Neuromorphic Sound Source Localization System with Efferent Feedback

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Hearing is a remarkable sense in humans and many other animals, enabling the detection of danger, enhancing spatial awareness, and supporting effective navigation. Furthermore, hearing actively adapts to the environment and deals with challenges like handling the wide input dynamic range, a multitude of background noises and identifying important sound sources. Given these functional requirements, hearing needs to be always active and real-time detection together with high efficiency are required. Furthermore, the auditory pathway exhibits multiple intermediate processing stages and many feedback connections between stages down to the sensors. Thus, it is an ideal example for developing efficient and real-time capable neuromorphic sensing and processing systems.

Here, we study the intricate interplay between sensing and processing due to efferent feedback based on the processing outcome on the example of sound source localization (SSL). The first stages in SSL are the hair cells in the cochlea (i.e. the sensors) and neurons in the medial nucleus of the trapezoid body (MNTB) and the lateral superior olive (LSO), which represent the processing stage to analyze the level difference of a sound signal impinging at the two ears. Efferent feedback from the LSO to the hair cells is believed to improve SSL by equalizing the hair cell response on both sides and modifying the sensitive range.

In our bio-inspired SSL system with efferent feedback (Fig. 1(b)), we combine bio-inspired, tunable, acoustic MEMS sensors [1] for sound transduction, a neural processing stage with two LSO neurons inhibited by two MNTB neurons [2] and four efferent feedback configurations (see Fig. 1(c)) [3]. The system was implemented in Matlab and verified with synthesized and measured sensor data.

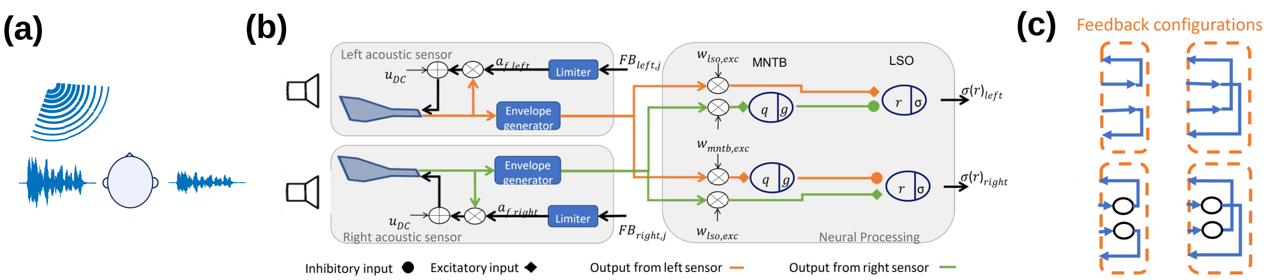

Figure 1: (a) Depiction of Interaural level differences (ILD) used for SSL. (b) Overview of bio-inspired SSL system with sensor stage and neuronal processing stage. (c) Different efferent feedback configurations tested in the bio-inspired SSL system. Figures reproduced from S. Durstewitz et al. [3] under Creative Commons Attribution License (CC BY).

The LSO neuron output is analyzed with respect to sensitivity and time to reach 90% of the maximum LSO response. The results demonstrate that efferent feedback can be used to tune the LSO sensor responses to a certain ILD range sensitivity and balance sensor differences. The proposed system can be fully implemented in hardware, e.g. for SSL in resource-limited systems like robots.

[1] C. Lenk et al., Nat Electron, 6, 370–380, 2023.

[2] T. Oess et al., PLOS Comp. Biol., 16(7), e1008020, 2020.

[3] S. Durstewitz et al., Front. Neurosci, 20, 1736957, 2026.