# Time-Frequency Analysis of Hippocampal Ripple-like Rhythms

***Jesse A. Gillis, Liang Zhang and Frances K. Skinner***
*Toronto Western Research Institute, University Health Network*
*and University of Toronto*

## ABSTRACT

EEG recordings of the hippocampus reveal the presence of distinct rhythms, including sharp wave associated ripples. We analyze *in vitro* hippocampal activity exhibiting drug induced ripple-like activity using time-frequency distributions drawn from Cohen's class of distribution and the wavelet transform. We characterize this behaviour and compare it to baseline data to identify any underlying trends. Through this comparison and employing mixture distribution analysis, we identify the presence of baseline activity sharing distinctively ripple-like characteristics, while not possessing the high frequency behaviour of ripples. These near-ripples differ from ripples in their duration, suggesting the abortive action of the ripple-like mechanism.

## SUMMARY

### Introduction

Electroencephalogram (EEG) recordings of the hippocampus reveal the presence of specific frequency associations with distinct behavioural states. Sharp wave associated ripple-like activity occurring in the 150-200 Hz range is present during awake immobility, consummatory behaviour, and slow-wave sleep. This frequency would be suitable for LTP induction, suggesting an important physiological role for ripple-like rhythms [1, 2]. One question which arises from recordings of these EEG signals is whether the classes of rhythmic activity characterized by different mean frequencies share underlying similarities in their frequency behaviour outside their differences in mean: Is the generation of ripples related in mechanism to the generation of baseline data? One example of this might be a similarity in the distribution of activity in a given frequency range. If these similarities were present in a continuum, they might suggest a single mechanism underlying otherwise different classes of activity, which is not true of mean frequency data for ripples [4].

### Signal Analysis Techniques

Because the rhythms observed are biological, techniques to characterize frequency which assume stationarity are often inappropriate. To generate time-frequency plots, a common choice is to use Cohen's class of distributions, the most familiar of which are the spectrogram and the Wigner distribution. Unfortunately, the Wigner distribution generates interference patterns from the interaction of cross-terms, due to its nonnegative energy distribution rendering it less suitable for multicomponent signals; this is a common problem.

Work focussing on the interference properties of these distributions, has yielded alternatives with more useful properties, such as the ZAM distribution [6] and the Reduced Interference Distribution (RID) [3]. Outside of Cohen's class of distribution, the wavelet transform results in a time-frequency domain tiled so that technique gives good frequency resolution at low frequencies, and good time resolution at high frequencies. Since signals which have high frequency might be thought to change frequency more rapidly with time, this is often an appropriate choice. Because we wish to have the option of comparing across data sets, the Matching Pursuit technique [5] was not considered.

In this work, we compare the suitability of these techniques to determine a more complete characterization of ripple-like behaviour. We examine its similarities with baseline activity.

## Experimental Data and Results

Ripples were induced in an *in vitro* preparation of the hippocampi of mice by application of 1,3-dipropyl-8-cyclopentylxanthine and 20 CA1/3 field EEG recordings, sampled at 10,000 Hz comprised the data set. Time-frequency plots of the data were generated using the spectrogram, the Wigner distribution, the ZAM distribution, the RID, and the wavelet transform. Local peaks in amplitude were extracted from the resultant plots using convolution with a smoothed derivative, characterized in terms of duration, binned, and examined for the presence of mixtures of normal distributions using the EM algorithm. The frequency distribution of the ripples was compared to the baseline signal to determine whether aspects of ripple-like behaviour preceded the occurence of ripples.

Ripples exhibited highly distinctive frequency distributions, even in the lower (5-30 Hz) frequency range, and these distributions remained similar between ripples and dissimilar from baseline activity. More interestingly, activity which would otherwise appear to be part of the baseline signal, also sometimes exhibited ripple-like behaviour within this frequency range, while still lacking the high frequency component which defines ripple-like activity. The incidence of these near-ripples seems unrelated to the appearance of ripples, but occurred at a similar level of incidence. Binning local highs by duration at a given frequency or over multiple frequencies placed near-ripples in a shorter duration range than that typical for ripples.

Ripple-like rhythms exhibited a highly distinctive frequency distribution throughout their domain, including that which overlap with the non-rippling signal. Since this distribution is very occasionally present in the baseline activity, it suggests the possibility of an abortive ripple before the full threshold for ripple-like oscillations is reached. Alternatively, this could represent hidden ripple-like activity which should be distinguished from the rest of the signal. Arguing against the latter possibility is that the near-ripples are of significantly shorter duration than clearly identifiable ripples, and no similarly hidden high frequency component is detectable.

In conclusion, our analysis suggests that elements of ripple-like rhythms can be extracted using time-frequency techniques. We suggest this as a possible avenue to explore for predicting the occurence of hippocampal ripple rhythms.

# References

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