„Bursting“ in the IC
*Surfing the Big Wave?*

PB

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Gross potentials in the IC
wave upon waves
anaesthetized Cat

Jewett, 1970

steel wire, ref tounge

Fig. 5

Recordings at various depths on a track at anterior = −1, lateral = 4, clicking contralateral ear at arrow (same experiment as Fig. 3).
A: Grey matter, 1000 ×.
B: Grey matter, 4 mm below A, 800 ×.
C: Inferior colliculus, 4 mm below B, 400 ×.
D: Junction of inferior colliculus and nucleus of the brachium conjunctivum, 2 mm below C, 400 ×.
E: 2 mm below D, vicinity of nucleus of the brachium conjunctivum and rubrospinal tract, 400 ×.
F: Near base of skull, 6 mm below E (a few millimeters anterior to the superior olive), 400 ×.
anaesthetized Cat
Caird et al., 1985
tungsten 10-20µm tip
BSER silver ball

Fig. 5. AFPs in left superior olive and right inferior colliculus compared to the BSER in the same experiment. In both colliculus and olivary complex, the AFP consists of a fast ripple followed by a slow wave. In the olivary complex this ripple corresponds in latency to P2-P3 (dotted lines). In the inferior colliculus this 'input wave' is the same latency as BSER P4 (solid lines) and the corresponding component in the olivary complex. The superior olivary AFP series was recorded dorsal to the medial superior olive (see Fig. 2). All stimulation parameters as in Fig. 2.

Fig. 6. AFPs in inferior colliculus. The latency of BSER P4 and P5 is indicated (lines). BSER P5 was relatively prominent in this experiment. All components show binaural reduction, shown by waves of opposite polarity in the BDP. As the electrode leaves the central nucleus of the inferior colliculus (ICC, dotted line), the BSER components show relative amplitude increases. These components are also more pronounced ventrally (i.e., nearer the inputs to the colliculus). The anatomical track reconstruction is from parasagittal sections, nearly parallel to the penetration. The approximate lateral position (based) was obtained by counting sections and transferring the result to a transverse section from another experiment.
anaesthetized Cat
Sontheimer et al., 1985
tungsten

Fig. 2. Interaural delay series. BSER (left column) and auditory field potential (AFP) in right inferior colliculus (right column) in the same experiment are displayed as in Fig. 1. The delay range is $\pm 2048$ $\mu$sec, the largest that could be tested and delay step size is 512 $\mu$sec. The times of left and right stimulation are shown by the dotted and dashed lines respectively. The BSER P5 wave is relatively prominent in this experiment (compare with Fig. 1). Stimulus level was 30 dB above visual CAP threshold. Note that the time axis is longer than in Fig. 1, to show the slow AFP waves.
Typically, responses recorded by a bipolar electrode from the ICX to both click (upper tracing) and toneburst (lower tracing) stimuli have 4 peaks (Fig. 1). Latency measurements revealed that the “A” peak reflects the termination of second-order input to the IC from the contralateral cochlear nucleus, that the “B” peak reflects the termination of third-order fibers from the ipsilateral superior olivary complex, and that the broad “D” peak is probably generated in the IC – most likely reflecting dendritic potentials (Szczepaniak and Møller, 1993). The “C” peak, which has a polarity opposite to the “D” peak, consists of a sharp component and a broader one. Microinjection of lidocaine into the IC abolishes the broad component but not the sharp peak or the “D” peak, which indicates that the latter may reflect the termination of fourth-order input to the IC from the nucleus of the lateral lemniscus. There were no noticeable changes in the “A” or “B” peaks after lidocaine injection. We assume that the broad peak reflects postsynaptic events in the IC (Szczepaniak and Møller, 1993).

anaesthetized Rat
Szczepaniak & Moeller, 1996
bipolar recordings
Teflon insulated AG-10 wires, tips 1mm apart
Fig. 3. The reconstruction of track 4 from Fig. 2 is shown with the field potentials and single neuronal responses recorded as a function of depth. All responses are to 20 µs clicks at 80 dB p.e. SPL.

Fig. 4. Field potentials and single neurone responses as a function of electrode depth. Stimuli for all responses were 20 µs clicks at 80 dB p.e. SPL.
Single and multi unit responses
bursting, chopping, synchrony
awake Rhesus Monkey
Ryan & Miller, 1978
tungsten (4-25µm, Imp ?)

Fig. 4. a Distribution of average initial latencies to intense stimuli observed in 44 units with excitatory onset responses during behavioral performance. b distribution of average initial latencies to intense stimuli of 52 units observed while subjects sat passively during stimulus presentation. Several units for which performance data could not be obtained have been included. (Average nonperformance initial latency for the 44 units in Figure 4a was 15.23 msec, with a standard deviation of 7.45 msec)

Fig. 8. PST histograms obtained at an intensity of 90 dB SPL from unit SR 3–2. Each histogram represents 30 nonperformance stimulus presentations. CF of the unit was 0.9 kHz.
anaesthetized Mongolian Gerbil
Semple & Kitzes, 1985
tungsten (Imp. ?)
single units

**Fig. 11.** A comparison of the temporal pattern of contralateral and ipsilateral responses elicited by a BF tone burst of 100 ms duration (3.0 ms rise/fall). Peristimulus time histograms are shown in pairs for a selection of FF units, with contralateral responses to the left and ipsilateral responses to the right. Details in text.
anaesthetized Cat
Langner & Schreiner, 1988
tungsten 1.5-2.5 MOhm (1kHz)
1-5 neurons (publication estimate)
anaesthetized Cat
Kuwada et al., 1997
Glass micropipette, 4% HRP, 0.5 M KCl, 0.04 M Tris buffer pH 8.6
30-100 MOhm -> Intracellular
anaesthetized Guinea Pig
Rees et al., 1997
tungsten, (Imp?)
isolated single units
anaesthetized Guinea Pig
Syka et al., 2000
glass micropipette, 3M KCl (Imp. ?)
isolated single units
Fig. 2. A representative IC neuron with the phasic burst pattern. A and B show the response to a single BF sound presentation of 80 dB SPL for 120 ms and the corresponding PSTH. The number of APs is shown above the PSTH. For this neuron, the recording depth was 715 μm, the BF was 11 kHz, and the resting potential was −43 mV. The symbol under trace A and the bar under abscissa in B represent sound stimuli.

anaesthetized Mouse
Fu et al., 2013
glass micropipette, 1 m/l tri potassium citrate (23-104 MOhm)
single units, intracellular
Recorded digitized spike waveforms were sorted prior to data analysis to eliminate poorly discriminated spikes, waveforms not related to neural activity, and redundant waveforms recorded on more than one channel. Channel-by-channel digitized waveform records were off-line sorted into single-unit records using a combination of principal component analyses and multivariate t-statistic sorting routines (Offline Sorter 2.7.1; Plexon, Inc, Dallas, TX).

Fig. 9. An exemplary bursting unit, 16L2b, selected from an acoustic-exposed chinchilla with evidence of tinnitus. A: Sagittal IC section intersecting the track of the multiprobe site from which the unit was recorded. The arrow indicates the recording site of the unit. Distances between the lesion-marked recording sites were 100 μm. B: The psychophysical performance of subject 16 (square data points), from which unit 16L2b was obtained, compared with the performance of non-tinnitus control animals (circular data points, error bars represent SEM). C: An oscilloscope trace of unit 16L2b showing its spontaneous burst pattern (minor tick marks: 0.5 msec). D: Low-resolution autocorrelogram of unit 16L2b, 1-sec window. E: High-resolution autocorrelogram of unit 16L2b, 20-msec window.
Own experience
Onset patterns since 2003
awake Mongolian Gerbil
Michael Ochse Dissertation 2004
tungsten 2.5-5 MOhm

Abbildung 42: Latenz und charakteristische Frequenz.
Dargestellt ist die Latenz der zusammengefassten Antwort auf alle Reizstimulatio- nen in Abhängigkeit von der charakteristischen Frequenz (CF) jedes Neurons. Die minimale Latenz ist durch die Laufzeit des Stimulus auf der Basilarmembran und der Zeit begrenzt, die der schnellsten Übertragung neuronaler Information zum ICC entspricht. Infolgedessen steigt dieser Wert für kleine charakteristische Frequenzen an. Die schnellste Über- tragung von den Haarzellen zum ICC kann zu ca. 2 ms abgeschätzt werden (schwarze Linie: \( t = 2 \text{ ms} + 1/\text{CF} \)). Im Mittel zeigt sich kein Anstieg für niedrige CF-Werte.
awake Mongolian Gerbil
Kathrin Schuth, Diploma Thesis 2006

Abb. 3.7: Einteilung der gemessenen Latenzen in Gruppen. Angegebener Wert stellt die Mitte der Gruppe dar.

Abb. 3.14: Vergrößerte Punktdarstellung einer Zelle mit CF 100Hz. Sinustöne dargeboten von 10dB bis 90dB. Ozillationen mit Pfeilen und Nummern markiert.


Abb. 3.20: Histogramm aller Zellen bei denen Ozillationen gefunden wurden (n= 63). Klassenbereich von 0ms bis 2,4ms und größer, in 0,1ms Schritten.
Kathrins Daten are not without problems...
Kathrins Daten are not without problems...
Abbildung 3.11 Latenzverteilung

Abbildung 3.15 Oszillationen mit verschiedenen Intervallen

Abbildung 3.14 Oszillationen im Stimulus Onset

Abbildung 3.16 Verteilung der Oszillationen Intervalle
Further evidence
Oscillations are found in different auditory nuclei like the cochlear nucleus and the inferior colliculus and are attributed to a class of neurons in the cochlear nucleus, the so-called “chopper neurons” (see e.g. Blackburn and Sachs, 1989). Chopper neurons are outstanding because of their response pattern. They generate oscillations with a distinct frequency relatively independent of changes of important stimulus parameters (Pfeiffer, 1966; Blackburn and Sachs, 1989; Winter et al., 2001; Wiegrebe and Winter, 2001). It was hypothesized that they play an important role in pitch perception (Langner, 1981; Hewitt et al., 1992; Wiegrebe and Winter, 2001).

(Bahmer & Langner, 2006)

Also:


Potential Origin T-Stellate Cells, VCN (‘Chopper Neurons’)

The multiple functions of T stellate/multipolar/chopper cells in the ventral cochlear nucleus

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Conclusions

- waves result likely presynaptic input mixed with spikes
- (first) spikes are associated with waves
- delay between wave and AP ~0.4 – 0.8 ms
- onset spiking mimics spiking of source -> CN T-stellate cells
- sustained responses integrate different input sources and become more typical for IC

Analysis should depend on research question:
- Input latency -> 1st wave + typical spike filtering (mind the ramp!)
- CF -> Spike onset (~1st 10 ms) because CN T-stellate cells narrow cochlear integration and many onset neurons
- for higher order processing (e.g. temporal, ITD, soundlevel) exclude onset when possible (e.g. not possible for slow temporal patterns -> each phase has onset response)
- keep anatomical projection pattern in mind: spatial proximity to incoming fibers, stronger influence of evoked potentials (Cant, 2013*; Mylius et al., 2013; Cant & Benson, 2008)

* The inputs from the cochlear nuclei form their densest terminations in the same part of the central nucleus that receives the inputs from the superior olivary complex (based on comparing the plots in Moore and Kitzes [1985] with those in Cant and Benson [2008] with those in the present results).


