Spatial Profiles of Correlation in Spike Timing to Broadband Noise Across Auditory Nerve

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Background

The cat auditory nerve (AN) contains ~50,000 neurons innervating ~2,500 inner hair cells across the cochlear basilar membrane. We are interested in the extent to which these neurons carry correlated temporal patterns, which depends on both the acoustic stimulus and intrinsic properties of the auditory periphery. Due to cochlear filtering, even Gaussian broadband noise (BBN) — for which adjacent frequencies have random phases — can produce correlated responses in fibers originating from nearby cochlear positions. We studied the spatial profile and extent over which correlated responses to broadband noise are found in the AN.

Spatial profiles of single AN fibers

Methods

Neural responses to repeated presentations of a single token of BBN (frozen noise, 50-30,000 Hz, 0.6 or 1 s in duration) were obtained from all fibers encountered in a given nerve. We collected spike trains from 149 AN fibers in 4 cats at 50dB SPL and 168 fibers in 5 cats at 70dB SPL. Spike trains from each fiber (reference fiber) were compared with spike trains of all other fibers ("test fibers") of the same animal in order to obtain normalized same-stimulus cross-correlograms (SSC) (Figure 1C). As reported earlier [2], such SSCs show maxima at delays that depend on the distance between cochlear positions of the two fibers (Figure 2). We measured correlation in two ways: a) as the height of the largest peak of the SSC (PH, PH), and b) as the SSC value at zero delay ("T0") (Figure 3A). The spatial correlation profiles were quantified in two ways: a) as the full-width at the half maximum (FWHM or "half-width"), and b) as the correlation area under the spatial profile (CA) (Figure 3B).

Population analysis

In order to identify significant across-fiber correlations, the noise floor was estimated by scrambling of spike times (keeping the same first-order inter-spike interval statistics) using a bootstrap method (with N=50 trials). The observed distribution of correlation values yielded confidence intervals. Noise floor was set to the upper confidence limit (at p=0.05).

A & B experiment

Unexpectedly, significant correlation re. scrambled ("scr") spike trains, were observed over widely separate cochlear locations (Figure 3B). To understand the source of this correlation, we collected coincidence spike trains to noise ("A") and an uncorrelated noise ("B"). We compared the noise floor (see box "Noise floor") in the scrambled condition with the noise floor in the uncorrelated noise condition (spike times to noise A vs. spike times to noise B). Blue = correlated noise. Black = scrambled control.

Global spatial profiles

The observed spatial profiles (Fig. 7) show broad regions of correlation (several mm) centered on the reference fiber, at all CFs. The half-width of the magnitude of correlation is surprisingly invariant with cochlear position, particularly when measured at a delay of 0 ms (T0, black symbols, Figure 7A,B). The correlation area, which provides a more global measure of the extent of correlation ("correlation extent"), clearly decreases towards the base, reflecting the gradual decline of temporal coding with increasing CF (Fig. 7D).

Conclusions

Global spatial profiles (Fig. 8) reveal that:

1) spatial profiles are narrower in shape when the range of delays is restricted to 0 ms, compared to when it is unconstrained;
2) an increase in stimulus level is not accompanied by a broadening in extent of across-fiber correlations, despite the known broadening in cochlear filter shape.

The results show that availability of monaural delays in the central nervous system (e.g. in cochlear nuclei) is an important factor in the spatial extent of correlation.

References


Supported by a Marie Curie IIF fellowship (CA 221755), National Science Foundation of Croatia & Croatia Science Fund via an STW fellowship to PV (8B-8134) and FWO (G.0633.07, G.0714.09) and BOF (OT/09/050).

Fig. 1 (A) A cross-section through the cochlear basilar membrane showing a single auditory nerve fibre (AN) innervating a single inner hair cell. The AN contains 50,000 neurons innervating ∼2,500 inner hair cells across the cochlear basilar membrane. (B) Different cochlear positions are denoted by different colors. These positions are labeled in the diagram. C: cross-correlogram for a pair of fibers with CFs of 522 Hz and 617 Hz. No smoothing or fitting has been applied. [From 2]

Fig. 2 Same-stimulus cross-correlograms (blue lines, SCC) of the reference fiber (CF ~1.5 kHz) with A) two fibers with similar CFs (4.1 kHz) and B) a fiber with high CF (14 kHz). Notice the shifts of the SCC compared to the auto-correlogram of the reference fiber [black line] caused by traveling wave delays in the cochlea.

Fig. 3 Graphical illustration of the correlation measures used in this study: A) Peak height (PH) is defined as the height of the largest peak in the correlogram. B) The half-width of the magnitude of the correlogram is defined as the full-width at the half-maximum of the correlogram. C) The correlation area is defined as the area below the correlogram determined by the PH and HW (see inset). [From 2]