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Article

Cortical Membrane Potential Signature of Optimal States for Sensory Signal Detection

Matthew J. McGinley,[1,*] Stephen V. David,[2] and David A. McCormick[1,*]
[1]Department of Neurobiology, Kavli Institute for Neuroscience, Yale University School of Medicine, 333 Cedar Street, New Haven, CT 06510, USA
[2]Oregon Health & Science University, MS: L335A, 3181 SW Sam Jackson Park Rd, OHRC, Portland, OR 97239, USA
*Correspondence: matthew.mcginley@yale.edu (M.J.M.), david.mccormick@yale.edu (D.A.M.)
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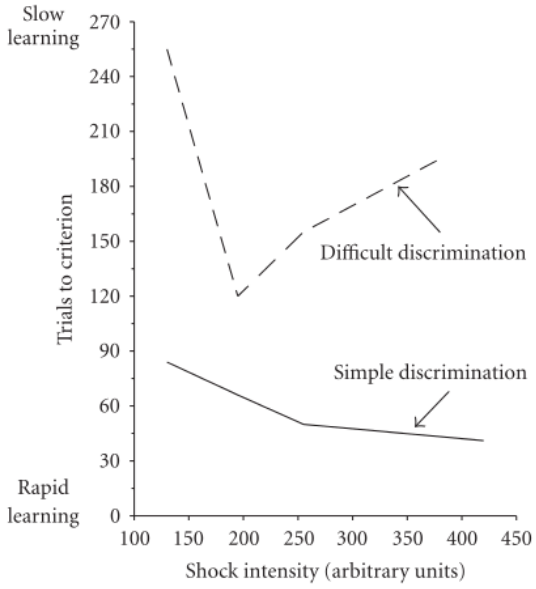
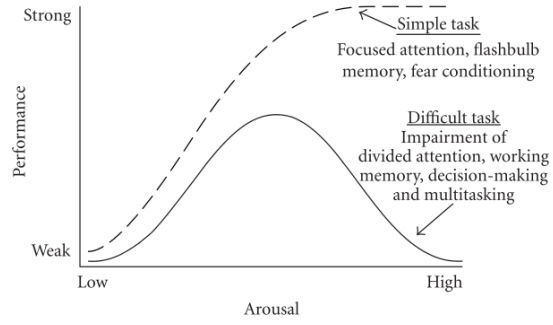
Optimal states for sensory signal detection

- inverted-U dependence on arousal: optimal performance occurs at intermediate levels of arousal





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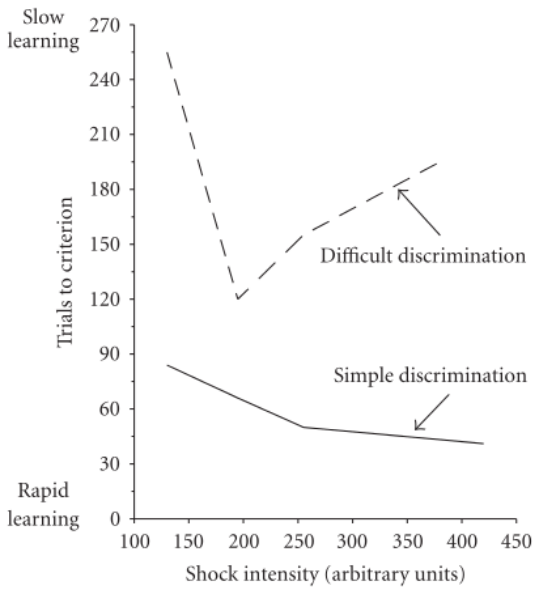

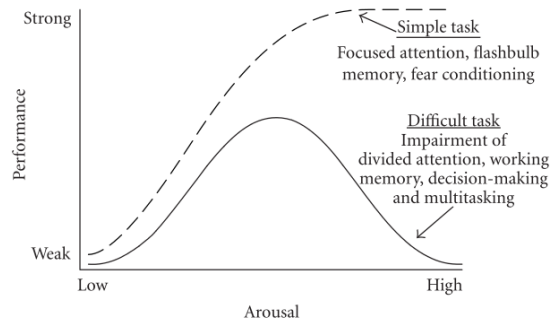

at what brain state does this occur?

- one hypothesis is that optimal states exhibit tonically depolarized cortical neurons with enhanced movement
  - whole cell patch clamp in monkey V1 during attention (Tan et al 2014)
  - and in mouse V1 while running (Stryker, Golshani,...)
- but recent experiments point to hyperpolarization in auditory cortex during arousal and running (Schneider et al, 2014, Williamson et al, 2015, ...)

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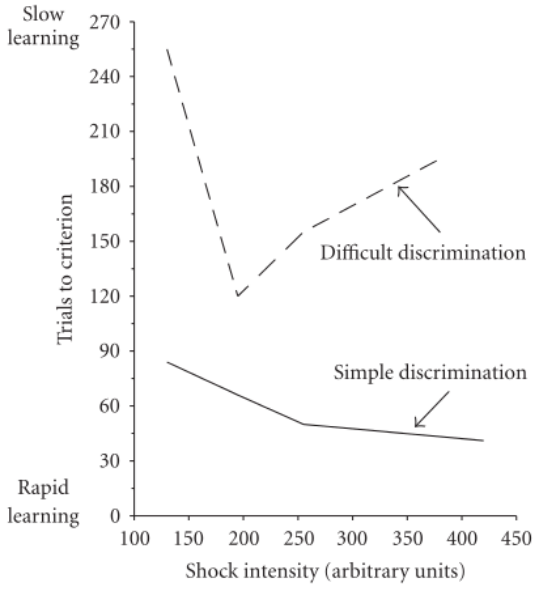
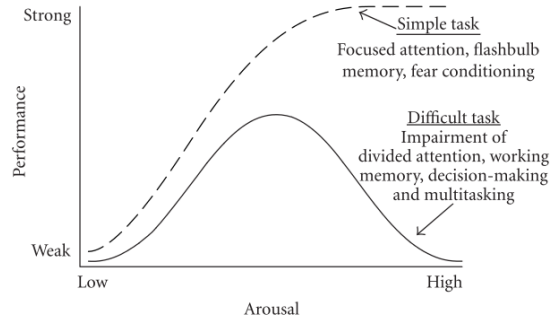
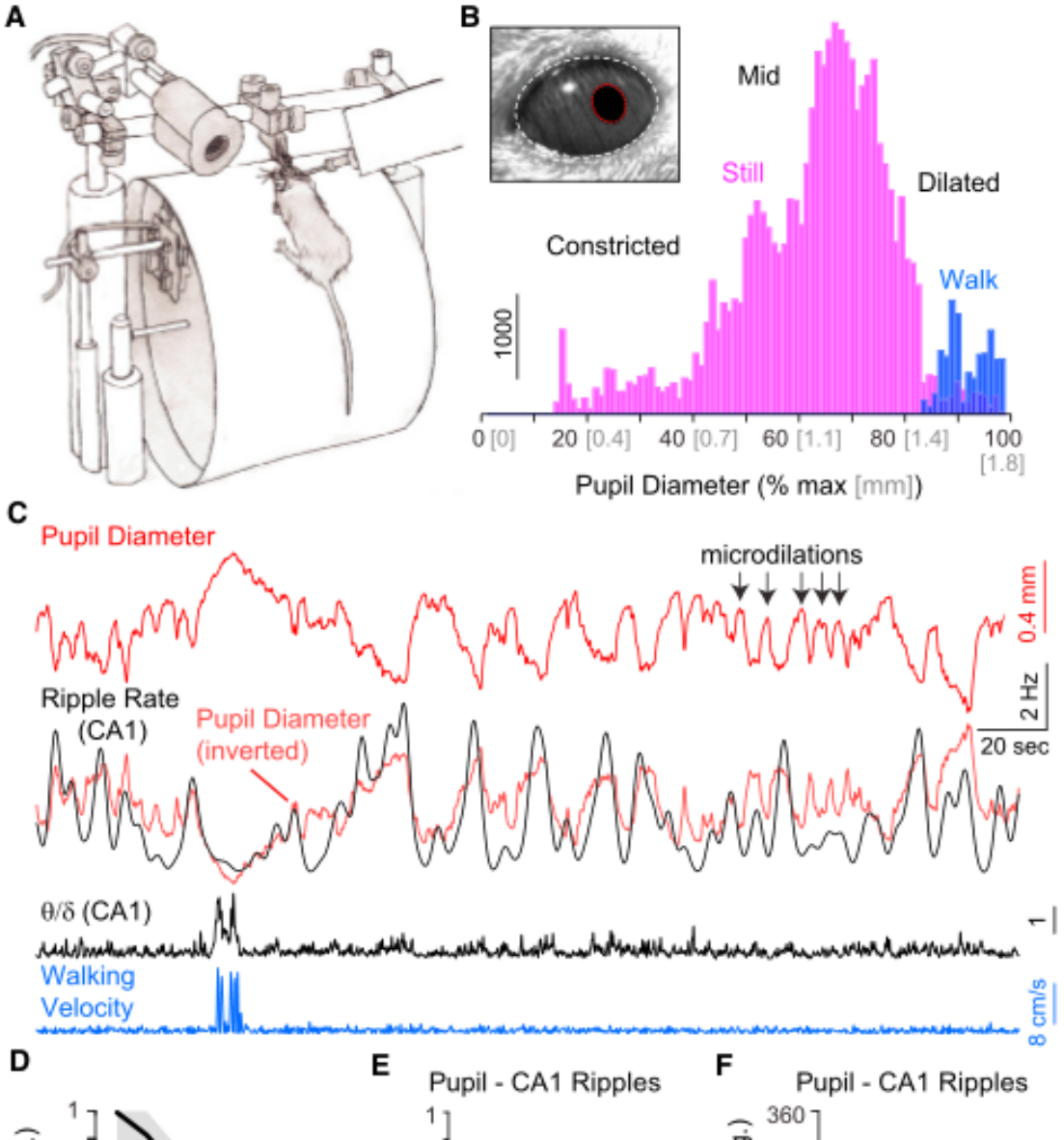




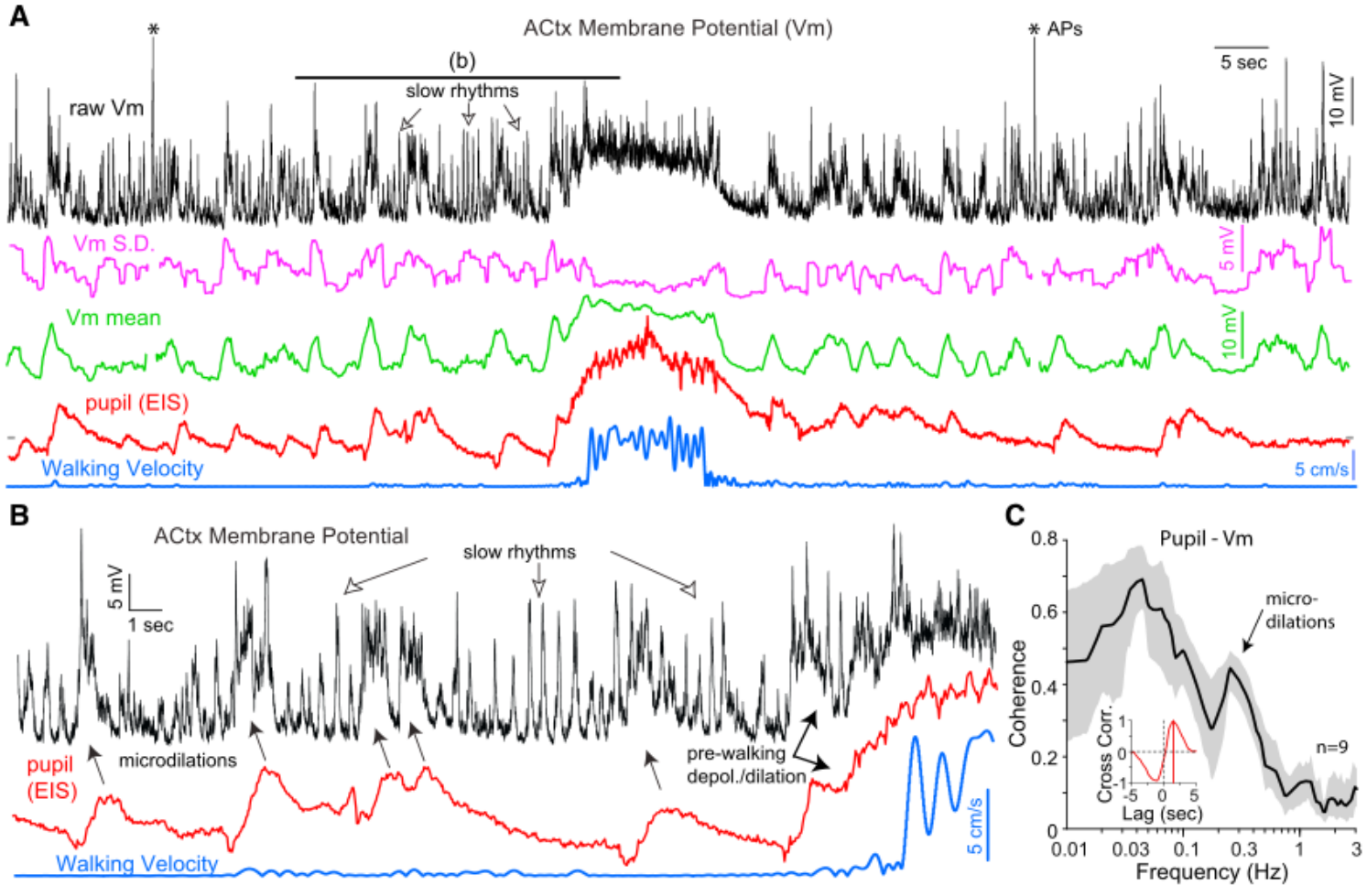
In this study,

- pupil closely tracks the rate of hippocampal sharp waves (another measure of arousal)
- slow fluctuations in low arousal, hyperpolarization in medium arousal and depolarization with hyper-arousal

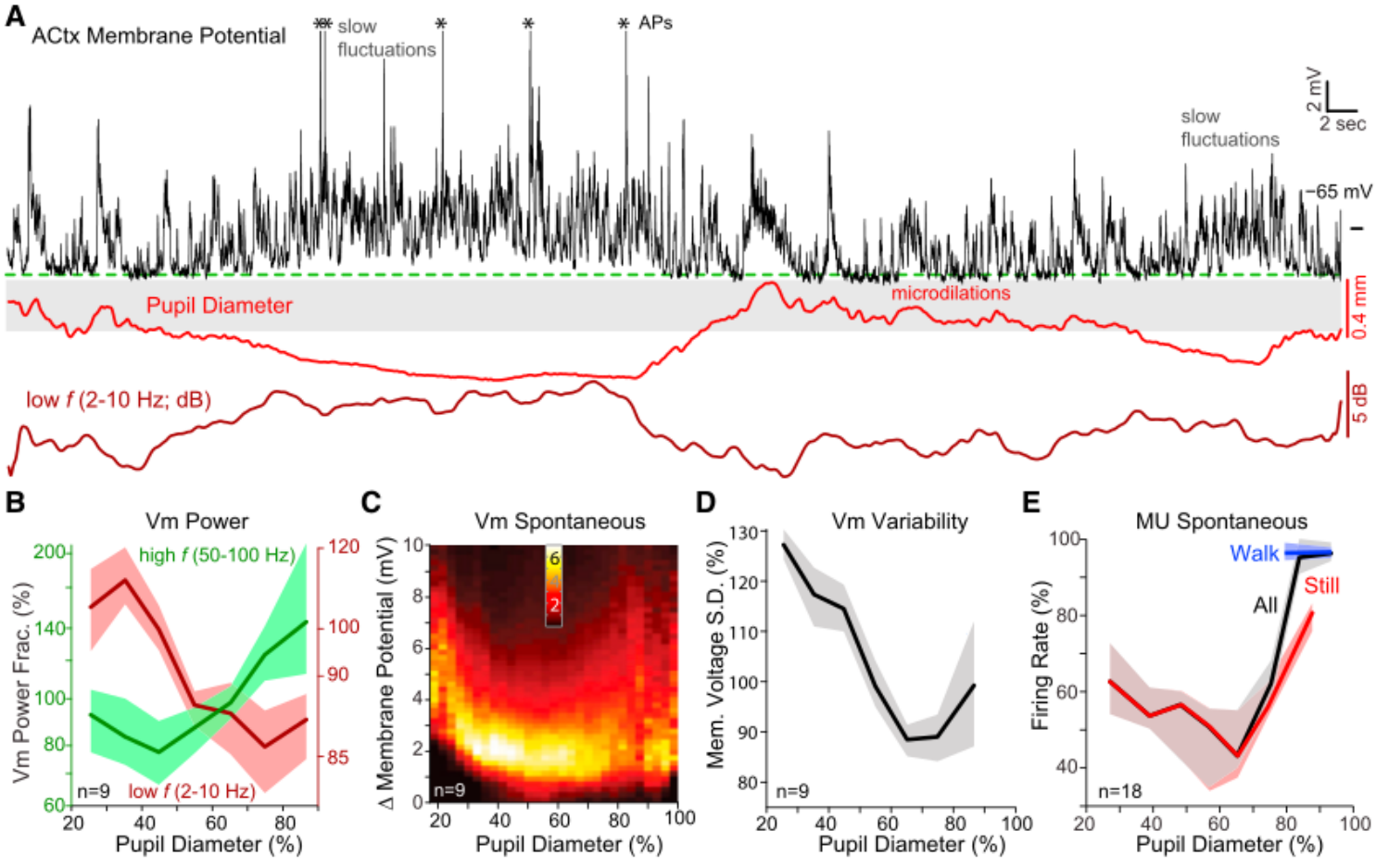
Peripheral and Central State Fluctuate Rapidly and Continuously in a Highly Correlated Manner in the Waking Mouse



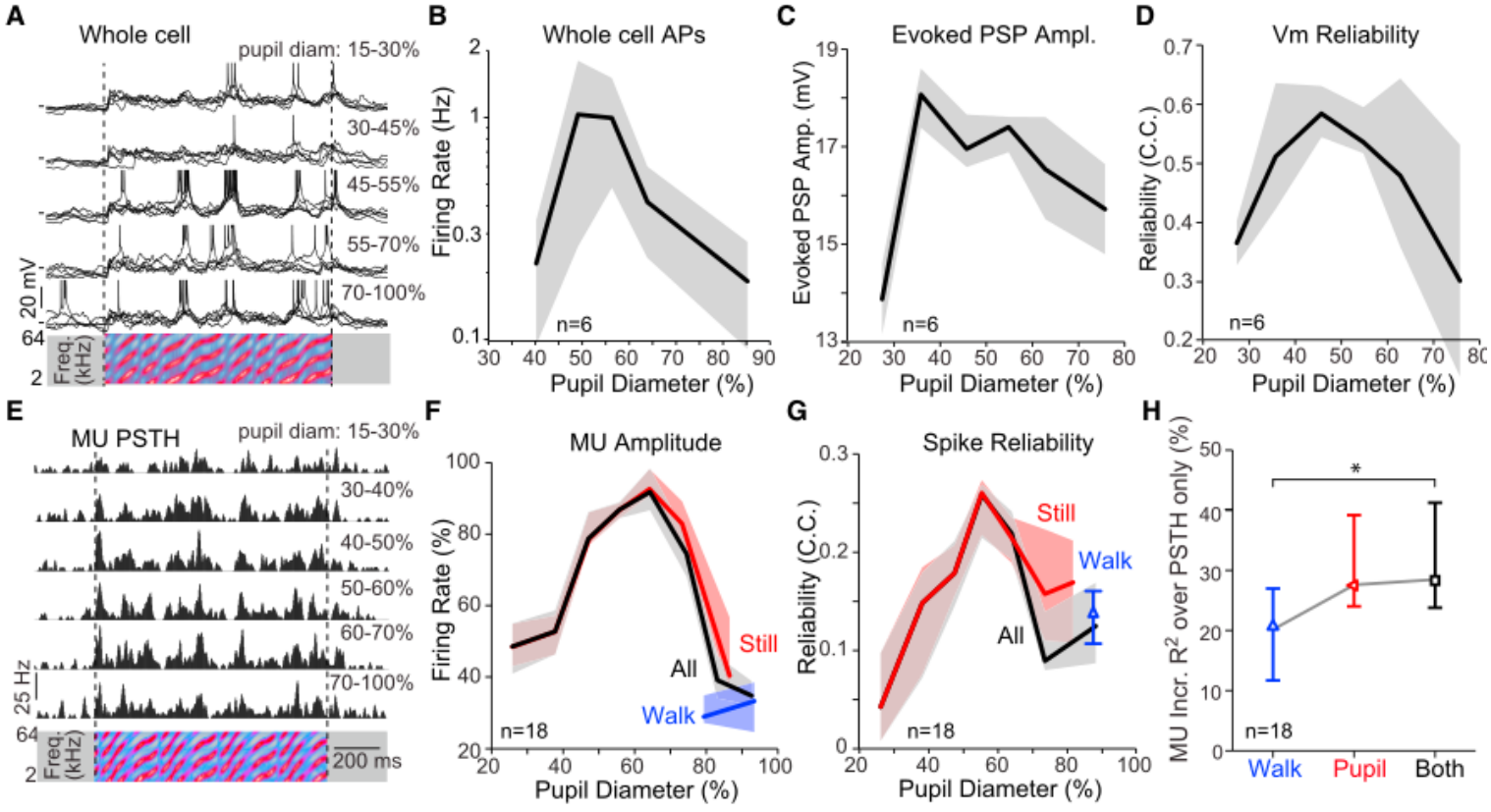
Global State Fluctuates Together with Cortical Membrane Potentials and Their Oscillations



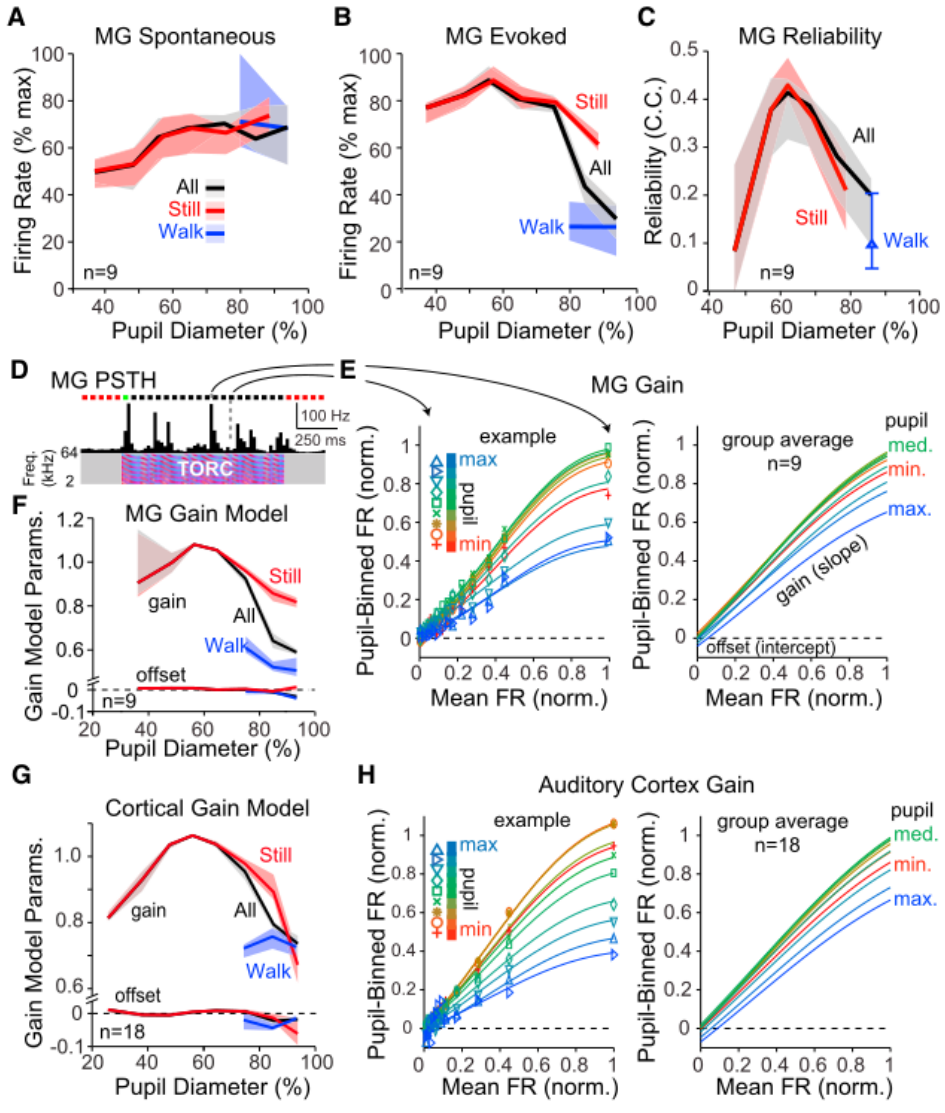
Neuronal Membrane Potentials and Their Variability Exhibit a U or an Inverted-U Relationship with Arousal, as Indexed by the Pupil Diameter



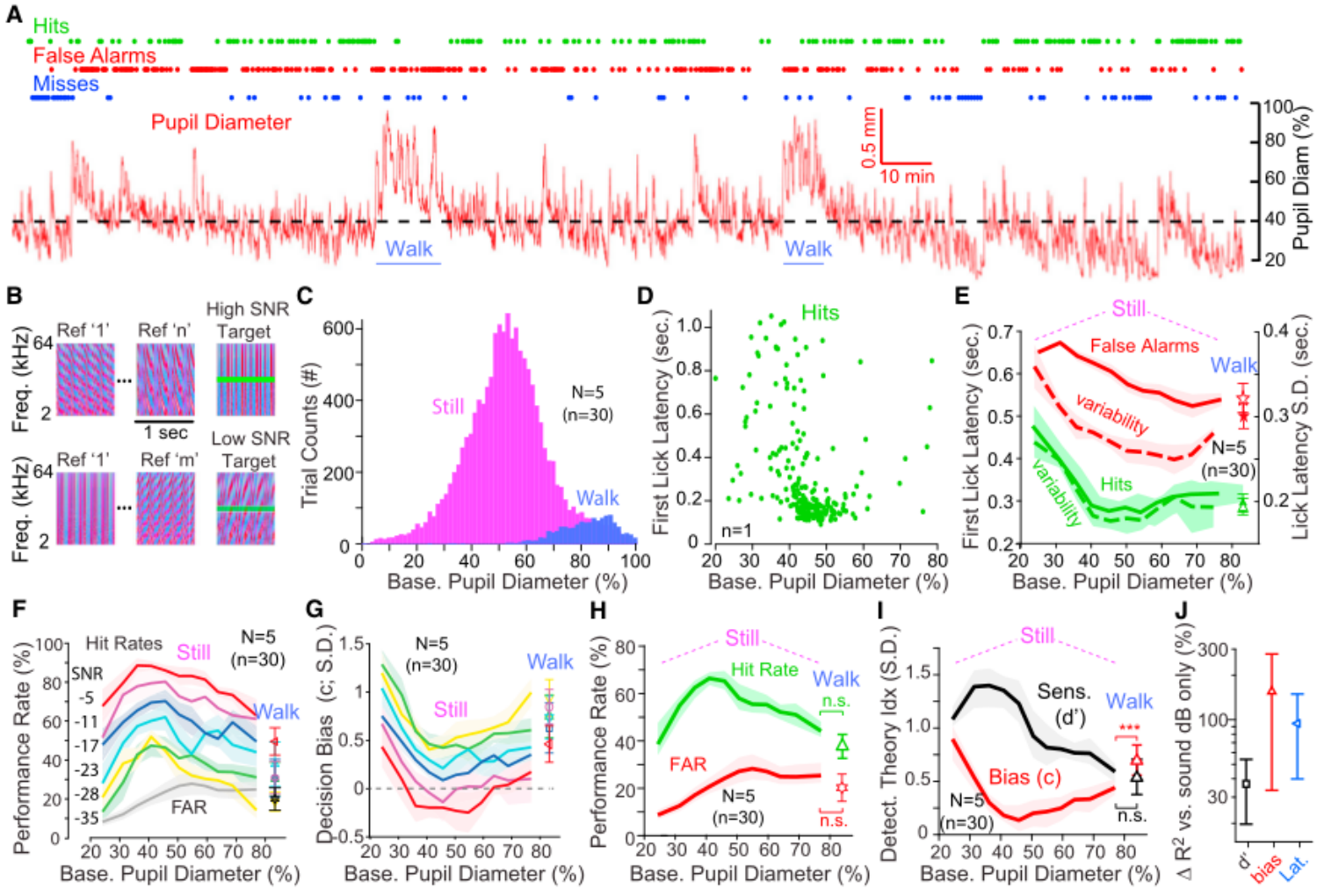
Subthreshold and Suprathreshold Evoked Responses in Auditory Cortex Are of Maximal Amplitude and Reliability at Intermediate Levels of Arousal



Gain of the signal is highest at intermediate pupil sizes



Sound Detection Performance Fluctuates Moment-to-Moment with State and Is Optimal at Intermediate Arousal Levels



Hyperpolarization of cortex before hit trials

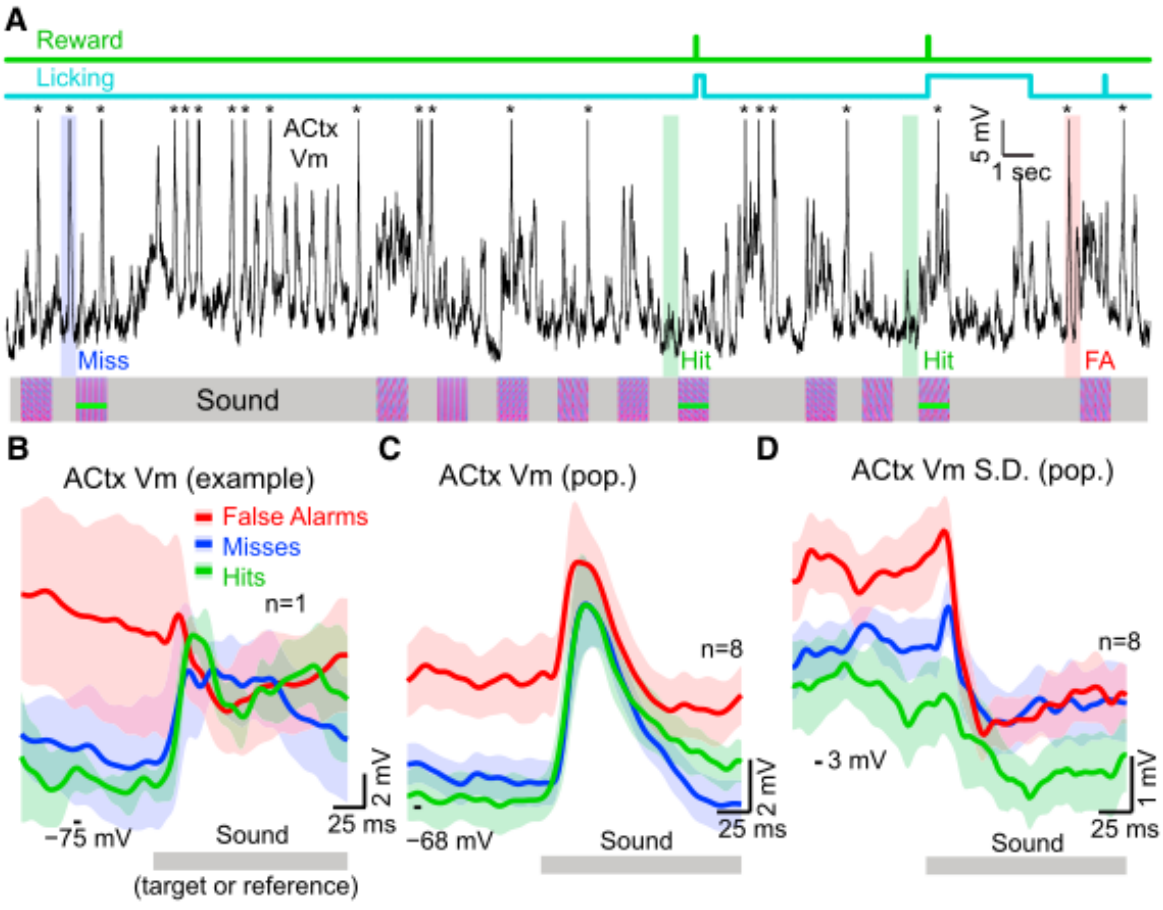


Figure 7. Auditory Cortical Membrane Potentials Are Most Hyperpolarized and Least Variable before Correct Target Identifications during the Detection Task

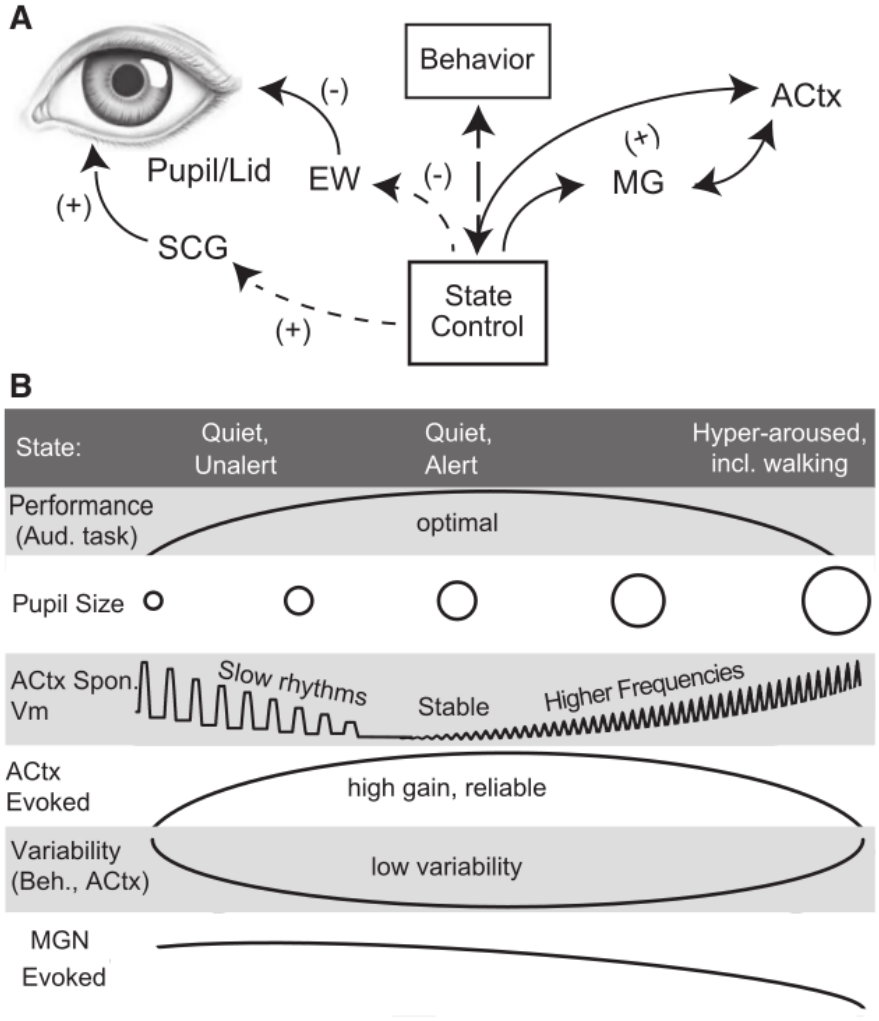
(A) An example membrane potential recorded during behavior. Lick patterns and reward administration are indicated at top. The sound spectrogram is recreated at bottom. Note horizontal green bars indicating the presence of target sounds and trial outcomes noted above. Asterisks indicate action potentials.

(B) The average membrane potential time course (± 1 SD) just before and after the start of sound, for all hits (green), misses (blue), and false alarms (FA; red) from an example recording during behavior.

(C) The average membrane potential trajectory sorted by trial type for the population of membrane potential recordings during behavior. Membrane potentials are hyperpolarized before hit trials, depolarized before false alarms, and intermediate before miss trials. Evoked responses are largest (from baseline) for hits and smallest for false alarms.

(D) The variability (SD) across trials of the membrane potentials, before and during the early component of sounds, is smallest for hit trials, largest for false alarms, and intermediate for miss trials. Data for Hit and Miss trials in (B)–(D) are resampled (1,000 times with replacement) to have equivalent target tone level distributions. Shaded areas indicate 68% CI unless noted.

Influence of Internal State on Neuronal and Behavioral Accuracy and Responsiveness



- activation of adrenergic receptors can reduce slow rhythms (blockage of these in mice eliminates depolarization from running)
- activation of inhibitory neurons (Schneider et al, 2014)