How to read an academic paper

CoB- Kavli Summer Scholar Workshop 2022

Presented by Sana Ali, Michael Preston & Quirine van Engen

Why read an academic paper?

Learn background information relevant to your research project e.g. what is known & what gaps exists

Gain inspiration for potential research questions or approaches to studying a topic of interest

What is an academic paper?

Review papers

Trends in Neurosciences

CellPress
REVIEWS

Special Issue: Time in the Brain

Forum

Millisecond Spike Timing Codes for Motor Control

Samuel J. Sober,[1] Simon Sponberg,[2] Ilya Nemenman,[3] and Lena H. Ting[4,*]

Millisecond variations in spiking patterns can radically alter motor behavior, suggesting that traditional rate-based theories of motor control require revision. The importance of spike timing in sensorimotor control arises from dynamic interactions between the nervous system, muscles, and the body. New mechanisms, model systems, and theories are revealing how these interactions shape behavior.

The brain uses sequences of spikes to encode sensory input and control motor output. In principle, neurons might encode information via their firing rates, the precise timing of their spikes, or some combination of the two. Rate-based approaches have generally dominated theories of motor coding, as they are computationally tractable and can account for many aspects of motor behavior. For example, spike rates in individual neurons or population ensembles computed over relatively long time-bins have predicted features of movement kinematics in a number of vertebrate species, suggesting a rate-based control scheme [1]. Another reason rate codes have dominated motor control is that muscle force production has been assumed to have slow dynamics and because muscle force grossly scales with spike rate. The role of spike timing, by contrast, is relatively underexplored in motor systems, although nonlinearities in muscle force production and movement biomechanics hint at its potential importance [3,4]. Notably, in the context of sensory systems, the importance of precise spike timing in information processing has been shown [2]. Critically, however, whether precise spike timing causally affects either perception or behavior remains largely unknown. Here we explore growing evidence that millisecond-scale precision in spike timing patterns can control motor behavior.

Far from being just low-pass filters, muscle and body biomechanics can afford many opportunities for spike timing to profoundly impact motor output. We emphasize that the diversity of codes in motor systems is neither a dichotomy ('rate vs. timing') nor a continuum between two extremes. Phase codes, context-dependent codes mediated by biomechanics, and higher-order codes that extend across multiple neurons or inter-spike intervals (higher-order rate/timing codes) comprise a broader family of codes that motivate further exploration.

When a Millisecond Matters: Correlative and Causal Evidence

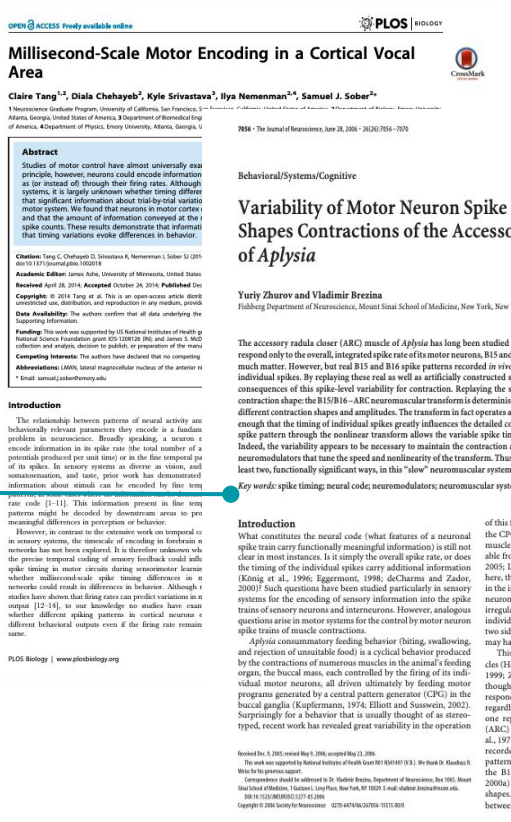
Correlative evidence that millisecond spike timing differences affect behavior has been shown across a wide range of species and behaviors. Mammalian motor units regularly exhibit doublets and triplets with interspike intervals of 5–10 ms; occurrences increase as muscles fatigue, presumably to increase force via central mechanisms [3]. Recent examples show that spike timing correlates with variations in both fast and slow periodic behaviors, or with selection of different behavioral programs (Figure 1A). In hawk moths, spikes in the left and right wing power muscles are synchronized with sub-millisecond precision; left-right spike timing differences of only 8 ms can drive 200% changes in muscle power and predict torques during turning [5]. In songbird vocalization, 1-millisecond variations in spike timing in motor cortex neurons provide far more information about song syllable acoustic structure than do variations in spike rates over tens of milliseconds [6]. Moreover, in songbird breathing behaviors, millisecond-scale changes in the timing of a single spike in a burst of respiratory muscle fibers predicts differences in breathing dynamics that unfold over hundreds of milliseconds. In flies, millisecond-scale timing differences between a giant fiber interneuron and parallel circuits predict a choice between escape behaviors: one slower and more stable, the other faster but less controlled [7].

Causal studies provide even stronger evidence for precise timing patterns in motor control. In both fast and slow mammalian muscles, adding one or two pulses of electrical stimulation at millisecond-scale intervals within a lower-frequency stimulation train increases peak muscle force by up to 50% without significantly altering spike rate [3]. In *Aplysia*, 'playbacks' of real and manipulated spike trains *in vitro* demonstrate that changes in spike timing on the scale of ~10 ms have large effects on ingestion behaviors that manifest over several seconds [4,8]. In insects, manipulating millisecond-scale spiking precision affects steering in hawk moths, and the selection of escape behaviors in flies [5,7]. Finally, in songbirds, precisely-timed millisecond-scale variations in electrical stimulation of respiratory muscles strongly modulate breathing output [9].

Why a Millisecond Matters: Motor Codes Interact with System Biomechanics

Intuitively, it would seem that a millisecond could hardly affect muscle force output, as a spike elicits a 40–100 ms force twitch in mammalian striated muscles [3]. Nonetheless, at least three classes of mechanisms enable small timing changes to profoundly alter motor output *in vivo*: (i) muscle properties, (ii)

Primary research articles



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PLOS | BIOLOGY

Millisecond-Scale Motor Encoding in a Cortical Vocal Area

Claire Tang[1,2], Diala Chehayeb[2], Kyle Srivastava[3], Ilya Nemenman[2,4], Samuel J. Sober[2]*

Abstract

Studies of motor control have almost universally exa
principle, however, neurons could encode information
as (or instead of) through their firing rates. Although
systems, it is largely unknown whether timing differe
that significant information about trial-by-trial variatio
motor system. We found that neurons in motor cortex
and that the amount of information conveyed at the
spike counts. These results demonstrate that informat
that timing variations evoke differences in behavior.

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Abbreviations: LMAN, lateral magnocellular nucleus of the anterior n

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Introduction

The relationship between patterns of neural activity an
behaviorally relevant parameters they encode is a fundam
problem in neuroscience. Broadly speaking, a neuron
encode information in its spike rate (the total number of a
potentials produced per unit time) or in the fine temporal pa
of its spikes. In sensory systems as diverse as vision, audi
somatosensation, and taste, prior work has demonstrated
information about stimuli can be encoded by fine temp
rate code [1–11]. This information present in fine temp
patterns might be decoded by downstream areas to pro
meaningful differences in perception or behavior.

However, in contrast to the extensive work on temporal co
in sensory systems, the timescale of encoding in forebrain n
networks has not been explored. It is therefore unknown wh
the precise temporal coding of sensory feedback could influ
spike timing in motor circuits during sensorimotor learnin
whether millisecond-scale spike timing differences in m
networks could result in differences in behavior. Although
studies have shown that firing rates can predict variations in m
output [12–14], to our knowledge no studies have exam
whether different spiking patterns in cortical neurons
different behavioral outputs even if the firing rate remain
same.

Behavioral/Systems/Cognitive

Variability of Motor Neuron Spike Timing Maintains and Shapes Contractions of the Accessory Radula Closer Muscle of *Aplysia*

Yuriy Zhurov and Vladimir Brezina

Fishberg Department of Neuroscience, Mount Sinai School of Medicine, New York, New York 10029

The accessory radula closer (ARC) muscle of *Aplysia* has long been studied as a typical "slow" muscle, one that would be assumed to respond only to the overall, integrated spike rate of its motor neurons, B15 and B16. The precise timing of the individual spikes should not much matter. However, but real B15 and B16 spike patterns recorded *in vivo* show great variability that extends down to the timing of individual spikes. By replaying these real as well as artificially constructed spike patterns into ARC muscles *in vitro*, we examined the consequences of this spike-level variability for contraction. Replaying the same pattern several times reproduces precisely the same contraction shape: the B15/B16–ARC neuromuscular transform is deterministic. However, varying the timing of the spikes produces very different contraction shapes and amplitudes. The transform in fact operates at an interface between "fast" and "slow" regimens. It is fast enough that the timing of individual spikes greatly influences the detailed contraction shape. At the same time, slow integration of the spike pattern through the nonlinear transform allows the variable spike timing to determine also the overall contraction amplitude. Indeed, the variability appears to be necessary to maintain the contraction amplitude at a robust level. This phenomenon is tuned by neuromodulators that tune the speed and nonlinearity of the transform. Thus, the variable timing of individual spikes does matter, in at least two, functionally significant ways, in this "slow" neuromuscular system.

Key words: spike timing; neural code; neuromodulators; neuromuscular system; motor control; feeding behavior

Introduction

What constitutes the neural code (what features of a neuronal spike train carry functionally meaningful information) is still not clear in most instances. Is it simply the overall spike rate, or does the timing of the individual spikes carry additional information (König et al., 1996; Eggermont, 1998; deCharms and Zador, 2000)? Such questions have been studied particularly in sensory systems for the encoding of sensory information into the spike trains of sensory neurons and interneurons. However, analogous questions arise in motor systems for the control by motor neuron spike trains of muscle contractions.

Aplysia consummatory feeding behavior (biting, swallowing, and rejection of unsuitable food) is a cyclical behavior produced by the contractions of numerous muscles in the animal's feeding organ, the buccal mass, each controlled by the firing of its individual motor neurons, all driven ultimately by feeding motor programs generated by a central pattern generator (CPG) in the buccal ganglia (Kupfermann, 1974; Elliott and Susswein, 2002). Surprisingly for a behavior that is usually thought of as stereotyped, recent work has revealed great variability in the operation of this feeding system. Essentially all parameters of the cycling of the CPG, the bursts of motor neuron firing, contractions of the muscles, and the movements of the behavior are extremely variable from one cycle to the next (Horn et al., 2004; Brezina et al., 2005; Lum et al., 2005; Zhurov et al., 2005b). As we document here, there is great variability also within each cycle, in particular, in the irregular timing of the successive spikes within each motor neuron burst. Intriguingly, Zhurov et al. (2005b) found that these irregular bursts are nevertheless synchronized down to even the individual spike level in the corresponding motor neurons on the two sides of the animal, suggesting that the detailed spike timing may have functional significance.

This, however, is puzzling. Like many other invertebrate muscles (Hoyle, 1983; Morris and Hooper, 1997, 1998; Hooper et al., 1999; Zoccolan et al., 2002), the buccal muscles of *Aplysia* are thought to be "slow." That is, it would be assumed that they respond only to the overall spike rate, integrated over long times, regardless of the detailed spike timing. Here we work *in vitro* with one representative buccal muscle, the accessory radula closer (ARC) muscle, and its two motor neurons B15 and B16 (Cohen et al., 1978). By replaying into the motor neurons the spike patterns recorded during normal feeding *in vivo* and other, comparable patterns with particular statistical properties, we investigate how the B15/B16–ARC neuromuscular transform (Brezina et al., 2000a) transforms the spike patterns into muscle contraction shapes. We find that the transform in fact operates at an interface between "fast" and "slow" regimens. It is fast enough that the

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Conducting a literature search

Databases:

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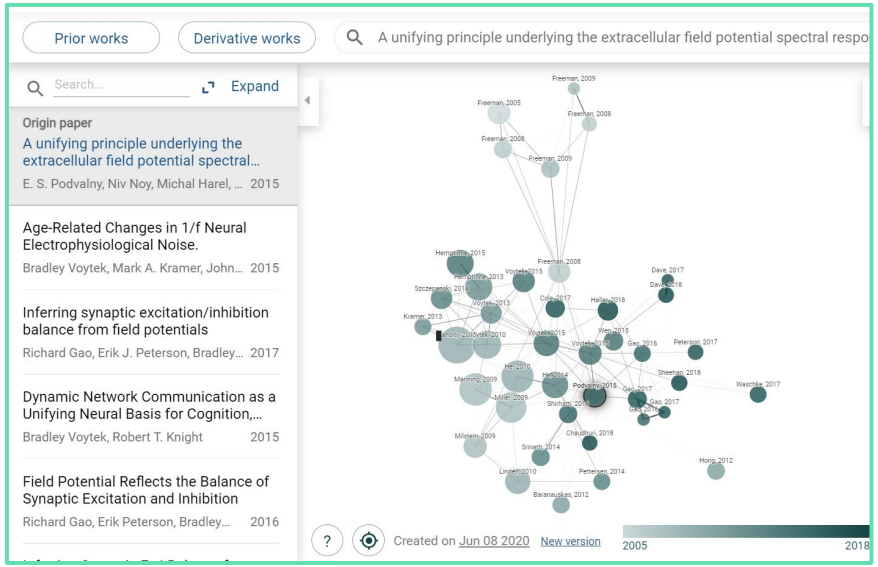
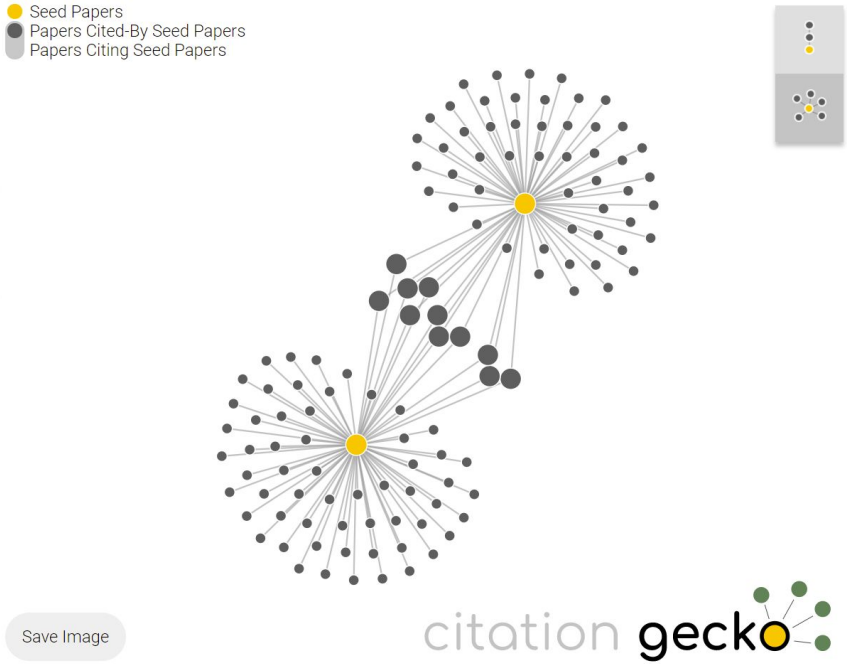
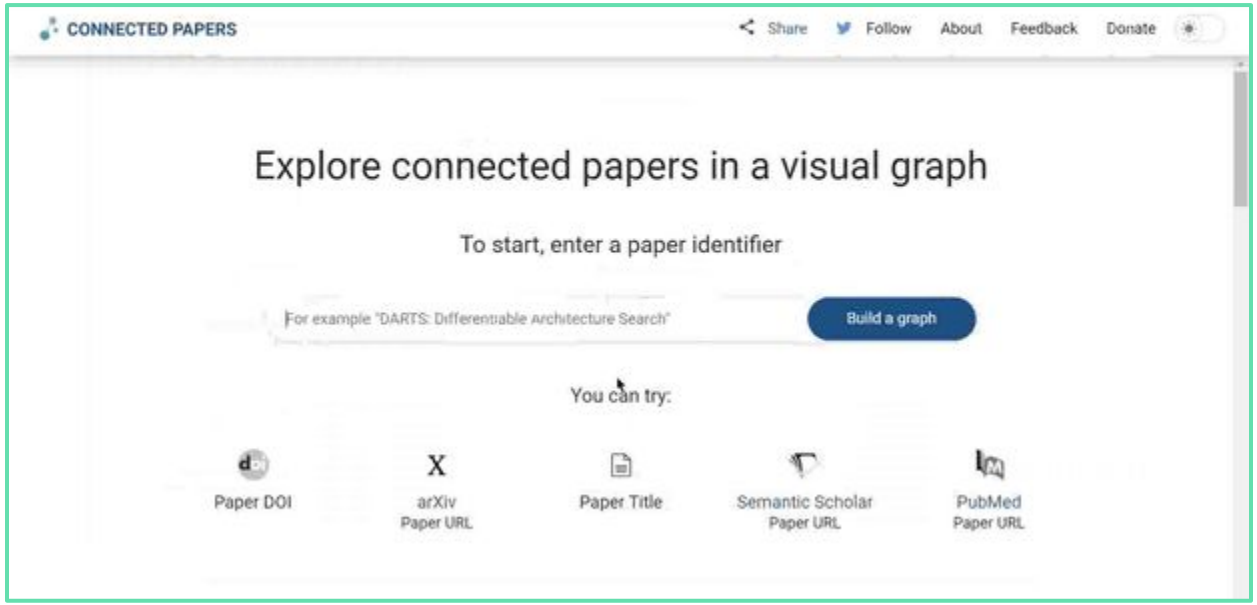
CONNECTED PAPERS





Finding connected papers



Reading an academic paper

General Structure

Title, abstract, keywords

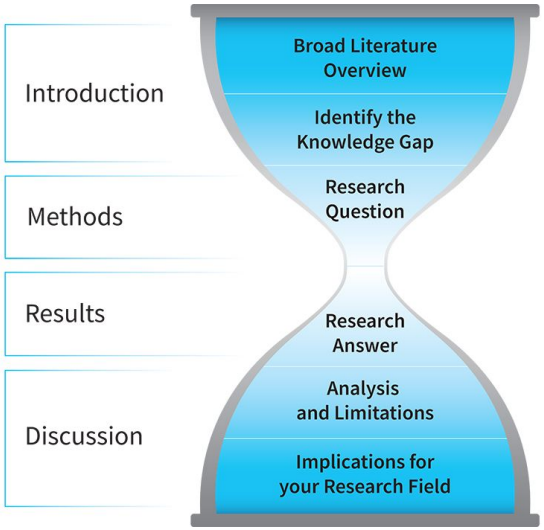
Easy for indexing and searching; condensed summary statement (~500 words); keywords assigned to article in journal

Main Text (IMRAD)

Introduction, Methods, Results And Discussion

Conclusions
Acknowledgments
References
Supplement

Citations; authors conflict of interest; supporting grants; supplementary information



Abstract

01

02

03

Summary of article
Help reader decide whether to read full article

Often addresses **major components** of manuscript

- *Intro*
- *Methods*
- *Results*
- *Conclusions*

Visual abstracts are becoming more popular

Memory-related hippocampal activation in the sleeping toddler

Janani Prabhakar[a,1], Elliott G. Johnson[a], Christine Wu Nordahl[b,c], and Simona Ghetti[a,d,1]

Nonhuman research has implicated developmental processes within the hippocampus in the emergence and early development of episodic memory, but methodological challenges have hindered assessments of this possibility in humans. Here, we delivered a previously learned song and a novel song to 2-year-old toddlers during natural nocturnal sleep and, using functional magnetic resonance imaging, found that hippocampal activation was stronger for the learned song compared with the novel song. This was true regardless of whether the song was presented intact or backwards. Toddlers who remembered where and in the presence of which toy character they heard the song exhibited stronger hippocampal activation for the song. The results establish that hippocampal activation in toddlers reflects past experiences, persists despite some alteration of the stimulus, and is associated with behavior. This research sheds light on early hippocampal and memory functioning and offers an approach to interrogate the neural substrates of early memory.

hippocampal development | episodic memory | early childhood development | fMRI

The first sentence typically introduces the topic; it also implies the question underlying this research study.

The next sentence details the data, research, and analytic methods used in this new study.

The major findings from the study.

The implications and significance of this study.

Keywords assigned to this article

Introduction

01

02

03

What is an introduction

- Introduces background information necessary to understand the article
- Identifies gaps in current knowledge that will be addressed in the paper

Goal of introduction

- Contextualizes the paper in the larger body of literature
- Explains the significance of the paper

When reading an introduction

- Identify main hypothesis and motivation for study
- Identify relevant literature for future review

Introduction

SUMMARY

Working memory is thought to result from sustained neuron spiking. However, computational models suggest complex dynamics with discrete oscillatory bursts. We analyzed local field potential (LFP) and spiking from the prefrontal cortex (PFC) of monkeys performing a working memory task. There were brief bursts of narrow-band gamma oscillations (45–100 Hz), varied in time and frequency, accompanying encoding and re-activation of sensory information. They appeared at a minority of recording sites associated with spiking reflecting the to-be-remembered items. Beta oscillations (20–35 Hz) also occurred in brief, variable bursts but reflected a default state interrupted by encoding and decoding. Only activity of neurons reflecting encoding/decoding correlated with changes in gamma burst rate. Thus, gamma bursts could gate access to, and prevent sensory interference with, working memory. This supports the hypothesis that working memory is manifested by discrete oscillatory dynamics and spiking, not sustained activity.

INTRODUCTION

The ability to keep information available in the absence of sensory input is a key component of working memory (WM) and one of the most studied cognitive functions (Fuster and Alexander, 1971; Goldman-Rakic, 1995; Miller and Cohen, 2001). It is widely assumed to have a neural correlate in sustained neural activity in higher-order cortical areas, such as the prefrontal cortex (PFC) (Fuster and Alexander, 1971; Funahashi et al., 1989; Goldman-Rakic, 1995; Miller et al., 1996; Pasternak and Greenlee, 2005). The mechanism, at first glance, seems straightforward: a sensory event elicits spiking activity that is maintained until that information is needed. This seemingly continuous delay activity may, however, reflect averaging across trials and/or neurons. Closer examination has suggested that the underlying dynamics are more complex (Rainer and Miller, 2002; Shafi et al., 2007; Stokes, 2015). For example, random sampling of neurons indicates that individual neurons bridging a multi-second memory delay is rare. Instead, most neurons show brief bouts of activity with variable onset latency and durations, sprinkled throughout the delay (Cromer et al., 2010; Shafi et al., 2007), suggesting highly dynamic activity (Durstewitz and Seamans, 2006; Stokes et al., 2013).

Continuous, persistent WM information can be simulated by attractor networks, originally serving as models for maintenance of saccade information (Amit and Brunel, 1997; Compte et al., 2000). In these models, information about saccade location is held in a persistent state without interruption. This state corresponds to a dynamic attractor and is supported by recurrent connections that sustain a pattern of activity. If this activity is disrupted, the information it was conveying is lost. By contrast, a related class of attractor models suggests that WM activity is non-stationary. Information is only expressed as spiking during short-lived attractor states. Between the active states, information is held by selective synaptic changes in the recurrent connections and therefore not lost with disrupted activity (Sandberg et al., 2003; Mongillo et al., 2008; Lundqvist et al., 2011, 2012). The limited lifetime of the attractor states has two advantages. First, less spiking is needed to store the information; energy is conserved during the silent states. Second, as information is not lost when activity is disrupted, attractors can hold multiple items in WM with minimal interference between them (or from sensory distractions). In these models, different items are serially encoded and read out, resulting in brief activations of spiking in the coding assemblies.

One of these models (Lundqvist et al., 2011; Figure 1A) implemented the functionality of short-lived attractor states using connectivity and synaptic plasticity constrained by known biology. The model predicts that a burst of gamma oscillations accompanies each attractor state (Figures 1B and 1C) and that the lifetime of such bursts should correspond roughly to an alpha/theta cycle. The gamma oscillations result from fast, local feedback inhibition (Figure 1C), which has two chief consequences. First, firing rates are reduced during attractor retrieval. This state is otherwise characterized by runaway excitation but instead excitation and inhibition are dynamically balanced, leading to the low-rate irregular firing observed in biology (Lundqvist et al., 2010). Second, feedback inhibition normalizes firing rates in a winner-takes-all dynamic, resulting in selective (informative) spiking in only a small subset of neurons (those that are part of the attractor; see Figure 1). This further predicts that there should be a close link between information in spiking and gamma power that goes beyond the broad-band increase in gamma power accompanying general increases in spiking activity. The model also predicts that, as more items are stored in the network, they are replayed more and more often leading to a higher density of gamma bursts (Figure 1B; Lundqvist et al., 2011). This could explain observed load-dependent power changes in gamma (Howard et al., 2003; Komblith et al., 2015; Honkanen et al., 2015), beta (Komblith et al., 2015; Honkanen et al., 2015), and theta/alpha (Jensen and Tesche, 2002; Palva et al., 2005) in primate cortex.

Non-stationary memory delay activity also has been suggested by observations that PFC activity and gamma oscillations show slow frequency modulation (Jensen and Tesche, 2002; Palva et al., 2005; Watrous et al., 2013; Axmacher et al., 2010). However, the model makes more specific predictions. On a single trial, there should be no prolonged baseline shift in gamma power following stimulus encoding. Gamma power should instead make sharp transitions into the high-power attractor state and repeatedly fall back to pre-stimulus baseline levels throughout the WM delay (thus manifesting what Stokes, 2015, refers to as active-silent states; Figure 1B). As a result, on a trial-by-trial basis, PFC activity is not modulated at slower frequencies in a highly periodic fashion. Instead gamma bursts occur irregularly and the slow periodicity previously observed is instead due to the lifespan of the gamma bursts. The power modulation only appears as periodic when averaging across trials.

We sought to test model predictions in local field potential (LFP) and spike data from the PFC of monkeys performing a multi-item memory task. We did so by performing a unique trial-by-trial analysis of neural activity. This avoided the cross-trial averaging that would obscure the complex temporal dynamics predicted by the model.

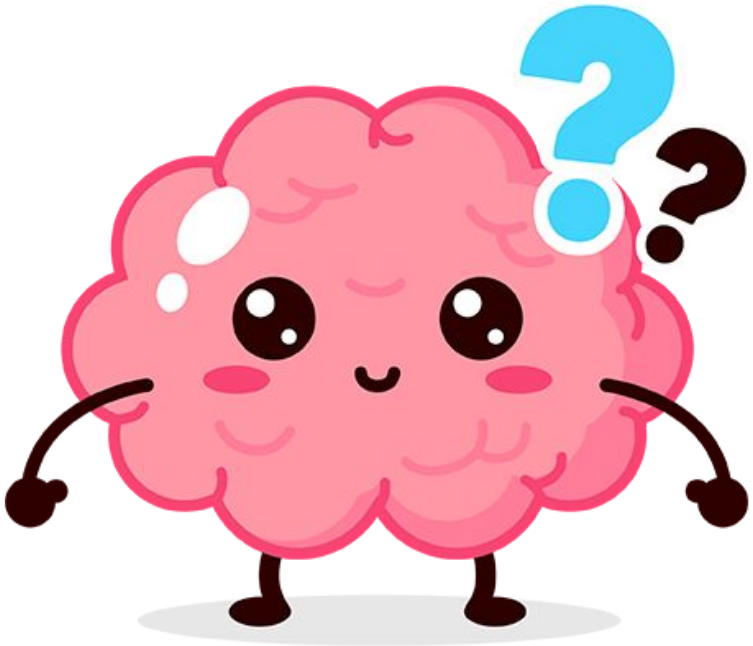
RESULTS

We trained two monkeys to retain multiple colored squares over a short memory delay period (Figure 2A). Each trial began with an encoding phase, where two or three squares appeared in a

Increasing specificity of background

1. Memory
2. Existing models of memory
3. The specific model to be explored
4. Detailed predictions of model
5. Focus of manuscript

Questions?



Methods: why do they matter?

EXPERIMENTAL PROCEDURES

Phototagging VTA-Projecting LH Neurons

To limit expression of ChR2 to only LH neurons projecting to the VTA, AAV_5-DIO-ChR2-eYFP was injected into the LH and HSV-EF1α-IRES-Cre-mCherry into the VTA. In NpHR inhibition experiments, AAV_5-CaMKIIα-eNpHR3.0-eYFP was injected into the VTA as well. An optrode was implanted in the LH and an optic fiber over the VTA.

Partial Reinforcement Sucrose Retrieval Task

For in vivo recording, animals were trained on a partial reinforcement sucrose retrieval task, where 50% of nosepokes were followed by a cue predicting the delivery of sucrose at the port entry. Adjustments were made to this task to examine the effects on reward omission by omitting sucrose deliveries from a subset of cues and to examine the effects on unexpected reward by the delivery of sucrose without the existence of the cue.

Sucrose Seeking in the Face of a Negative Consequence

To study the effect on conditioned responding by stimulation of LH-VTA projections, we developed a task wherein an animal must cross a shock floor to obtain a sucrose reward. Wild-type animals with ChR2, NpHR, or eYFP injected either unilaterally (AAV_5-CaMKIIα-ChR2-eYFP) or bilaterally (AAV_5-CaMKIIα-eNpHR3.0-eYFP) in the LH with an optic fiber placed over VTA or VGLUT2::Cre and VGAT::Cre animals with AAV_5-DIO-ChR2-eYFP injection in the LH and optic fiber over the VTA were tested. Because LH-VTA:ChR2 mice showed an increase in sucrose seeking in the face of a negative consequence, these animals were sated before evaluating the effects of photostimulation on feeding on normal chow. In contrast, LH-VTA:NpHR mice showed a decrease in sucrose seeking in the face of a negative consequence and were therefore mildly food restricted before testing the effects of photostimulation on feeding on normal chow.

Ex Vivo Characterization of LH-VTA

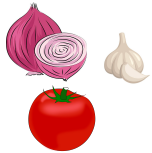
Whole-cell patch-clamp recordings were used to study the input of LH neurons onto DA and GABA VTA neurons. DA neurons were identified by filling cells with biocytin and post-hoc immunostaining for TH. GABA cells were identified during recordings by fluorescence due to AAV_5-DIO-mCherry injection into the VTA of VGAT::Cre animals.

Nieh et al. (2015) Cell

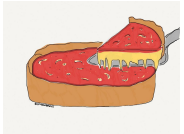
a metaphor

making the dough

making the sauce



putting the pizza together



in science, as in cooking, this improves reproducibility AND helps compare across results!

variations in methodology

↓

variations in results!

Methods: how to read them?

what is “phototagging”?

EXPERIMENTAL PROCEDURES

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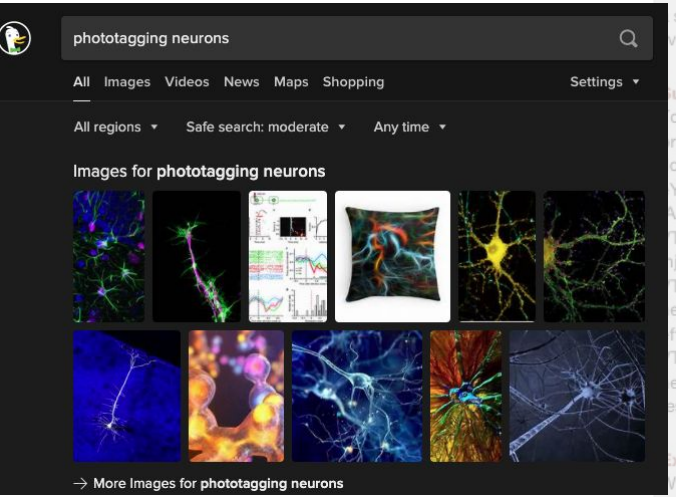
x Vivo C

Whole-cell onto DA and GABA VTA neurons. DA neurons were identified by filling cells with biocytin and post-hoc immunostaining for TH. GABA cells were identified during recordings by fluorescence due to AAV_5-DIO-mCherry injection into the VTA of VGAT::Cre animals.



PINP: A New Method of Tagging Neuronal Populations for ...

https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0006099

Tagging **neurons** is a novel application of ChR2, used in this case to monitor activity instead of manipulating it. PINP can be readily extended to other populations of genetically identifiable **neurons**, and will provide a useful method for probing the functional role of different neuronal populations in vivo.

notebook/computer etc.
notes:

Phototagging: tagging neurons to monitor their activity

Methods

what is “ChR2”?

EXPERIMENTAL PROCEDURES

Phototagging VTA-Projecting LH Neurons

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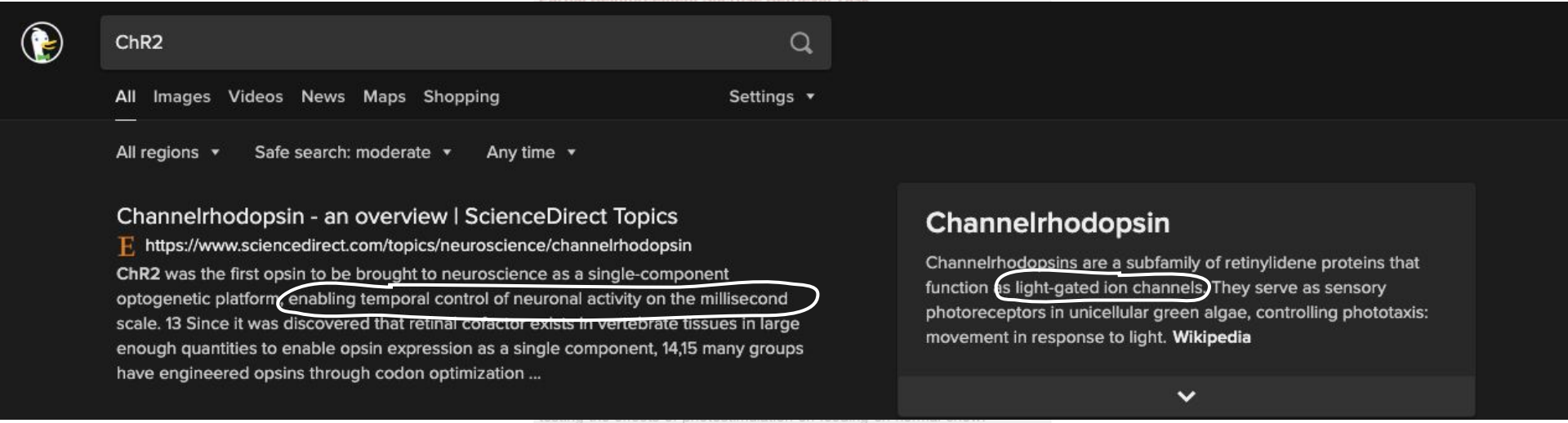

principles for research disciplines across the board (and maybe for life in general 😂)

(1) if information is overwhelming, ***break it up*** into smaller pieces, & ***identify what you don’t understand***
(2) ***look up*** first and/or ***ask your research team*** about anything you don’t understand!

Results and Figures: Multiple Streams of Information

range regardless of light intensity or spike probability (Fig. 3h), indicating that the gamma oscillations evoked by FS activity are a resonant circuit property. In addition, randomly patterned light stimulation of FS cells with frequencies evenly distributed across a broad range evoked a significant increase in LFP power specific to the gamma range ($n = 7$ sites in 4 animals; $P < 0.05$; Supplementary Fig. 7), further indicating that FS-evoked gamma oscillations are an emergent property of the circuit and do not require exclusive drive in the gamma range.

Natural gamma oscillations require FS activity

To test whether intrinsically occurring gamma oscillations show a similar dependence on FS activity, we gave single light pulses during epochs of natural gamma. We found that brief FS activation shifted the phase of both spontaneously occurring gamma oscillations ($n = 26$ trials, 4 animals; Kruskal–Wallis test with Dunn's post-test; $P < 0.01$; Fig. 3i) and those evoked by midbrain reticular formation stimulation ($n = 18$ trials, 2 animals; $P < 0.05$; Supplementary Fig. 8). Furthermore, light-induced gamma oscillations were largely eliminated by blocking AMPA (α-amino-3-hydroxy-5-methyl-4-isoxazole propionic acid) and NMDA (*N*-methyl-D-aspartate) receptors, despite high levels of evoked FS firing ($n = 4$ sites in 4 animals; $P < 0.01$; Supplementary Fig. 9). These results indicate that induced gamma oscillations depend on rhythmic excitatory synaptic activity, as predicted by computational models of natural gamma oscillations and previous experiments[4,9,11,12,26]. In further agreement, spontaneous RS activity was entrained by 40 Hz FS stimulation, resulting in RS firing during the decay phase of the IPSP and preceding subsequent evoked FS spiking (Supplementary Fig. 10).

Evoked gamma phase regulates sensory processing

Gamma oscillations are thought to have a functional impact on cortical information processing by synchronizing the output of excitatory neurons[27,28]. This synchrony selects cell assemblies involved in a common task, such as encoding a sensory stimulus, and enhances their impact on downstream targets[27]. The cyclical FS inhibition underlying gamma oscillations is believed to cause this synchrony by rhythmically gating synaptic inputs[27,29]. Synaptic inputs arriving at the peak of inhibition should therefore produce a diminished response, but those arriving at the opposite phase in the gamma cycle should evoke a large response.

To test this hypothesis directly, we stimulated FS cells at 40 Hz with light pulses to establish gamma oscillations, and recorded the responses of RS cells to a single vibrissa deflection presented at one of five phases relative to a single gamma cycle ($n = 20$ cells in 3 animals; Fig. 4a). The timing of vibrissa-induced RS action potentials relative to light-evoked inhibition and the gamma cycle had a significant impact on the amplitude, timing and precision of the sensory-evoked responses of RS cells (Fig. 4b, c). The presence of gamma oscillations significantly decreased the amplitude of the RS sensory response at three phase points, consistent with the enhanced level of overall inhibition in this state ($P < 0.05$; 1-way ANOVA with Dunnett's post-test; Fig. 4d)[28]. Gamma phase also modulated the overall timing of the sensory response ($P < 0.01$; Fig. 4e), with spike latency delayed at phases 1–3 and unaffected at phases 4–5 (ref. 28). The precision of sensory-evoked spikes was significantly enhanced in a gamma-phase-dependent manner ($P < 0.01$; Fig. 4f). Our results indicate that the rhythmic, FS-induced IPSP restricts sensory transmission during its peak, and permits transmission after its decay, leading to a temporal sharpening of cortical sensory responses (Fig. 4g).

Our results provide the first causal demonstration of cortical oscillations induced by cell-type-specific activation. Synchronous FS-PV$^+$ interneuron activity driven by periodic stimulation of light-activated channels generated gamma oscillations in a cortical network, and these gated sensory processing in a temporally specific manner. These findings also demonstrate a unique application of optogenetic engineering in the *in vivo* brain for the study of discrete neuronal cell

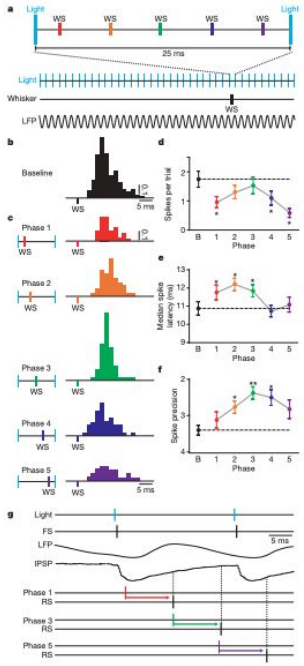

Figure 4 | Gamma oscillations gate sensory responses of excitatory neurons. **a**, In each trial, FS-PV$^+$ inhibitory interneurons were activated at 40 Hz and a single vibrissa deflection (whisker stimulus, WS) was presented at one of five phases. **b**, Baseline response of one layer 4 RS cell to single vibrissa deflections, shown in units of spikes per trial. **c**, Responses of the same cell when the whisker was deflected at each of five temporal phases relative to the induced gamma oscillation. **d**, Average spikes evoked per trial under each condition. Dotted line indicates baseline responses. **e**, Timing of the RS spike response, measured as median spike latency. **f**, Spike precision of the RS responses. **g**, Schematic model of the gating of sensory responses by gamma oscillations. IPSP and LFP examples are averaged data traces. $^*P < 0.05$, $^{**}P < 0.01$; error bars, mean ± s.e.m.

main text

graphics

caption

Results and Figures: Multiple Streams of Information

graphics

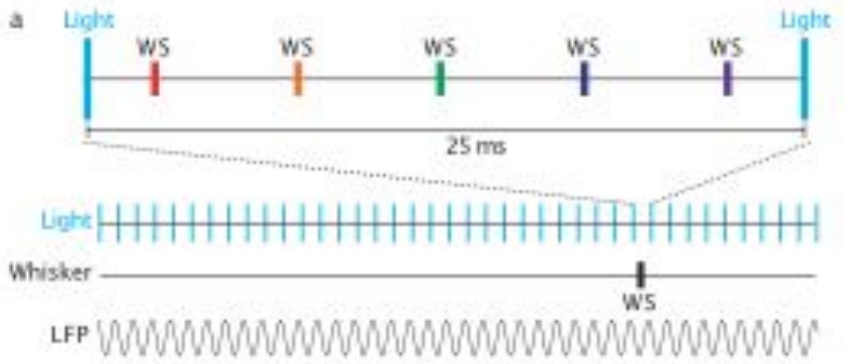

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Figure 4 | Gamma oscillations gate sensory responses of excitatory neurons. **a**, In each trial, FS-PV$^+$ inhibitory interneurons were activated at 40 Hz and a single vibrissa deflection (whisker stimulus, WS) was presented at one of five phases. **b**, Baseline response of one layer 4 RS cell to single vibrissa deflections, shown in units of spikes per trial. **c**, Responses of the same cell when the whisker was deflected at each of five temporal phases relative to the induced gamma oscillation. **d**, Average spikes evoked per trial under each condition. Dotted line indicates baseline responses. **e**, Timing of the RS spike response, measured as median spike latency. **f**, Spike precision of the RS responses. **g**, Schematic model of the gating of sensory responses by gamma oscillations. IPSP and LFP examples are averaged data traces. $^*P < 0.05$, $^{**}P < 0.01$; error bars, mean ± s.e.m.

Conclusion / Discussion

01

02

03

What is discussed:

- Interpretation of results
- Implications of new knowledge

Additional elements:

- Limitations of study
- Open questions and future directions

When reading a conclusion/discussion:

- Take notes: What are the arguments? What evidence is provided for each?
- Consider alternative interpretations

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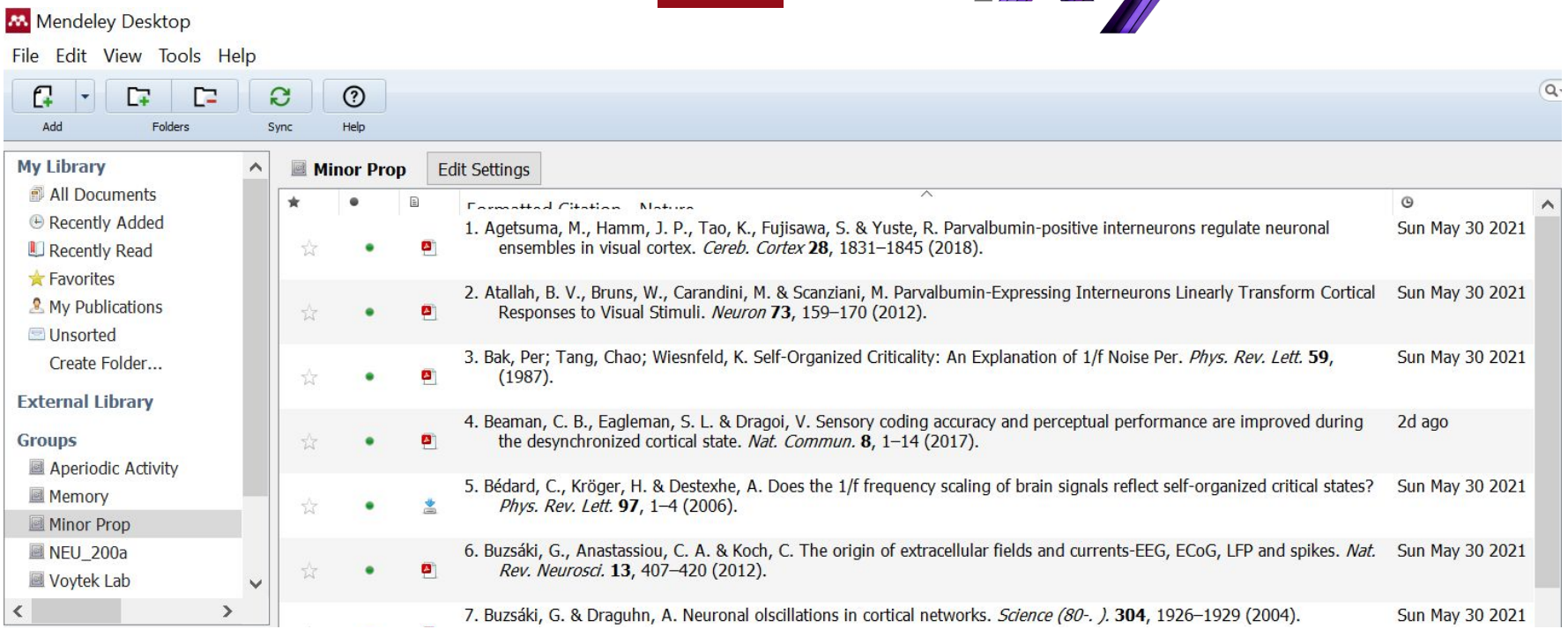
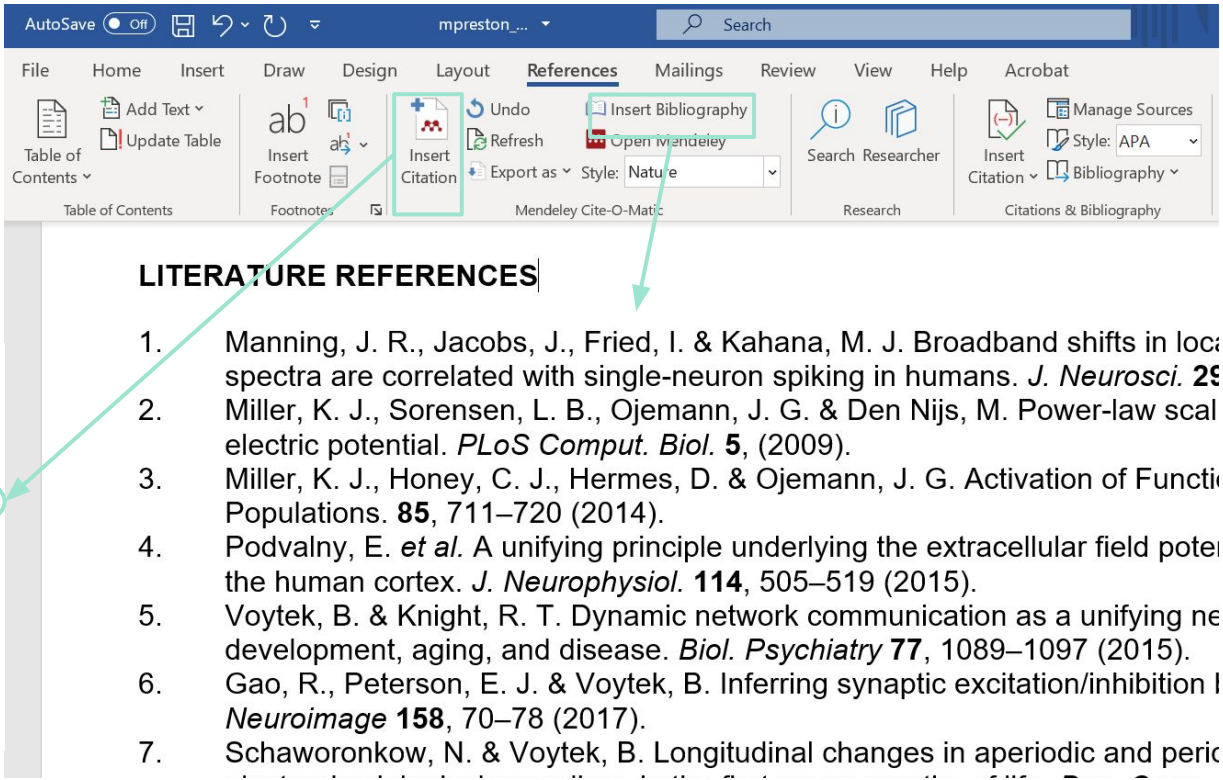
Reference managers

[UCSD Library Guide](#)
[Mendeley](#)
[Zotero](#)
[Endnote](#)

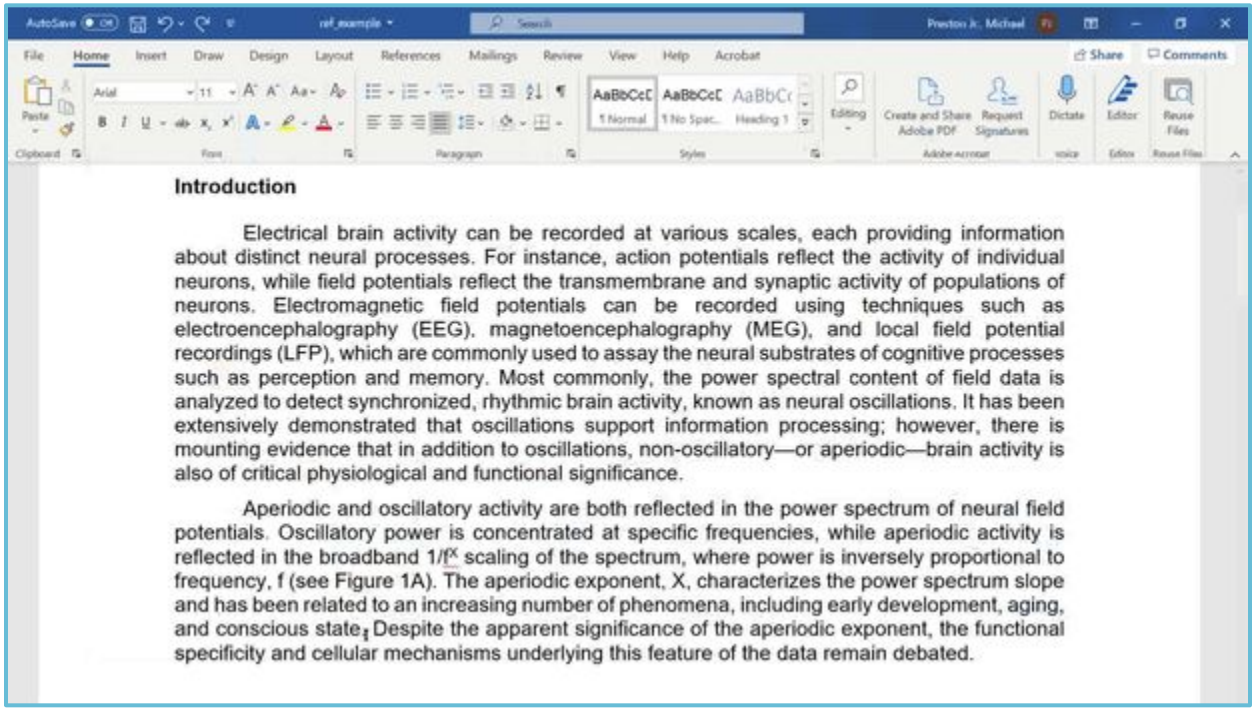


Interfacing reference managers with Microsoft Word



d, rhythmic brain activity, known as neural
unting evidence that in addition to oscillations,
physiological and functional significance[1–7].
um of electromagnetic field potentials that can
and magnetoencephalography (MEG). While
power spectra also exhibit a broadband $1/f^X$
periodic exponent, X, characterizes the power
f phenomena, including development[7], visual

Interfacing reference managers with Microsoft Word

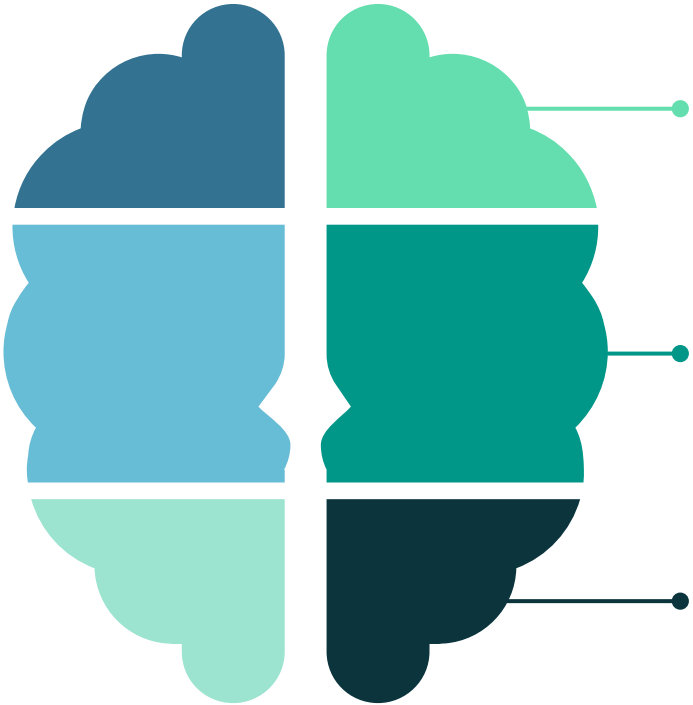


Introduction

Electrical brain activity can be recorded at various scales, each providing information about distinct neural processes. For instance, action potentials reflect the activity of individual neurons, while field potentials reflect the transmembrane and synaptic activity of populations of neurons. Electromagnetic field potentials can be recorded using techniques such as electroencephalography (EEG), magnetoencephalography (MEG), and local field potential recordings (LFP), which are commonly used to assay the neural substrates of cognitive processes such as perception and memory. Most commonly, the power spectral content of field data is analyzed to detect synchronized, rhythmic brain activity, known as neural oscillations. It has been extensively demonstrated that oscillations support information processing; however, there is mounting evidence that in addition to oscillations, non-oscillatory—or aperiodic—brain activity is also of critical physiological and functional significance.

Aperiodic and oscillatory activity are both reflected in the power spectrum of neural field potentials. Oscillatory power is concentrated at specific frequencies, while aperiodic activity is reflected in the broadband $1/f^{X}$ scaling of the spectrum, where power is inversely proportional to frequency, f (see Figure 1A). The aperiodic exponent, X, characterizes the power spectrum slope and has been related to an increasing number of phenomena, including early development, aging, and conscious state. Despite the apparent significance of the aperiodic exponent, the functional specificity and cellular mechanisms underlying this feature of the data remain debated.

Summary



- Academic papers communicate original work and ideas
- Literature searches leverage databases and supplementary search engines
- Abstracts are ‘advertisements,’ used to decide whether to read a paper
- Introductions state significance and can guide future literature review
- Methods provide a ‘recipe’ to reproduce the results
- Results should be critically examined using multiple streams of information
- Discussions are interpretive: consider alternatives and open-questions
- Reference managers can be leveraged for effective literature review

Do it yourself exercise

- ❑ Pick a paper **relevant** to your research question
- ❑ Read abstract and write **one sentence summary** of the article
- ❑ Read through each section
  - ❑ *Introduction*
  - ❑ *Methods*
  - ❑ *Results*
  - ❑ *Conclusion/Discussion*
- ❑ References
- ❑ **Note** anything that did not make sense to you
- ❑ **Look up** anything that did not make sense to you
- ❑ If you're still having trouble, reach out to your mentor pods!

Next Week

Day	Date	Time	Location	Person(s)	Workshop/Event
Monday	June 27	1:30-2:30 PM	The Loft at UCSD	Leadership	Orientation
Tuesday	June 28	4:00-5:00PM	CNCB Small Conference Room	Celina Nguyen, Mini Contreras	Introduction to Entering Research and Research Experience Expectations/Mentor-Mentee expectations
Thursday	July 7	4:00-5:00PM	CNCB Small Conference Room	Mari, Christian	Introduction to research conferences and travel awards/funding sources
Friday	July 8	5:00 PM			SACNAS Travel Award Application Deadline
Wednesday	July 13	4:00-5:00PM	CNCB Large Conference Room	MJ, Quirine, Sana	Reading Scientific Papers
Friday	July 15				Abstract Submission deadline for UCSD SRC
Tuesday	July 19	4:00-5:00PM	CNCB Small Conference Room	Celina Nguyen	Journal Club
Wednesday	July 27	4:00-5:00PM	CNCB Large Conference Room	Jilly	Documenting your Research
TBD	TBD			Christian, Sana	Presenting your research / Poster
Tuesday	Aug ust 9	4:00-5:00PM	CNCB Small Conference Room		Poster Workshop/Practice Talks
Thursday & Friday	Aug 11 & 12		TBD (Price Center prob)		UCSD SUMMER RESEARCH CONFERENCE
Tuesday	Aug 16	4:00-5:00PM	CNCB Small Conference Room	JC, Kween	Mental Health and Well-being/Balancing lab with life
Wednesday	Aug 24	4:00-5:00PM	CNCB Small Conference Room	Pam, Eena	Applying to research fellowships and grant resources
TBD	TBD			JC	Data Blitz

Questions?