Focused NSF Site Visit Workshop
Temporal Dynamics of Learning Center

Timing and Learning

Meeting Rooms on 15, The Village, UC San Diego
June 19, 2014

This is an assistive site visit focusing on areas of opportunity. We highlight a subset of the research portfolio of our center, bringing attention to findings that emerged from group focus on shared questions that forge links across domains and levels of analysis. The format is a series of workshop-style presentations intended to promote in-depth discussion of featured topics, and demonstrate new questions and findings that were enabled by the center. The presentations feature a line of research that investigates brain dynamics and sensory/motor representation as a building block for learning, from basic rhythms in the brain through autonomous robot tools.

2014 NSF Site Visit Talk Abstracts:

April Benasich (Rutger's University): ***Brain dynamics underlying early language acquisition.***

Oscillatory dynamics play a crucial role in the activity-dependent self-organization of developing networks, however, oscillatory brain rhythms, and their co-modulation across frequency bands is relatively unexplored in human infants. Research in my lab has established a link between infant processing of rapidly successive auditory signals and later language proficiency. Invasive and non-invasive studies across labs have shown that specific cognitive functions, including language, are differentially correlated with oscillatory activity in particular frequency bands. Our newest research is aimed at understanding maturational changes in oscillatory mechanisms over early infancy and in particular how oscillatory signatures are specifically related to developing cognitive processes.

In this presentation, a subset of data from converging paradigms, specifically dense-array EEG (both spontaneous and evoked), structural and functional MRI, and behavioral assessment will be shown. Examination of our longitudinal cohorts, 4-months through 5 years-of-age, reveals a continuing impact of fine-grained acoustic processing in the tens of millisecond range during early infancy. Specifically, we demonstrate that typical maturational changes in the morphology of infant evoked-response potentials (ERPs) can be differentiated in typically developing infants with a familial risk of language learning disorders as compared with those with no such family history. Focused analyses of maturational neural dynamics including spontaneous and evoked oscillations suggest that local low-frequency oscillatory synchrony underlies rapid processing and can robustly index auditory perception in young infants. Further results in 6-month-olds demonstrate the role of gamma oscillations in supporting syllable discrimination in the earliest stages of language acquisition, particularly during the period in which infants begin to develop preferential processing for linguistically relevant phonemic features in their environment. Finally, we show that differences in the pattern and density of power spectra (e.g. gamma, theta, delta) through the toddler years index pre-linguistic auditory abilities and predict later language outcomes.

Dan Feldman (UC Berkeley): ***Cortical states and sensory processing.***

In cerebral cortex, information processing and learning take place on a background of rhythmic voltage oscillations, measured with EEG or local field potential (LFP), which reflect distinct cortical brain states. Cortical state varies dynamically with arousal and attention. Local brain state strongly influences the accuracy of sensory coding, which is a prerequisite for learning. TDLC research has shown that in auditory cortex, an active, asynchronous state is critical for accurate encoding of auditory sequences. In visual cortex, cholinergic neuromodulation shifts cortex into an active, asynchronous state that improves neural encoding and visual discrimination behavior. Gamma oscillations (30-90 Hz) are particularly linked to attention, memory, and perception, and can be spatially very local. In somatosensory cortex, the basic capacity of a cortical column to generate gamma depends on the animal's history of sensory experience. Circuit-level analysis shows that experience modulates activation of the parvalbumin-positive (PV) interneurons that generate gamma. Theoretical analysis predicts specific sites of plasticity, and suggests that gamma modulation arises via a shift between two distinct circuit mechanisms for gamma generation. Together, these findings promote the view that optimization of brain state, perhaps by sensory or cognitive training, may improve the capacity for sensory perceptual learning.

Kenneth Harris (University College London): ***Overview of cortical dynamics and processing: Matching dynamics to the world.***

The ability to perceive speech is acquired in early childhood, and disruption of early speech learning can have devastating consequences throughout life (Fitch et al., 1997). The neuronal mechanisms of early speech perception learning are still unclear, but are likely to involve plasticity of circuits in the juvenile neocortex. Research in animal models has revealed the phenomena and mechanisms of plasticity in juvenile sensory cortex in increasing detail (Feldman, 2012). Yet an understanding of how these mechanisms allow neural circuits are to learn tasks such as speech perception, remains elusive. This talk will describe a novel derivation of a learning rule that maximizes the skewness of subthreshold membrane potentials. This rule is compatible with multiple *in vitro* observations including spike timing dependent plasticity, but also extends them. The application of this rule to simulated spiking networks shows that it causes these networks to form unsupervised representations of speech sounds. Thus, this work may ultimately explain how synaptic plasticity processes similar to those observed in juvenile sensory can allow simulated cortex-like networks of spiking neurons to perform speech perception.

Terry Sejnowski (UCSD/The Salk Institute): ***Cortical oscillations arise from contextual interactions.***

Precise spike times are important for synaptic plasticity at cortical synapses. Synchronizing oscillations such as gamma bursts lasting 100 ms could coordinate spike times, thus regulating information transmission and synaptic plasticity in the cortex. Deficits in gamma power in the EEG occur in babies who are at risk for later developing language and learning impairments and in schizophrenia patients. In a cortical circuit model with strong inhibitory feedback to the pyramidal neurons, the amplitude and frequency of gamma oscillations in the local field potentials depend on the balance of inputs in monosynaptic and disynaptic pathways to fast-spiking inhibitory interneurons. In particular, strong monosynaptic inputs from surrounding regions of the cortex suppress the firing rates of pyramidal neurons, activate strong gamma oscillations and elicit precisely timed spikes. In contrast, strong input within the receptive field of a neuron elicits high firing rates, little or no power in the gamma range and irregular spike timing.

Paula Tallal (UCSD/The Salk Institute): ***Overview: Timescales of dynamics for educating a brain: from milliseconds to years.***

TDLC's multidisciplinary research orientation has the potential to build bridges for experimental and theoretical inquiry across multiple levels of analysis and timescales. I will provide an overview of our human subject research that builds an additional bridge toward scientific advances that have potential for later translation. I will discuss the role of oscillatory dynamics and sensorimotor timing as building blocks for language. Specifically, I will describe our recent work using anatomically constrained magnetoenchalography (aMEG) to investigate the role of temporal dynamics in auditory processing of nonverbal as well as speech stimuli, specifically as it pertains to hemispheric lateralization. This work takes advantage of aMEG's unique capability of providing both the spatial and temporal resolution needed to better understand the neural dynamics of auditory temporal information processing in real time. I will also set the stage for the following talk from Terry Jernigan's group. Their large-scale prospective, longitudinal studies focus on linking individual differences in brain structure and genetics with cognitive, academic and emotional development of young school age children.

Terry Jernigan (UCSD): ***Links between brain development and cognitive skills.***

Our research attempts to improve models of the processes by which individual differences in behavioral phenotypes emerge during development - among these individual differences in cognitive and academic skills. These processes are certainly highly complex, and it is likely that differences in neural genotypes modify the responses of children to the critical learning experiences upon which cognitive and intellectual forms of expertise depend. We are following children longitudinally with broad assessments of their emerging skills and we are attempting to monitor their experiences; however we also collect genetic information and use noninvasive imaging to measure the status of biological brain development and other neural architectural features that may relate to cognitive development. In this presentation, I will summarize work by our group and by others that establishes that individual differences in cognitive skills are mirrored to some degree by differences in the still developing architecture of the brain. Challenges to the interpretation of these associations, and implications of the alternative accounts, will be discussed.

Javier Movellan (UCSD): ***The faces of engagement***

This talk will describe novel work with automatic facial expression recognition for detection of student engagement. While the morning talks addressed brain states that are better for learning, here we explore detection of better states for learning from the face. Student engagement is a key concept in contemporary education, where it is valued as a goal in its own right. We studied whether human observers can reliably judge engagement from the face; analyzed the signals observers use to make these judgments; and automated the process using machine learning. We found that human observers reliably agree when discriminating low versus high degrees of engagement. We used machine learning to develop automatic engagement detectors and found that for binary classification (e.g., high engagement versus low engagement), automated engagement detectors perform with comparable accuracy to humans. Finally, we show that both human and automatic engagement judgments correlate with task performance. In our experiment, student post-test performance was predicted with comparable accuracy from engagement labels (r = 0:47) as from pre-test scores (r = 0:44).

The talk also describes analysis of group facial responses to the social robot, RUBI, in an early childhood education classroom. The goal of the RUBI project is to accelerate progress in the development of social robots by addressing the problem at multiple levels, including the development of a scientific agenda, research methods, formal approaches, software, and hardware. The project is based on the idea that progress will go hand-in-hand with the emergence of a new scientific discipline that focuses on understanding the organization of adaptive behavior in real-time within the environments in which organisms operate; as such, the RUBI project emphasizes the process of *design by immersion*, i.e., embedding scientists, engineers and robots in everyday life environments so as to have these environments shape the hardware, software, and scientific questions as early as possible in the development process. The focus of the project so far has been on social robots that interact with 18- to 24-month old toddlers as part of their daily activities at the early childhood education center at the University of California, San Diego. RUBI-5 was left alone for a 28-day period to interact autonomously with 16 toddlers at the UCSD Early Childhood Education Center. The latest prototype of RUBI, RUBI-5, was designed to operate as an autonomous “digital ethnographer” that would embed itself in the daily routine of the toddlers life and enrich their environment while gathering and analyzing the observed behaviors. RUBI-5 was left alone for a 28-day period to interact autonomously with the pre-school children. The resultant study is an important milestone in social robotics; both for the length of time the robot could interact autonomously with children, and for the richness of the data that it provided. The results indicate that social robots have the potential to act as low cost autonomous “digital ethnographers” in a manner that may revolutionize the science and technology of early childhood education.

Janet Wiles (University of Queensland): ***iRat as a social neuroscience research tool.***

This talk will review recent results in the study of a bio-inspired robot called the iRat developed at the University of Queensland for research at the intersection of neurorobotics, neuroscience and embodied cognition. Biorobotics has the potential to provide an integrated understanding from neural systems to behavior that is neither ethical nor technically feasible with living systems. Robots that can interact with animals in their natural environment open new possibilities for empirical studies that include temporal, spatial and social factors intrinsic to mammalian biology. Designing a robot that can interact with a rodent requires considerations that span a range of disciplines, starting with the initial safety and social interactions of both rat and robot. Bio-inspired robots are also useful for embodying neural systems. Multidisciplinary teams have developed spiking models of a range of neural systems used in navigation, including cell birth and maturation, the hippocampal circuit, head direction cells, and grid cells. Recent results include a spiking model that incorporates explicit temporal delays to study sequence learning. This presentation will provide an overview the current capabilities of the iRat and its neural models and laboratory behaviors. It will also highlight recent collaborative efforts aimed towards endowing iRat with social behaviors towards the creation of the first robotic tool for enabling social neuroscience.