Specialized Potassium Channel Properties Define the Tonotopic Gradient in the Avian Cochlear Nucleus

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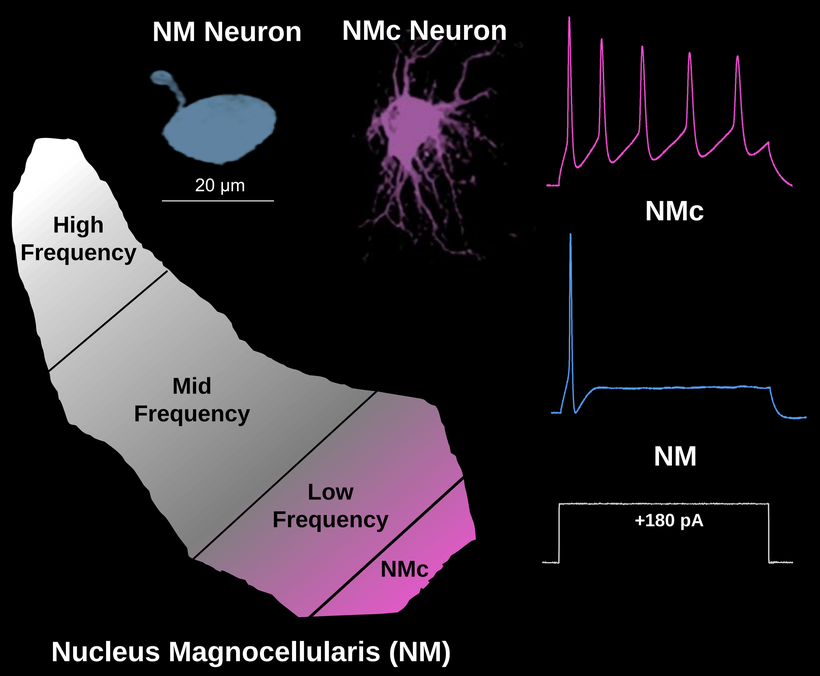
Background

- The avian nucleus magnocellularis (NM) is an analogous structure to the mammalian anteroventral cochlear nucleus (AVCN) and has a specialized tonotopic gradient.
- Low-frequency NM neurons (denoted NMc) have distinct structural and functional differences compared to higher-frequency NM neurons (Hong et al., 2018).
- Mature NM neurons are mostly adendritic, while NMc neurons retain profuse dendrites throughout development
- Functionally, NM neurons respond to a somatic current injection with one onset action potential, while NMc neurons fire multiple action potentials.
- NM and NMc neurons express differing amounts of potassium channels, but it is unknown how this affects the magnitude and speed of naturalistic potassium currents.
- Measuring the kinetics of potassium currents in these neuronal subtypes is essential to explain how and why NM and NMc neurons react differently to electrical input.



Nucleus Magnocellularis (NM)

Methods

Acute brainstem slices were prepared from White Leghorn chicken (*Gallus gallus domesticus*) at mature embryonic stages (embryonic days 19-21). Whole-cell current and voltage clamp recordings were obtained from NMc neurons in the most caudal slices of NM. Once the NMc phenotype was confirmed in current clamp recordings, potassium currents were isolated by adding 1µM TTX to the bath. Voltage commands of varying durations and strengths were activated in the soma of NMc and high-frequency NM neurons using an Axon Multiclamp 700B amplifier. Results were acquired and analyzed using Clampfit 11.0 analysis software.

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Potassium Tail Currents

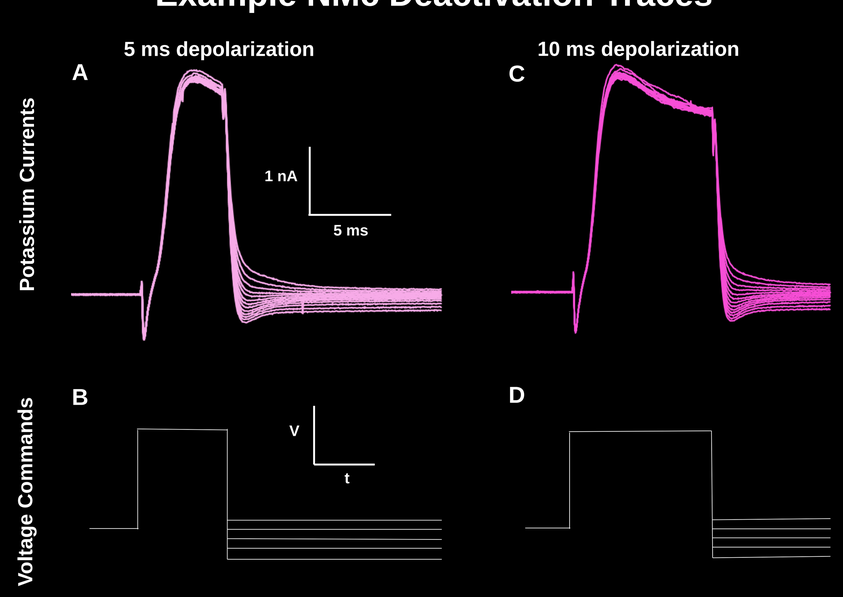

Figure 1: Representative traces of voltage deactivation steps. NMc neurons were held at -60 mV and then depolarized to +10 mV for 5, 10, or 75 milliseconds. Neurons were then repolarized to varying potentials between -64 and -124 mV. (A) Example potassium current traces in response to the voltage commands in (B), with a depolarization lasting for 5 ms. (C) Example potassium current traces in response to the voltage commands in (D), with a depolarization lasting for 10 ms.

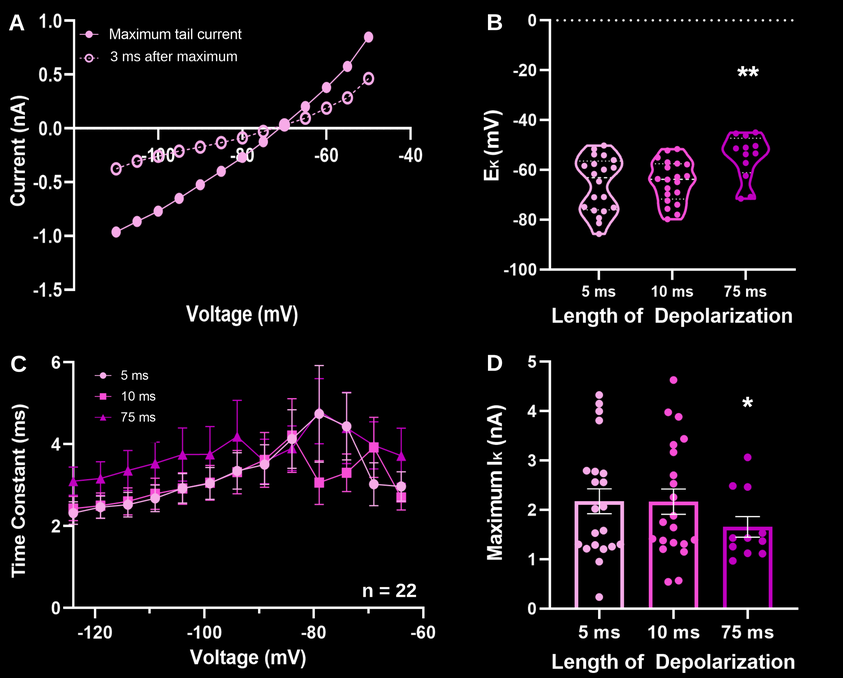

Figure 2: Characterization of potassium currents across depolarization lengths. (A) Representative I-V curve with tail currents plotted at their maximum and at 3 ms after their maximum. These were used to measure the reversal potential for potassium (E_K). (B) Reversal potentials for potassium measured across different depolarization lengths. (C) Time constants for potassium tail currents across different depolarization lengths. (D) Maximum potassium currents during a +10 mV depolarization step across different depolarization lengths.

NMc Versus NM Potassium Currents

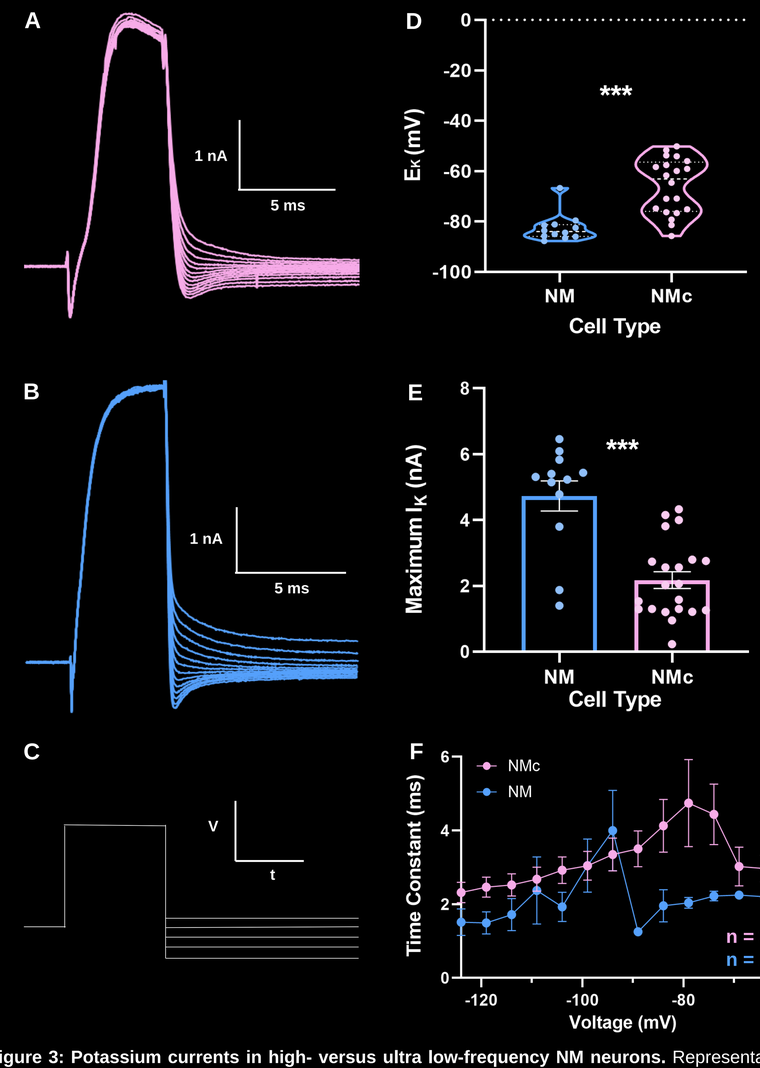

Figure 3: Potassium currents in high- versus ultra low-frequency NM neurons. Representative currents from (A) NMc and (B) NM neurons in response to the (C) voltage deactivation steps protocol with a 5 ms depolarization. (D) Measured reversal potentials for potassium, (E) Maximum potassium currents during a +10 mV depolarization, and (F) time constants of potassium tail currents are all significantly different across tonotopic regions.

Conclusions

1. Potassium tail current analysis contributes to the rich characterization of NMc neurons compared to their NM counterparts.
2. Depolarization length during voltage clamp protocols significantly affects the magnitude and speed of potassium currents. Shorter depolarizations (i.e., 10 ms or less) may elicit more relevant naturalistic potassium currents.
3. NM and NMc neurons exhibit unique potassium currents in response to voltage commands, as shown by their differences in current magnitude, time constant, and potassium reversal potential.
4. Future work using voltage clamp should incorporate shorter depolarization lengths to better mimic naturalistic electrical stimuli.