Supplementary Discussion

Inter-species differences in neural activity are common in the brain

Our finding of differences in hippocampal theta oscillation between echolocating-bats and rodents is not unusual in comparative studies of the brain: In fact, inter-species differences in neural activity have been widely reported in many brain areas. For example, the coding of sound location in brainstem auditory nuclei is different between birds and mammals, with place coding in birds and coding via precisely-timed inhibition in mammals\cite{1-3}; interestingly, a recent model has proposed that both of these coding schemes arise from common principles, and the coding difference may be due to differing constraints on sensory inputs\cite{4}. An example of between-mammal species differences is the temporal structure of neuronal responses in mammalian auditory cortex: In awake bats the responses are usually very brief and consist of $\leq 1$ spike per stimulus\cite{5,6}; in contrast, in awake (or lightly-anesthetized) monkeys and cats the responses tend to be prolonged, consisting of multiple spikes per stimulus and continuing throughout the stimulus duration\cite{7-10}, and sometimes hundreds of milliseconds after the stimulus ends\cite{10}. Finally, an example which involves network oscillations comes from olfactory processing in the insect antennal lobe: In some species (e.g. locusts) there is rate coding of odors as well as temporal coding, in the form of pronounced field-potential oscillations to which the spikes phase-lock\cite{11}, whereas in other species (e.g. drosophila) there is also a clear rate coding, but no evidence for oscillations in this brain area\cite{12}.

Evolutionary relations between bats and other mammals, and implications for neural activity

Evolutionary history may explain some of the reported inter-species differences in hippocampal activity, between species that show continuous theta (e.g. rodents, rabbits, cats) and species that seem to show intermittent bouts of theta (bats, monkeys, humans). Rodents and rabbits are two groups that are closely related evolutionarily\cite{13-16}, so it may not be surprising that their theta oscillations have quite similar properties. Until recently, classifications of mammalian species, based largely on morphology, considered bats (together with flying lemurs and tree shrews) as the closest relatives of primates, placing them all together in one grand-order, Archonta\cite{13,16} – so one might speculate that these phyletic relations could underlie similarities in brain function between bats and primates. Recent studies\cite{14-16}, however, that have also incorporated molecular data, have
suggested that bats are in fact less close to primates and are more closely related to carnivores, such as cats – making this evolutionary link less likely for theta-bouts, but providing a possible link between bats and cats, both of which show maximal theta during non-locomotion behaviors.

References