Cochlear Neurectomy (UCN)

Immunohistochemistry
KCC2
Confocal imaging

Immunohistochemistry
KCC2
Confocal imaging

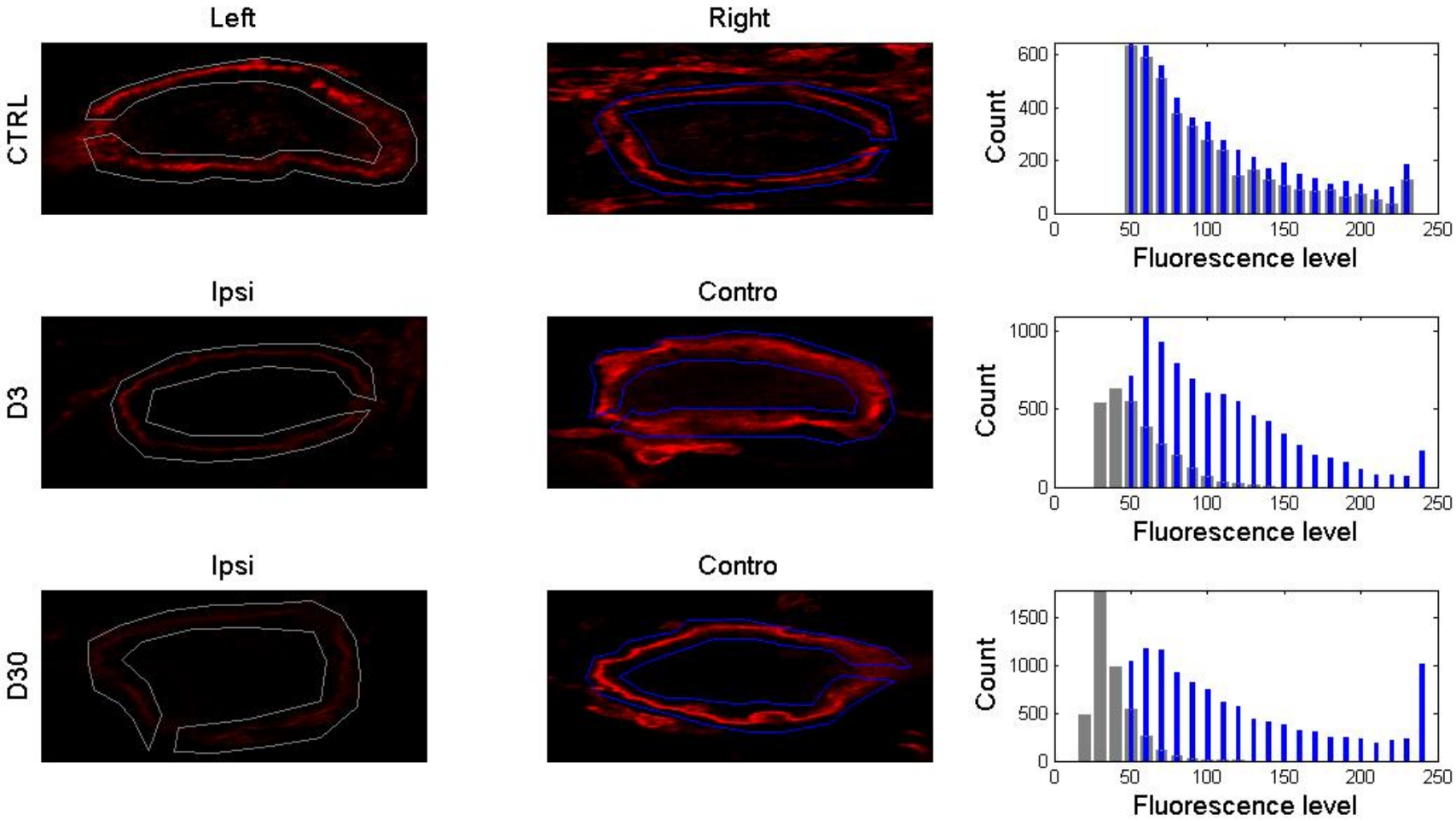


Co-transporter KCC2



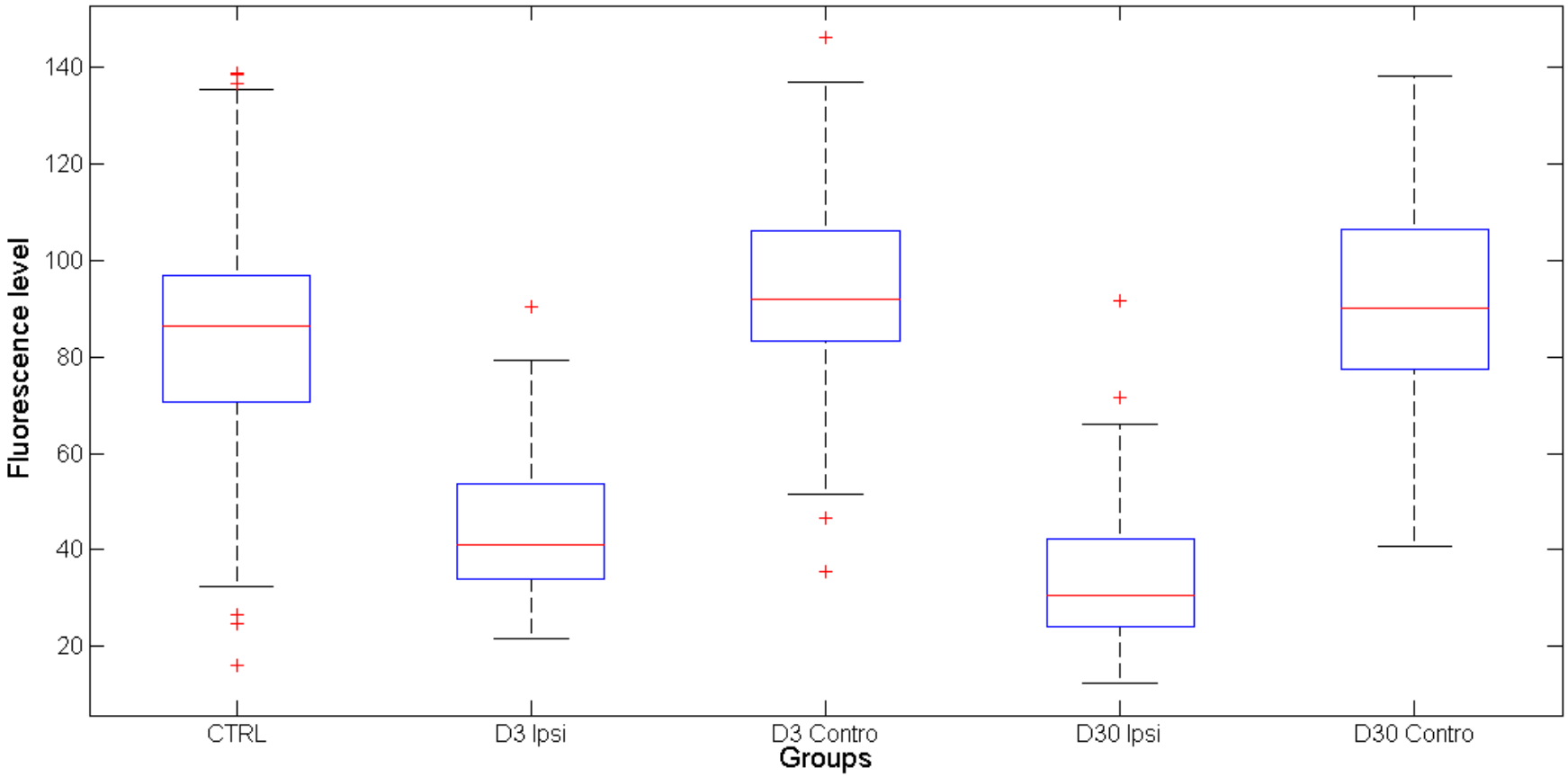
Tighilet et al., 2016

Co-transporter KCC2



Tighilet et al., 2016

Co-transporter KCC2

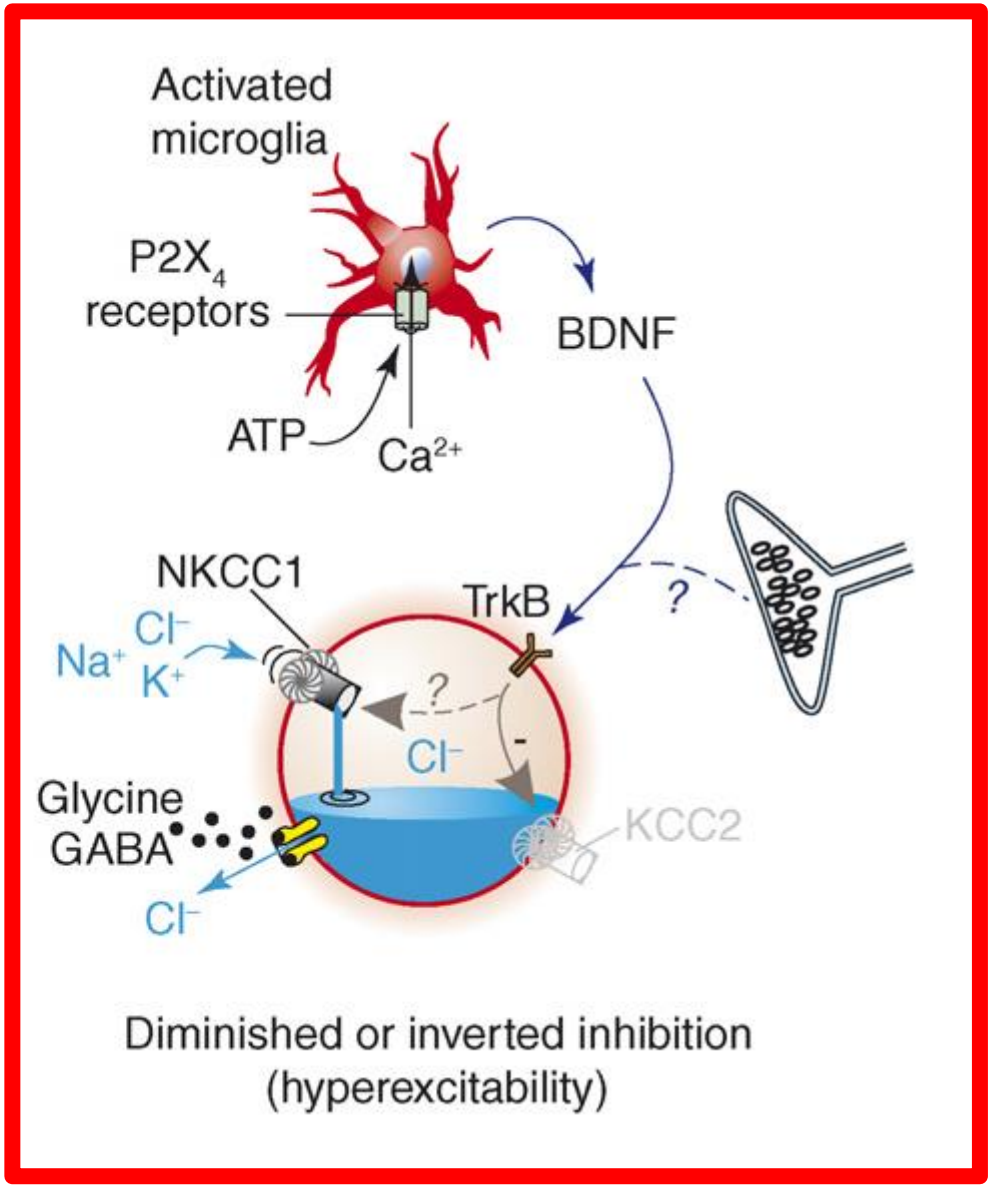


Tighilet et al., 2016

Central inhibition

- GABA and the intracellular concentration of Cl^-

GABA may become excitatory after deafferentation



Tinnitus

Aberrant spontaneous activity underpinning a continuous auditory percept

Cochlear tinnitus

Centres are passive

- Pre-synaptic
  - OHC operating point
  - Endocochlear pot
  - Stereocilia lesions (rootlets)
- Post-synaptic
  - NMDA receptors

Central tinnitus

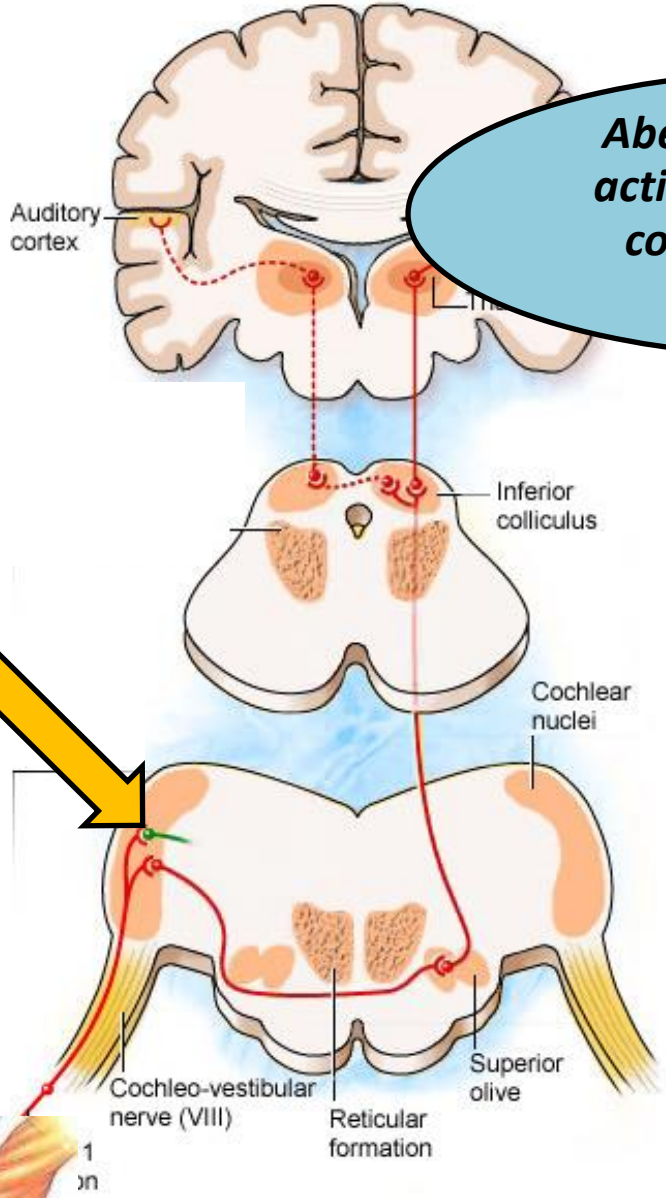
Centres are active

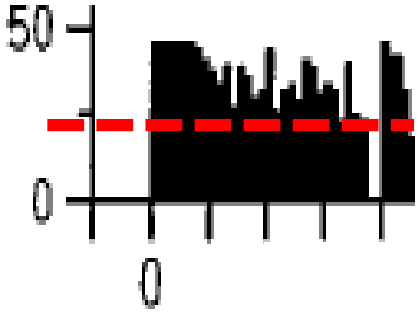
- Dependent from the periphery
- Independent from the periphery
  - Homeostatic plasticity
  - Tonotopic map reorganization
  - Multi-modal plasticity
  - Thalamo-cortical dysrythmia

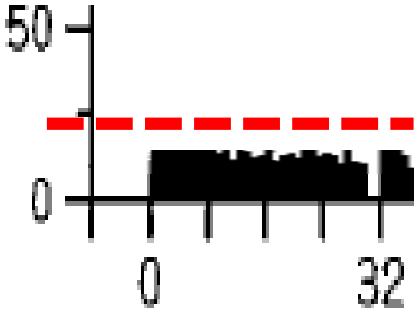
Norena, 2015

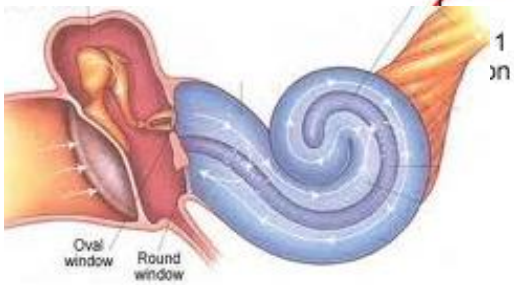
Aberrant spontaneous activity underpinning a continuous auditory percept

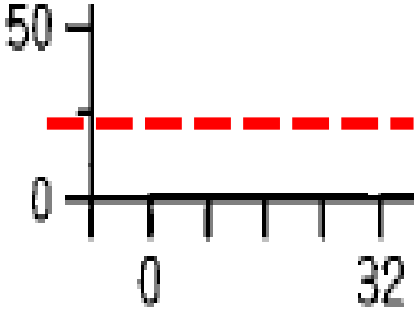
Inputs from non-auditory regions











Acouphènes somato-sensoriels

- Acouphènes déclenchés et/ou modulés par des stimulations de la face, contraction de certains muscles (Levine, 2003):
  - Cou (sterno-cleido-mastoidien…)
  - Jonction temporo-mandibulaire (masséters…)

Acouphènes somato-sensoriels

Ten contractions involved the jaw as follows:

1) Clench the teeth together as forcefully as possible,

2, 3) Maximally open the mouth, with and without maximal restorative pressure applied by the heel of the subject or examiner's hand,

4, 5) Maximally protrude forward the jaw, with and without maximal restorative pressure,

6, 7) Maximally slide the jaw to the left, with and without maximal restorative pressure,

8, 9) Maximally slide jaw to right, with and without maximal restorative pressure, and

10) Maximally retract jaw.

With the head in the neutral position, contractions were made to resist maximal pressure applied by the examiner to the:

11) Occiput,

12) Forehead,

13) Vertex,

14) Mandible (upward),

15) Right temple, or

16) Left temple.

17) With the head turned to the right, resist maximal tortional force applied by the examiner to the right zygoma.

18) With the head turned to the left, resist maximal tortional force applied by the examiner to the left zygoma.

19) With the head turned to the right and tilted to the left, maximally resist full force applied by the examiner to the left temple (left sternocleidomastoid)

20) With the head turned to the left and tilted to the right, maximally resist full force applied by the examiner to the right temple (right sternocleidomastoid)

Five involved extremity contractions as follows:

21) Locking the subject's flexed fingers of the two hands together and pulling them apart as forcefully as possible.

Contractions were made to resist maximal pressure applied by the examiner to the subject's

22) Abducted right shoulder,

23) Abducted left shoulder,

24) Flexed right hip, or

25) Flexed left hip.

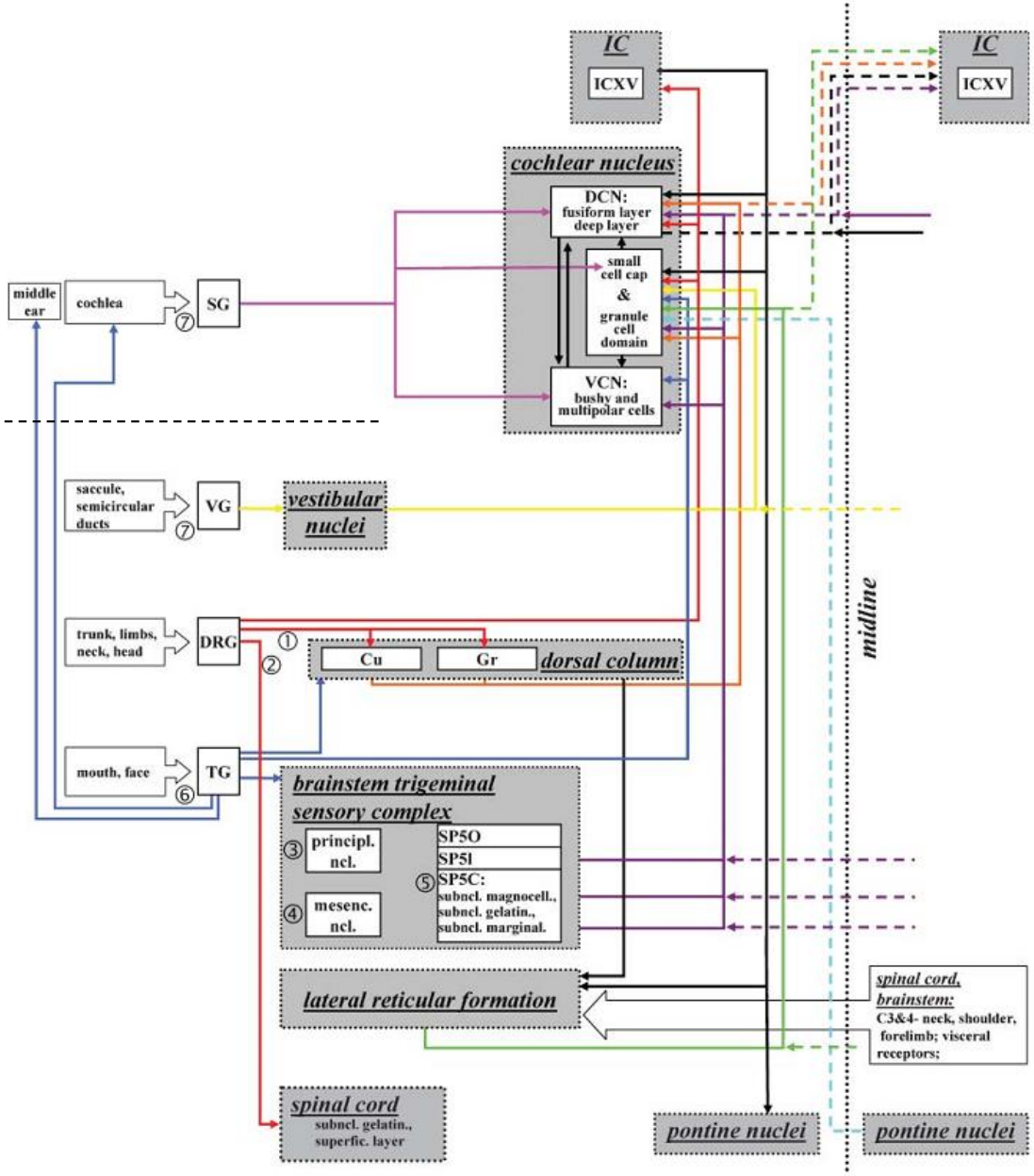
Acouphènes somato-sensoriels

Table 2 Somatic modulation in non-clinical subjects as related to whether or not they were experiencing tinnitus at the time of testing

Subject type	Somatic modulation		Totals
	Present	Not present	
With ongoing tinnitus	23 (79%)	6 (21%)	29
Without tinnitus	19 (58%)	14 (42)	33
Totals	42 (68%)	20 (32%)	62

Auditory inputs

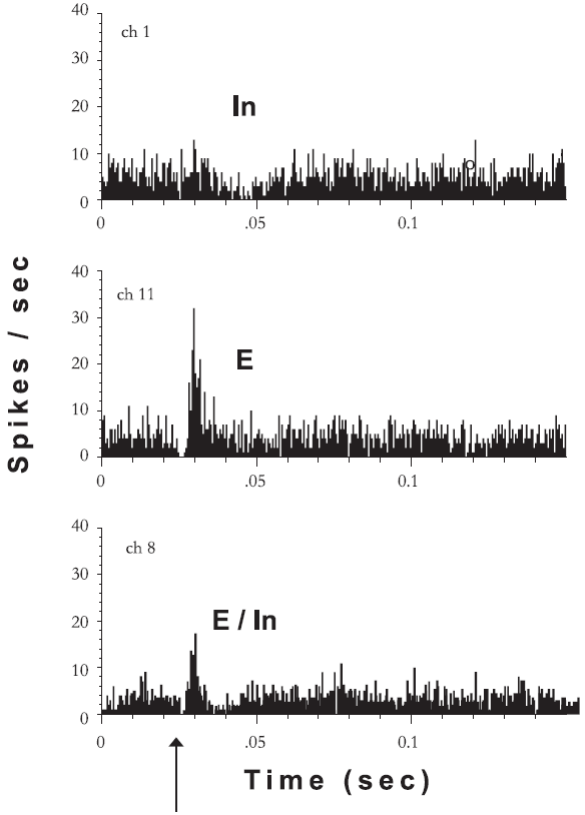
Non-auditory inputs



Dehmel et al.,
Am. J. Audiol, 2008

- Multi-modal interactions & effects on SA

DCN

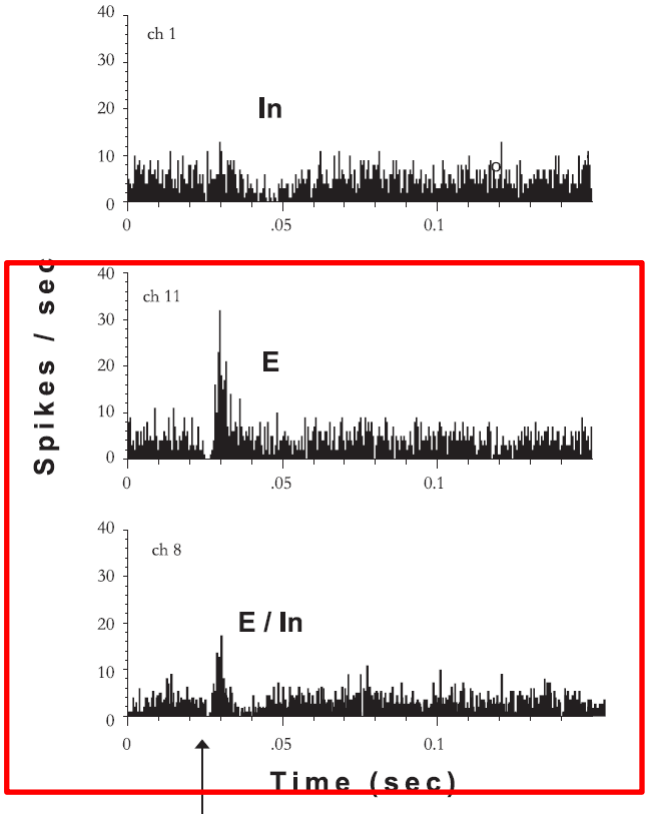


Trigeminal stimulation

Shore et al., EJN, 2008

- Multi-modal interactions & effects on SA

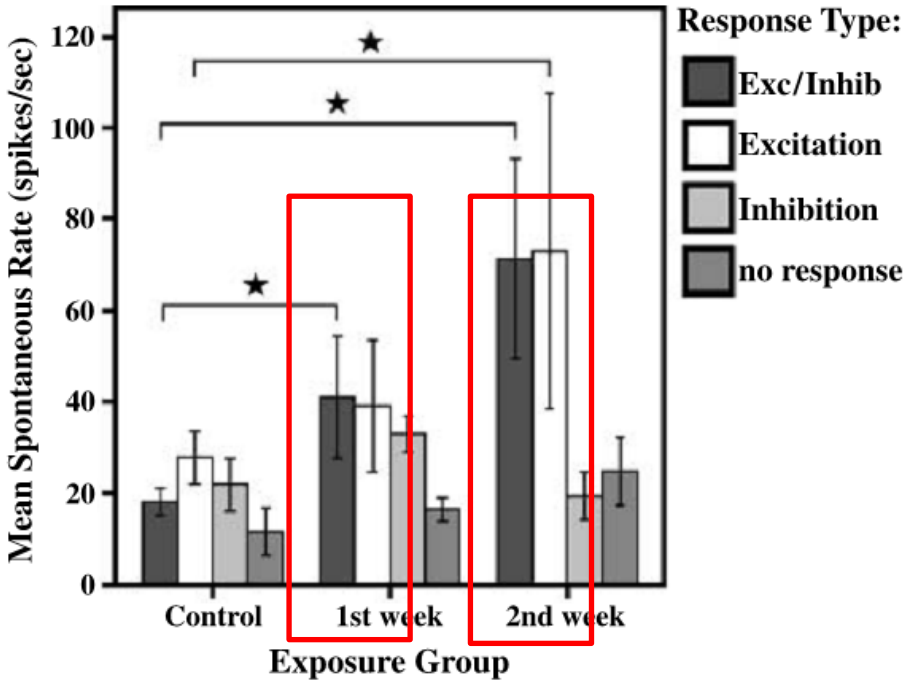
DCN



Trigeminal stimulation

Effects of noise trauma

DCN



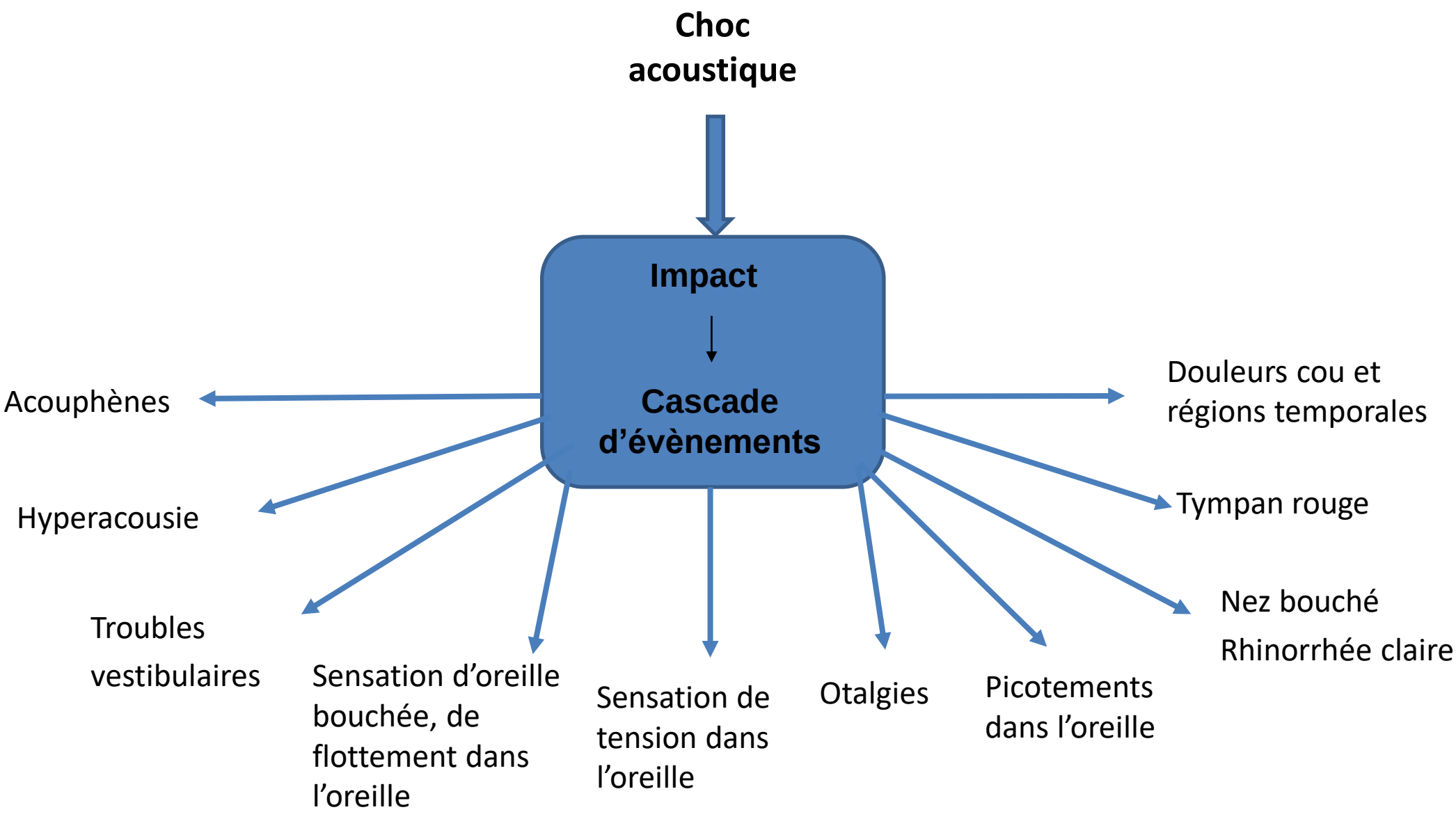
Shore et al., EJN, 2008

Dehmel et al., Am. J. Audiol, 2008

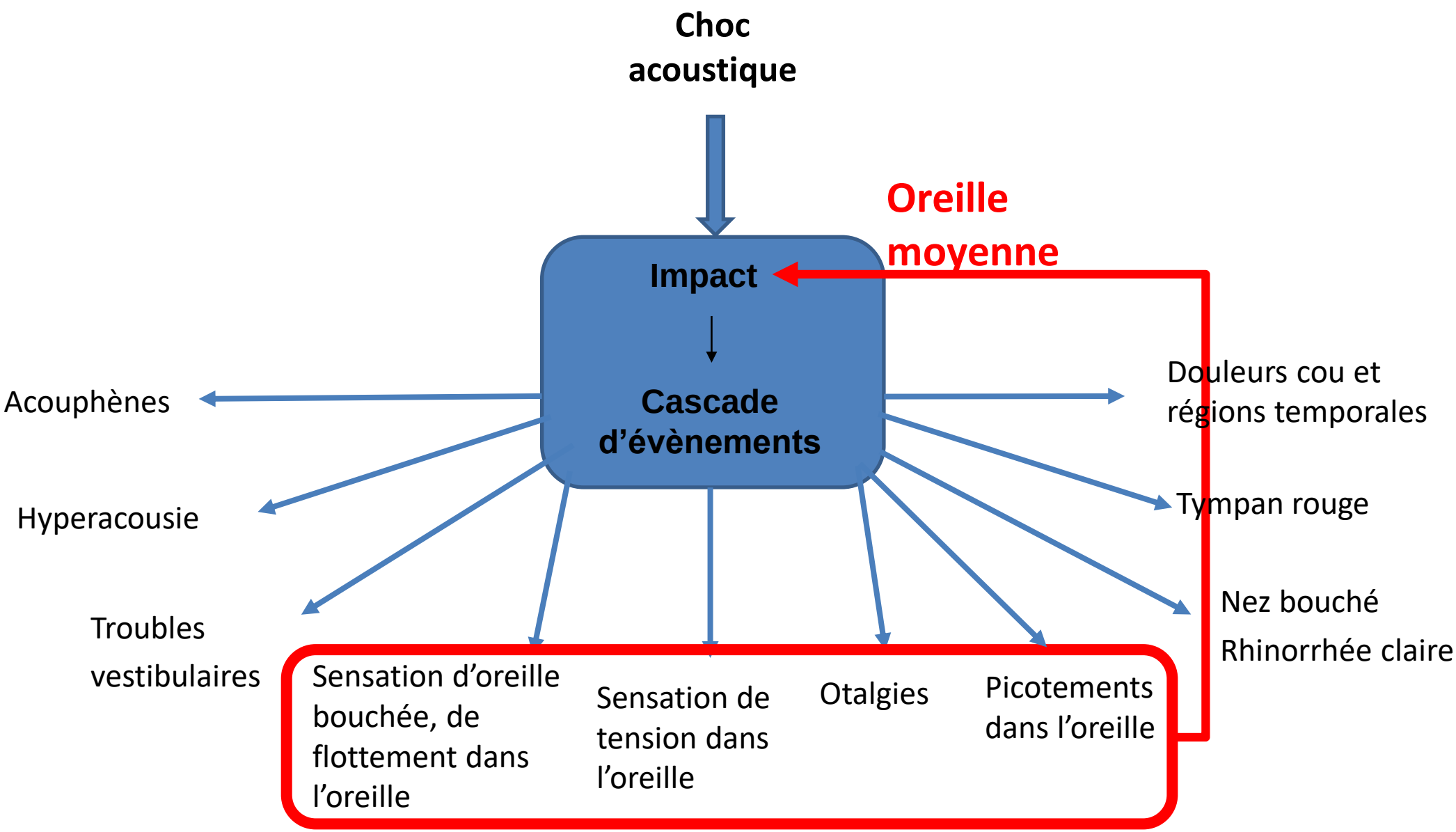
Le choc acoustique

- Evènement acoustique, *a priori* pas suffisant pour endommager la cochlée, qui peut être associé à des symptômes qui peuvent être sévères et chroniques
  - Acouphènes
  - Hyperacousie
  - Troubles vestibulaires
  - Sensation d'oreille bouchée, de flottement dans l'oreille
  - Sensation de tension dans l'oreille
  - Douleurs au niveau de l'oreille
  - Douleurs irradiant au niveau des régions oro-faciales, cou et régions temporales
  - (…)

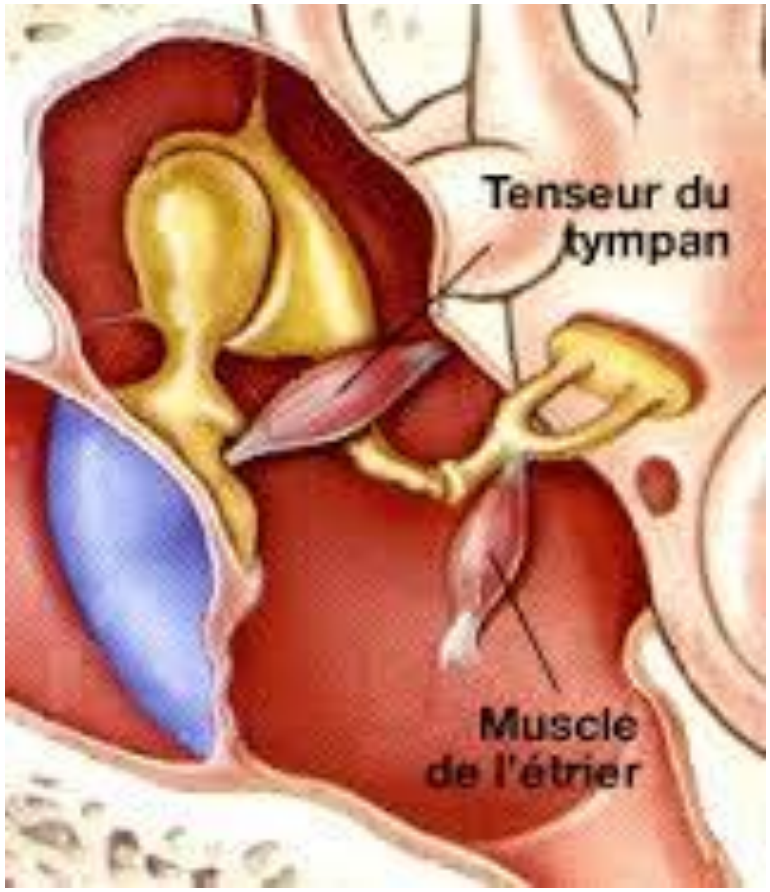
Pourquoi s'intéresser au choc acoustique?



Pourquoi s'intéresser au choc acoustique?



Tonic Tensor Tympani Syndrome? (Klockhoff)



Tonic Tensor Tympani Syndrome? (Klockhoff)

Associated Symptoms - the "TENSOR TYMPANI SYNDROME"

The tonic tensor phenomenon is associated with symptoms of such a high representation that it seems justified to talk of a TENSOR TYMPANI SYNDROME.

The ear symptoms are: "Fullness", "tinnitus" and "dysacusis

There is a high relation to tension headache and vertigo.

It is a psychosomatic syndrome caused by increased psychic tension due to mental stress.

The fullness in the ear is more or less episodic and can be otalgic.

The tinnitus is mostly of a low sensation level and is sometimes pulsating.

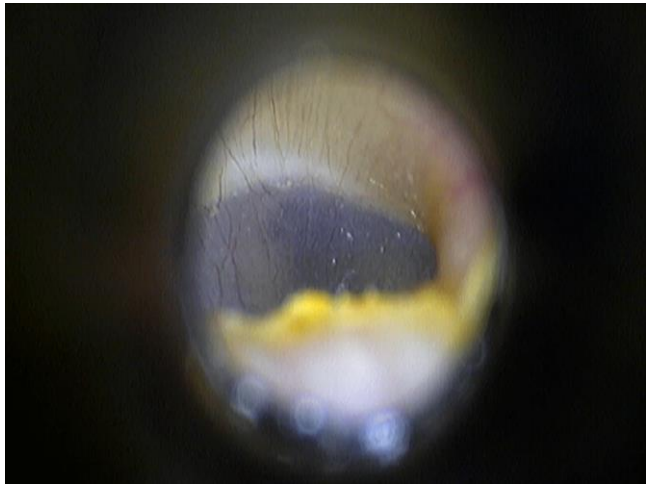
The dysacusis consists of various abnormal acoustic sensations such as murmurs, clicks, tickling sensations, etc. and may involve distortion.

Méthodes

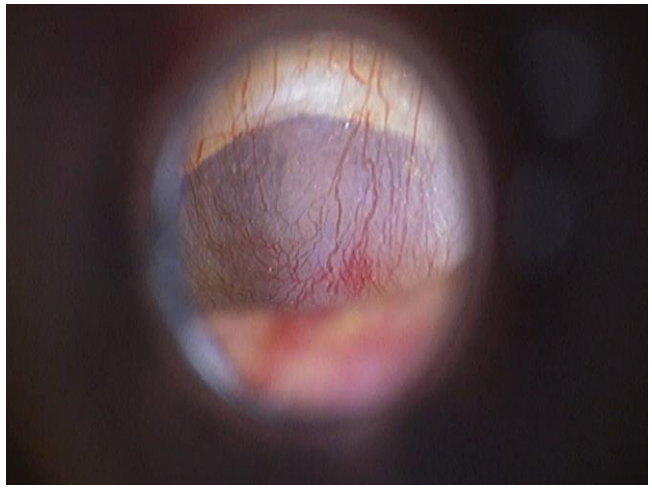
- 1 patient (28 ans) – médecin généraliste
- 10 nov 2013: Choc acoustique (coup de feu stand de tir, à 7m)
- Audiogrammes et autres examens normaux
- 1-9 mai 2015:
  - La sévérité de 7 symptômes a été estimée à partir d'une EVA
  - Photos du tympan
- Mars 2017: Visite à Marseille
  - Psychoacoustique des acouphènes
  - tympanométrie

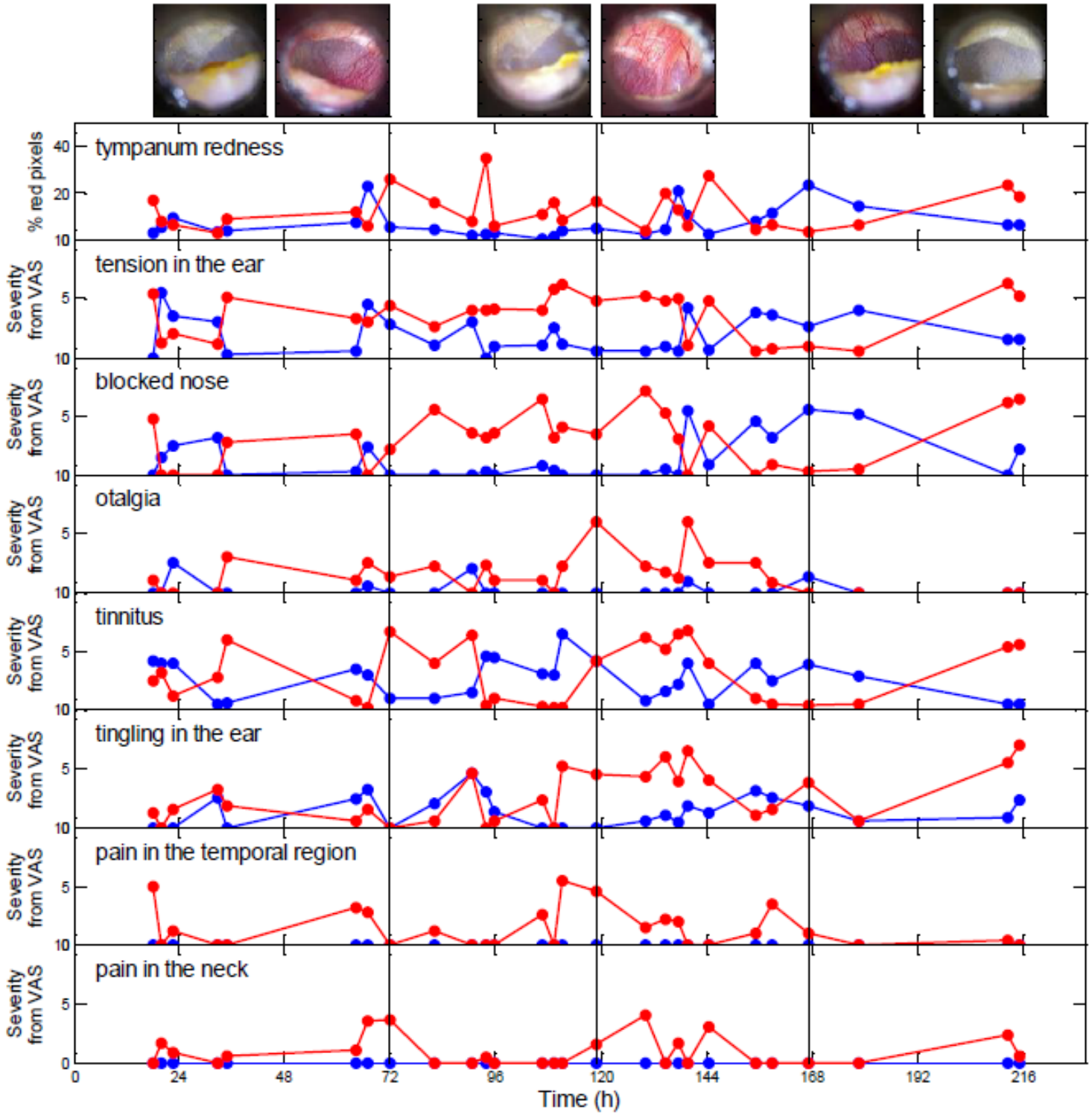
Vidéos

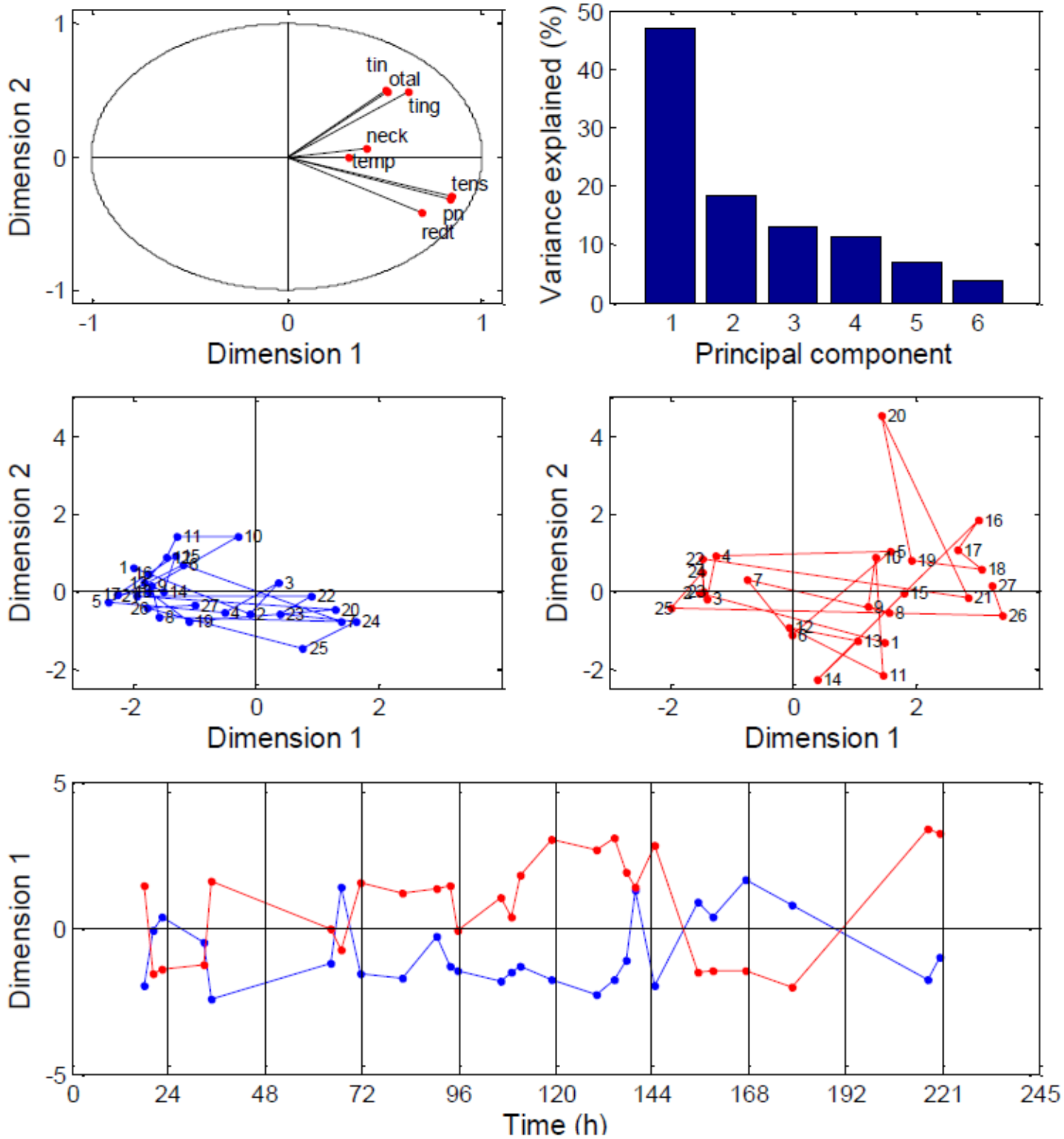
Oreille calme / tendue

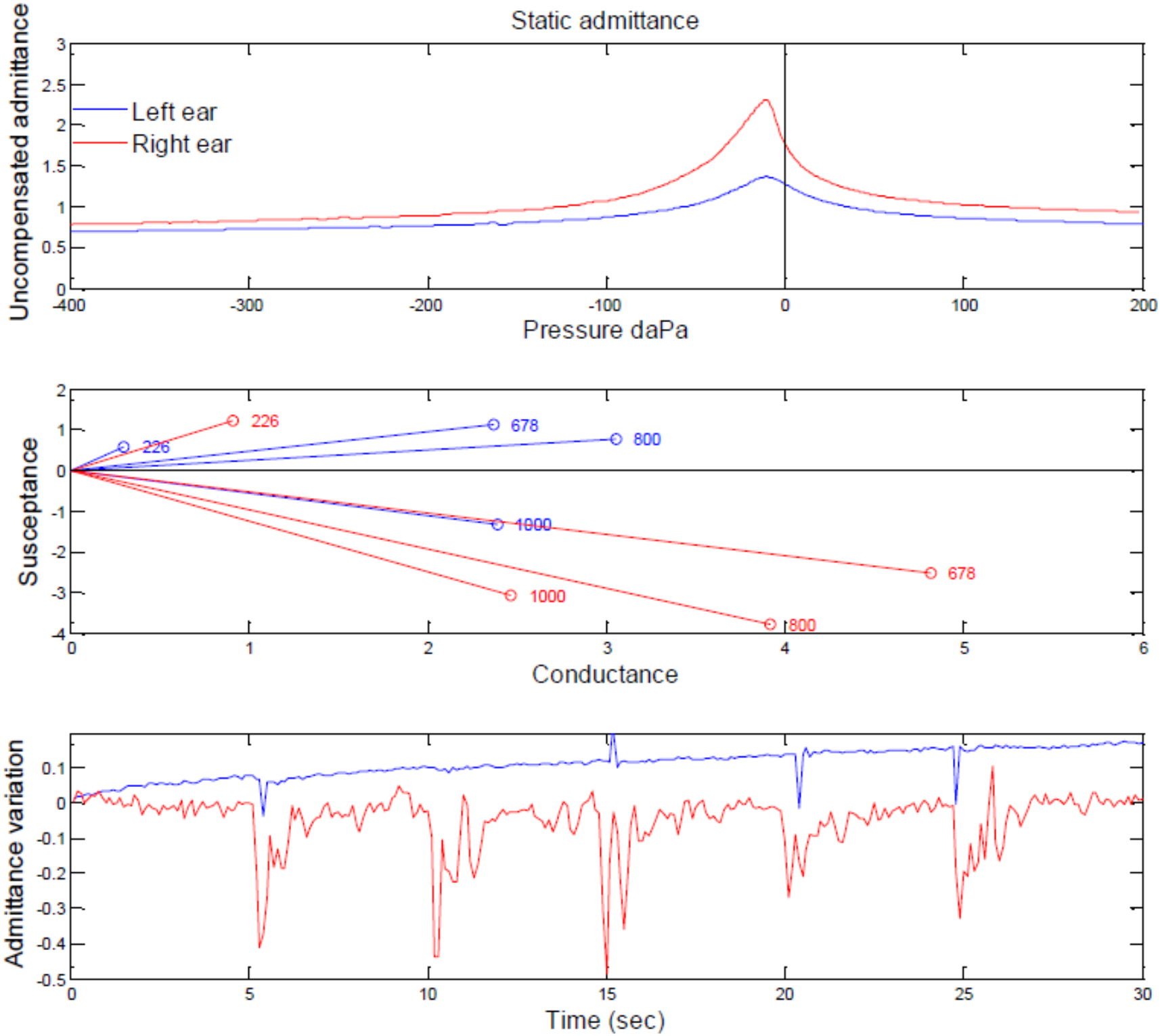


Oreille tendue et contraction (mylo-hoidien)

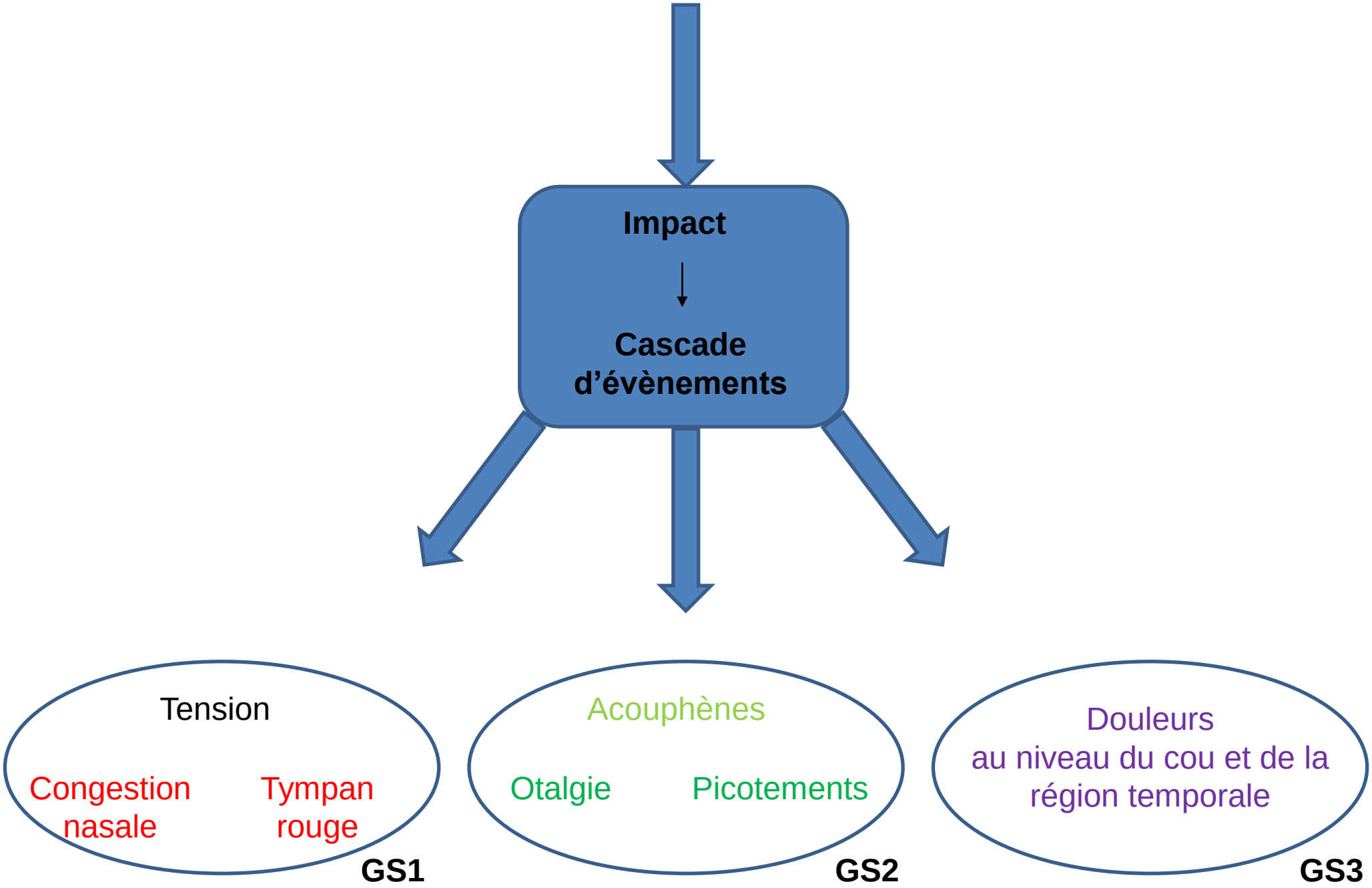



tympanum redness
% red pixels
tension in the ear
blocked nose
otalgia
tinnitus
tingling in the ear
pain in the temporal region
pain in the neck
Severity from VAS
Time (h)
0
24
48
72
96
120
144
168
192
216


tin
otal
ting
neck
temp
tens
pn
redt
Dimension 1
Dimension 2
Variance explained (%)
Principal component
Time (h)


Static admittance
Uncompensated admittance
Left ear
Right ear
Pressure daPa
Susceptance
Conductance
226
678
800
1000
Admittance variation
Time (sec)

Choc acoustique



V1

V2

V3

To thalamus

Hypothalamus

PAG

LC

TGN

SSN

SPG

IV

TNC

MRN

Symptômes autonomiques

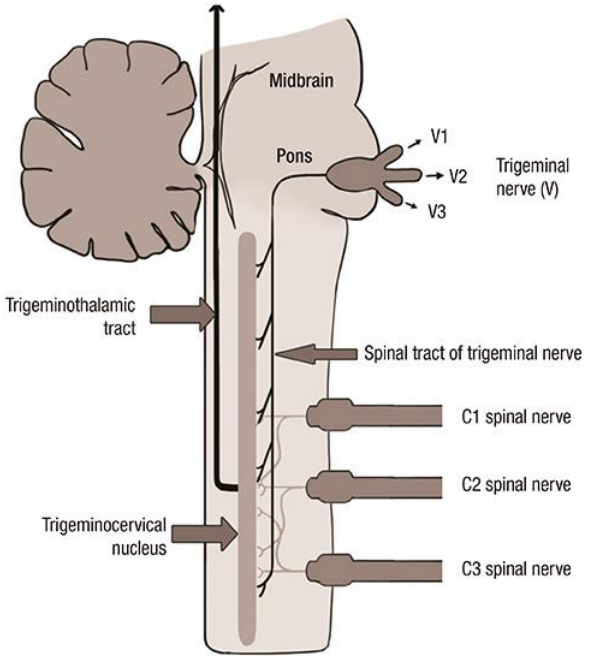
Tenseur du tympan

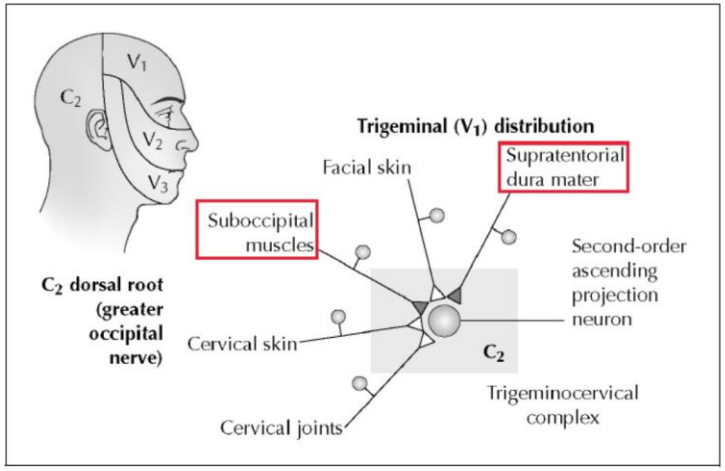
Muscle de l'étrier

Acouphènes

Otalgie

Douleurs projetées





Les neurones du TCC sont multi-modaux

Conclusion

- Tinnitus are prevalent and can impair quality of life

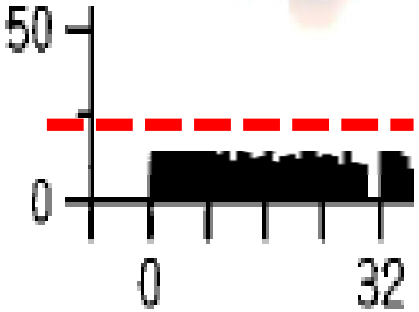
- Several tinnitus sub-types:
  - Cochlear tinnitus: many mechanisms can account for cochlear tinnitus
    - OHC stereocilia (rootlets)
    - NMDA receptors
    - OHC operating point

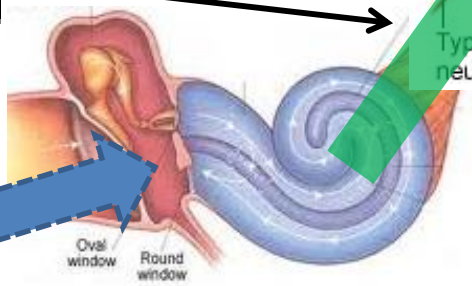
  - Central tinnitus:
    - Homeostatic plasticity: tinnitus may be the price to pay for the auditory system to adapt central sensitivity to reduced sensory inputs
      - Excitation
      - Axonal initial segment
      - Inhibition
    - Cortical reorganization
    - Contribution of somatosensory inputs

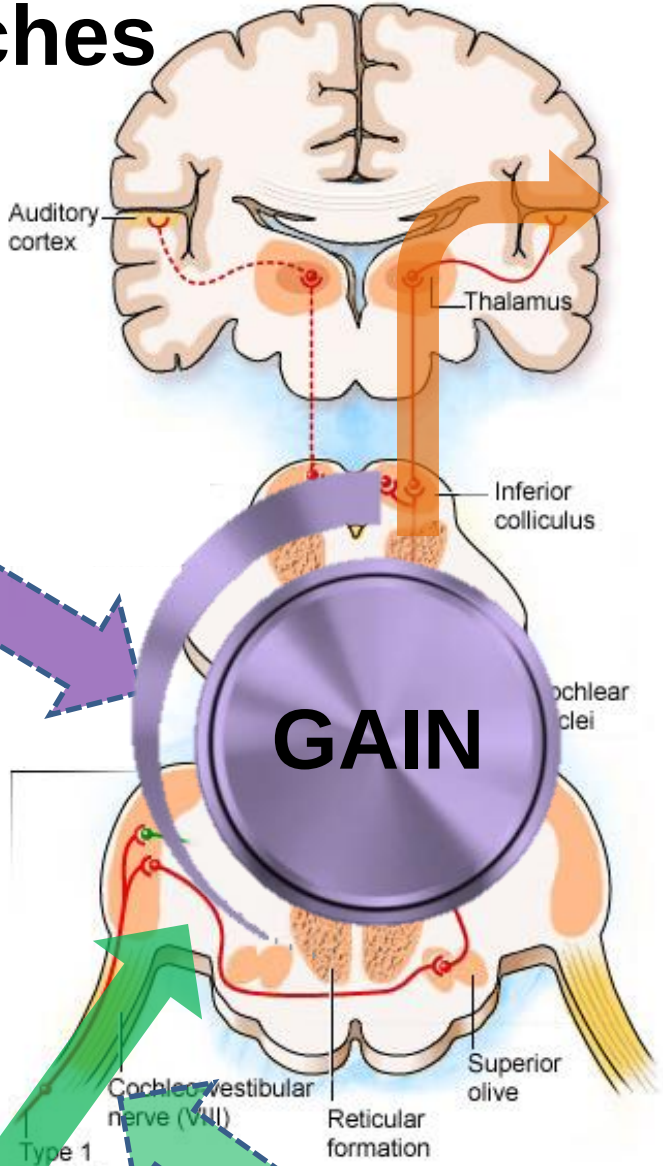
  - Both tinnitus may co-exist: « Noisy (cochlear?) tinnitus » vs. « tonal (central) tinnitus »?

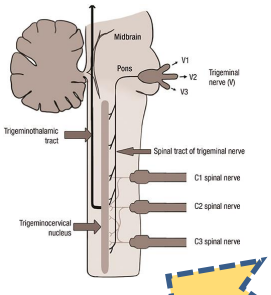
Therapeutic approaches

Reduction of « Central Gain »









Action au niveau du TGN

Repos/réparation du TT

Reduction of cochlear spontaneous activity

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