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Title: Exploring attention at different neuronal scales

Abstract:
Visual attention enhances the signal to noise ratio of neuronal responses in the visual cortex, however the mechanisms by which these attentional modulations occur are not known. Visual attention is also studied at multiple scales from single neurons to local field potentials (LFPs) to voxels in fMRI. What can we learn from studying attentional modulation at these various neuronal scales? Here we compare attentional modulation across different scales within the early visual pathways, taking into consideration the local circuitry as well as reciprocal thalamo-cortico-thalamic circuits linking the visual thalamus with primary visual cortex.

When we examine attentional modulation of individual neurons, we see that attentional modulation of firing rate depends critically on the match between an individual neuron's feature selectivity and the features attended in order to successfully complete the task. We see similar patterns when we examine local circuits, or monosynaptically connected pairs of neurons in primary visual cortex. However, multi-unit recordings in primary visual cortex do not necessarily recapitulate single-unit results, in part because multi-units represent an average of activity across diverse neurons recorded with the same electrode contact. Our results are lending support to the notion that attention effects measured across multiple units recorded on a single contact may in fact reveal more about local diversity in visual physiological responses than about attention.

When we examine attentional modulation at the level of LFPs, yet another picture emerges. We find that attentional modulation of LFPs is temporally dynamic; there is more attentional modulation of LFP timing (i.e. phase) and communication across circuits than there is attentional modulation of LFP amplitude. We do not observe frequency-specific tagging of signals relayed in distinct early visual circuits, with the exception of attentional enhancement of gamma-band activity in the feedback corticogeniculate circuit linking visual cortex with the visual thalamus. New methods to combine single-unit activity with LFPs recorded on the same contact – a spike-triggered LFP wavelet analysis – indicate that subtle changes in subthreshold activity occurring at various time points during trials could signal the onset of attentional modulation of individual neurons.

Together these results suggest that a holistic approach is probably required to fully understand the neuronal mechanisms of visual attention. While individual neurons provide important insight into links between spatial and feature attention within cortical columns, LFPs provide a clearer picture of the temporal dynamics of attention on short timescales. Additionally, the diversity of visual physiological responses across recorded neurons must be considered when interpreting attentional modulation of population neuronal responses.

Cognitive control from the perspective of control theory: computational modeling and fMRI

Joshua W Brown
Indiana University

Abstract Cognitive control is often cast in terms of inhibition, working memory, task rules or sets, and attention allocation. We propose that cognitive control can be understood from the perspective of engineering control theory. The idea is that behavior is directed toward goals as desired states or set points, and cognitive control functions to drive behaviors that move the individual's state closer to the set point.

To demonstrate the utility of this control-theoretic approach, we implemented it in a computational neural model, the Goal-Oriented Learning and Sequential Action (GOLSA) model, and then tested the model predictions against human fMRI data with representational similarity analysis. The model learns the structure of state transitions, then plans actions to arbitrary goals via a novel hill-climbing algorithm inspired by Dijkstra's algorithm, and similar to that used in GPS navigation devices. The model provides a domain-general solution to the problem of solving problems and performs well.

Our model-based fMRI with representational similarity analysis (RSA) shows that in addition to solving complex planning problems, the GOLSA model provides a novel computational account of network interactions of a number of brain regions involved in flexible action planning. In particular, the orbitofrontal cortex matches model components that represent both a cognitive map and a flexible goal value representation. The hippocampus and striatum represent a conjunction of the current state and desired future state transition. The model accounts for specific roles of visual cortex, anterior inferior temporal cortex, and motor cortex as well.

Brain states and chemical neuromodulation of cortex

Anita Disney

Duke

In response to the challenge of a dynamic environment, organisms move through behavioral states that can sometimes be observed as changes in “brain state”. Brain state is traditionally assayed using electrophysiological methods, but implicit (occasionally explicit) in much of the discourse around brains states is the hypothesis that – at least some of the time – state specification is achieved through the release of chemical neuromodulators such as acetylcholine and noradrenaline. The dynamic control of the moment-to-moment circuit responsiveness and connectivity that these molecules yield is poorly understood, but probably also a crucial variable in describing and predicting neural activity.

We propose a new approach to studying the neurochemical environment of the cortex, inspired by models that present neural activity as N-dimensional, where each dimension is one neuron’s train of action potentials. We view neurochemistry as needing to undergo a similar evolution; the N-dimensional space in this case being almost certainly non-orthogonal and with each axis defined by an extracellular signaling molecule. A nonsynaptic component to most modulatory signaling means that such a description will probably also call for accompanying data and models for the spatial and temporal profile of molecular diffusion through the extracellular space. I will present a series of experimental methods and tools that we are developing in the lab to address the need for better neurochemical data and models. These methods are designed to be integrated with traditional behavioral/electrophysiological approaches to the study of cognitive variables and encompass a range of neurochemical techniques including electrochemistry, in vivo imaging, microdialysis, and mass spectrometry. Feedback at this early stage in our endeavor is very welcome.

A deterministic approach to the problem of 3D-cue integration

Fulvio Domini

Brown University

Bayesian theories of cue integration postulate that 3D perception is a probabilistic inferential process. Specifically, it assesses the probability that a given 3D scene has generated the retinal images. The probabilistic nature of this inference is thought to arise from the partial ambiguity of depth-cues in specifying the Euclidean structure of objects. Therefore, depth-cues map to probability distributions over possible metric solutions and the standard deviation of these distributions is a measure of their ambiguity or, conversely, reliability. An optimal Bayesian estimator (1) combines single-cue estimates in order to maximize the reliability of the combined estimate and (2) it is unbiased. Although experiments based on discrimination tasks conform to the first assumption, other empirical results show that 3D estimates are systematically biased.

Here, I discuss a normative model of cue integration postulating deterministic mappings between depth-cues and 3D estimates. This model does not attempt to estimate the several scene parameters (e.g. material properties, illuminant characteristics, location and motion of the observer) that are needed in order to derive the Euclidean structure of objects. Instead, depth modules are tuned to ideal values of these parameters, taking place within the personal space of the agent and typical environmental conditions. If single-cue mappings are assumed to be learnt simultaneously as components of a general deterministic mapping, we can define the function characterizing this mapping based on the normative criteria that this function is maximally sensitive to variations in the value of the 3D property relative to variations of the scene parameters.

We show that this model can predict previous findings on depth discrimination predicted by the Bayesian approach, but with an entirely different interpretation of Just Noticeable Differences. Moreover, it can predict perceptual biases that cannot be accounted for by the previous theories of 3D-cue integration.

Population synchrony in cortical networks

Valentin Dragoi
U. Texas, Huston

Brain activity during wakefulness is characterized by fluctuations in neural responses at different time scales. Whether these fluctuations play any role in modulating the coding of sensory information and the accuracy of behavioral responses is poorly understood. By simultaneously recording the responses of multiple neurons I will show that slow changes in local population synchrony in monkey visual cortex impair the coding of sensory information and perceptual performance. These changes also occur in executive areas, such as prefrontal cortex, while monkeys freely explore their environment during foraging. However, while slow fluctuations in population synchrony are detrimental for sensory coding, they play a beneficial role at more rapid time scales. Indeed, by simultaneously recording visual cortical populations in multiple areas (V1 and V4) we recently discovered that the precise temporal coordination between the spikes of three of more neurons carries information about perceptual reports in the absence of firing rate modulation. Altogether, these results demonstrate differential impacts of synchrony in local cortical networks at slow and rapid time scales.

3D Shape from Bounding Contour

James Elder

York U.

The bounding contour of an object serves as an important constraint in recovering 3D shape. In the image, the bounding contour is planar, but it projects from a 3D space curve lying on the object - the *rim* (Koenderink, 1984) - that may be oblique to the observer and non-planar. For sparsely textured and/or backlit objects, surface cues are weak and the 3D shape of the rim becomes an important constraint on the global 3D object shape. While determining the 3D shape of this space curve from a 2D projection is ill-posed, we hypothesize that statistical regularities of objects (e.g., smoothness, symmetry, parallelism) provide cues. Here we explore this hypothesis both computationally and psychophysically. Our computational analysis reveals that a simple statistical model links the missing depth dimension to the 2D shape of the object boundary, and our psychophysical studies show that human observers are able to use this relationship to make relative depth judgements about boundary points. These monocular shape cues are found to interact with binocular stereo cues in determining judgements of depth, suggesting a perceptual rather than cognitive origin.

Spatiotemporal dynamics of corticostriatal dopamine in learning and decision making

Michael Frank
Brown University

The basal ganglia and dopaminergic systems are well studied for their roles in reinforcement learning and reward-based decision making. Much work focuses on "reward prediction error" (RPE) signals conveyed by dopamine and used for learning. Computational considerations suggest that such signals may be enriched beyond the classical global and scalar RPE computation, to support more structured learning in distinct sub-circuits ("vector RPEs"). Such signals allow an agent to assign credit to the level of action selection most likely responsible for the outcomes, and hence to enhance learning depending on the generative task statistics. I will first describe the computational models spanning levels of analysis from implementation to function. I will then present evidence across species and methods -- from fMRI and EEG in humans to calcium imaging of striatal dopamine terminals in rodents -- that RPE signals are modulated by instrumental task demands, in accordance with vector RPEs.

Our Concept Of Approximate Number Cannot Be Inferred From Continuous Dimensions Such As Density, Area, and Convex Hull

Emily Sanford & Justin Halberda
Johns Hopkins University

A brief glance at an apple tree is enough to form a surprisingly accurate impression of the number of apples on its branches. What is the basis of this capacity? Can our abstract numerical representations be directly traced back to primitive early visual representations of number, or must we learn to construct them from low-level non-numerical features (such as surface area, density, or convex hull) over the course of development? If cognitive representations of number must be constructed from non-numerical visual features, then it must be the case that the visual evidence available to us sufficiently determines the number of items in a display. Here, we explore this assumption by making use of some surprisingly underutilized resources: the visual images that children look at when learning number from counting books and real-world images. If the non-numerical visual cues in these images fail to capture number, then children could not rely on them to learn how many items are on a page. This implies that vision must rely on a more direct number signal. Much work suggests that the concept *number* must be constructed from early visual features, so we analyzed how well such features track cardinality across 50 children's counting books and even more real-world images. We found that continuous features were at best weakly correlated with number. A linear regression over the three most predictive features explained a modest amount of variability in the number of items. Further, a system of visual number that only uses evidence from non-numerical features will perform much worse than children do in typical number tasks. We show that children's number abilities go beyond that which could be provided by low-level visual features and therefore must involve either a more direct numerical extraction or an inference beyond the evidence of non-numerical features.

Oscillatory Recurrent Gated Neural Integrator Circuits (ORGaNICs): A Unifying Theoretical Framework for Neural Dynamics

David Heeger
NYU

Abstract: Working memory is an example of a cognitive and neural process that is not static but evolves dynamically with changing sensory inputs; another example is motor preparation and execution. We introduce a theoretical framework for neural dynamics, based on oscillatory recurrent gated neural integrator circuits (ORGaNICs), and apply it to simulate key phenomena of working memory and motor control. The model circuits simulate neural activity with complex dynamics, including sequential activity and traveling waves of activity, that manipulate (as well as maintain) information during working memory. The same circuits convert spatial patterns of premotor activity to temporal profiles of motor control activity, and manipulate (e.g., time warp) the dynamics. Derivative-like recurrent connectivity, in particular, serves to manipulate and update internal models, an essential feature of working memory and motor execution. In addition, these circuits incorporate recurrent normalization, to ensure stability over time and robustness with respect to perturbations of synaptic weights. ORGaNICs can also be applied to model sensory processing, commensurate with the hypothesis that executive functions, motor preparation/control, and sensory processing share a common, canonical computational motif. Finally, these circuits can be implemented with a simplified biophysical (equivalent electrical circuit) model of pyramidal cells.

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Characterization of Age-related Microstructural Changes in Locus Coeruleus and Substantia Nigra Pars Compacta

Jason Langley, Sana Hussain, Justino J. Flores, Ilana J. Bennett, and Xiaoping Hu

University of California Riverside, Riverside, CA

Locus coeruleus (LC) and substantia nigra pars compacta (SNpc) degrade with normal aging, but not much is known regarding how these changes manifest in MRI images, or whether these markers predict aspects of cognition. Here, we use high-resolution diffusion-weighted MRI to investigate microstructural and compositional changes in LC and SNpc in young and older adult cohorts, as well as their relationship with cognition. In LC, the older cohort exhibited a significant reduction in mean and radial diffusivity, but a significant increase in fractional anisotropy compared to the young cohort. We observed a significant correlation between the decrease in LC mean, axial, and radial diffusivities and measures examining cognition (Rey Auditory Verbal Learning Test delayed recall) in the older adult cohort. This observation suggests that LC is involved in retaining cognitive abilities. In addition, we observed that iron deposition in SNpc occurs early in life and continues during normal aging.

Size is NOT embodied! Even when tested with an explicit sensorimotor task or more salient manipulation.

Natalie A. Kacinik[1,2]
[1]Brooklyn College and [2]The Graduate Center, City University of New York

Numerous studies have shown that the processing of linguistic stimuli is respectively facilitated or hindered by perceptually or motorically consistent vs. inconsistent contexts. These findings have been used as evidence that our semantic representations are embodied or grounded in sensorimotor experiences (Barsalou, 2008; Glenberg, 2015). However, at a previous AIC meeting I presented experiments that manipulated size and failed to support this theory, even when participants explicitly judged the size of a word's appearance, or the size of the item the word represents. The current research consisted of 2 more experiments designed to further push and investigate the embodiment of size. One involved deciding whether each word represented something that could be easily picked up and held in one's hand (a task requiring explicit activation of sensorimotor information), while participants in Experiment 2 decided if the word represented something big or small. This was the same "item decision" task we used in a previous experiment, but this time the stimuli were presented with greater, more pronounced differences in text size of 10, 22, and 34-point Arial font vs. the 16, 22, and 28-point fonts used before. Similar to our previous findings, the "hand" task failed to produce significant effects. In contrast, the results for the more salient size manipulation were significant and seemed to initially support the embodiment hypothesis. However, separate analyses of words representing big and small items revealed effects in opposite directions, indicating that participants were generally slower at processing words in the smallest 10-pt font regardless of their meaning. All of our results thus fail to support the embodiment of word meaning regarding the property of size, but some issues and potential explanations will be discussed. We are about to start conducting similar studies that involve manipulating color. Depending on the status of this work and if time permits, I may also present our initial results with color.

Michael Landy
NYU

Title: The effect of joint attention on visual-tactile integration and recalibration

Abstract:

We tested experimentally whether task-enforced shared attention toward visual and tactile stimulus locations fosters cross-modal recalibration (i.e., the visual-tactile ventriloquism aftereffect) and integration (i.e., the visual-tactile ventriloquism effect), and then used causal-inference modeling to isolate the mechanisms behind the attentional modulation. In both experiments, we found stronger effects of vision on touch with shared attention toward both modalities. Model comparison confirmed that localization responses were based on Bayes-optimal causal inference. In contrast, simultaneously collected common-source judgments --- indicating whether the two stimuli were perceived as spatially-aligned --- relied on a sub-optimal heuristic.
The best-fitting model revealed that shared attention increased sensory noise and strengthened the expectation of correspondence between the two signals. Thus, a weak default link between vision and touch can be strengthened by concurrent attention toward both modalities.

Bayesian Decision Theory and Navigation *Redux*

Timothy P. McNamara

Effective navigation depends on the ability to combine information from multiple spatial cues to estimate one's position and the locations of goals. Spatial cues include landmarks, and other visible features of the environment, and body-based cues generated by self-motion (vestibular, proprioceptive, & efferent information). A number of projects have investigated the extent to which visual cues and body-based cues are combined optimally according to statistical principles. Although several studies have documented optimal or near-optimal cue combination, other studies have shown that navigators sometimes fail to combine cues optimally or even at all. Last year at this conference, I showed that a complete Bayesian decision model could account for some of these discrepencies; this year, I will show that it can account for others, including situations in which navigators seem to be using only one spatial cue. A general conclusion is that previous investigations of human navigation have not capitalized on the full explanatory power of Bayesian decision theory.

Context Affects Vocal Signal Processing in Primate Prefrontal Cortex Neurons

Cory Miller

UCSD

Vocal communication is characterized by the active, reciprocal exchanges of vocalizations between freely-moving conspecifics . However, most prior studies of vocalization processing have involved traditional, head-restrained subjects that are either passively listening to conspecifics calls or conditioned to respond to these vocal signals. Here we examined the responses of prefrontal cortex neurons in marmoset monkeys to vocalizations across several behavioral contexts – ranging from more traditional head-restrained contexts to freely-moving subjects engaged in active communication. Specifically, we were interested in testing whether data recorded in more traditional contexts was predictive of the pattern of neural responses observed to the same vocalization stimuli during natural communication.. Subjects were presented with vocalizations and various white noise stimuli at a consistent inter-stimulus interval in test sessions comprising head-restrained and freely-moving passive-listening contexts. The same neurons were also recorded in a third active communication context as subjects engaged in reciprocal exchanges of phee calls, a behavior known as antiphonal conversations. Furthermore, we recorded head position of the marmosets in freely-moving conditions and tested head direction in head-restrained contexts in order to determine whether the relative position to the speaker was a key source of variance on neural responses. Analysis have shown that a population of neurons in ventrolateral prefrontal cortex is responsive to acoustic stimuli – including vocalizations – while subjects are head-restrained. However, the same neurons exhibit no response to the identical vocalization stimuli while animals are engaged in active communication. This suggests that prefrontal cortex is not only highly affected by behavioral context and that elucidating its role in natural communication likely necessitates studying within that context. More broadly, these data suggest that neural responses during more traditional head-restrained paradigms may not be predictive of their role in natural behaviors.

Evaluation of tablet-based methods for assessment of contrast sensitivity

Jeff Mulligan
NASA

Some astronauts suffer degradation of vision during long-duration space flight, a condition that has come to be known as Spaceflight Associated Neuro-ocular Syndrome (SANS). While related morphological changes can be observed with imaging technologies such as optical coherence tomography (OCT), a rapid method for functional vision assessment could be useful for tracking the progression of the condition. We compared three tablet-based psychophysical methods for rapid measurement of contrast sensitivity: 1) a relatively novel method developed expressly for touch screens, in which the subject "swipes" a frequency/contrast sweep grating to indicate the boundary between visible and invisible patterns; 2) a method-of-adjustment task in which the subject adjusts the contrast of a grating patch up and down to bracket the visual threshold; and 3) a traditional two-alternative forced choice (2AFC) task, in which the subject is presented with a variable-contrast stimulus in one of two intervals, and must report the interval containing the stimulus. The swipe method produces raw data that are points on the contrast sensitivity function (CSF); these were fit with a parabola following Lesmes et al. (2010). For the other two methods, thresholds were estimated for the 7 spatial frequencies tested, and parabolas were fit to the resulting points. Each CSF was characterized by three parameters: the peak sensitivity, the spatial frequency of peak sensitivity, and "acuity" (the spatial frequency with a contrast threshold of 1). The swipe method shows variability comparable to that of the 2AFC method, while the adjustment method is somewhat worse. The swipe method shows good agreement with the 2AFC method in estimates of the spatial frequency of peak sensitivity, but overestimates the sensitivity, perhaps because subjects are biased to trace outside of the visible pattern region. While "quick-and-dirty," the swipe method may nevertheless be useful for longitudinal monitoring and detection of gross changes.

Multi-holed donuts and categorical selection

Shreesh Mysore
Johns Hopkins University

Categorical neural representations enhance the ability of animals to select accurately in the presence of sensory and neural noise. This is especially true when competing options just straddle the selection boundary. We show that a structured 'donut-like' inhibitory projection pattern generated by each option – one that suppresses all options except itself, is a highly effective circuit mechanism for categorical selection, more so than the commonly proposed alternatives of feedback inhibition, and recurrent excitation. Additionally, pooled divisive normalization, a mechanism involving uniform suppression of all options and thought to underlie decision-making is also not very effective at generating robust-to-noise responses. We then demonstrate experimentally not only that a donut-like mechanism exists in the barn owl midbrain, but also that it serves precisely to improve robust-to-noise, categorical responses. Indeed, the key inhibitory tegmental neurons involved implement an exquisitely tuned multi-holed donut-like pattern of inhibition to accommodate the established combinatorial function of these neurons. Our results indicate that structured, self-sparing inhibition may be a central module for categorical selection and decision making.

Neda Nategh
Department of Electrical and Computer Engineering
Department of Ophthalmology and Visual Sciences
University of Utah

Neural and computational basis of visuospatial perception during saccadic eye movements

Physiological studies have shown that the responses of neurons throughout prefrontal, parietal, and visual areas undergo various changes across a saccade, including shifting their receptive fields (RFs) to their post-saccadic location, called future field (FF) remapping, or toward the saccade target (ST remapping). Psychophysical studies have also shown multiple perisaccadic changes in the perceived location, motion, and duration of visual stimuli. However, the correspondence between the perisaccadic neural and psychophysical phenomena is poorly understood. Although it is always a challenge to establish a causal link between a particular neurophysiological phenomenon and a specific behavior, this challenge is even greater when the focus is on the short time scale of physiological and psychophysical phenomena around the time of saccades. Quantitatively describing the computations occurring in visual neurons during eye movements by modeling neuronal responses with single-neuron and single-spike resolution, and using model-based decoding to infer their perceptual effects, is a promising way to circumvent this challenge.

Here we present a statistical framework integrated with physiological experiments, to uncover the nature of computations underlying the neuron's response generation across saccadic eye movements (described by an encoding model). The first challenge is to handle the combination of high dimensionality, short timescales, and sparse data associated with fast, nonlinear perisaccadic response modulations. We overcome this difficulty via a combination of temporally precise experimental paradigms, a data-driven dimensionality reduction approach, and a new time-varying statistical model. Our computational method is capable of tracking the dynamics of visual information encoding and tracing perisaccadic sensitivity changes in extrastriate neurons with high temporal precision in sparse perisaccadic neuronal data.

Beyond the precise descriptions of computations, the model also enables an unbiased way to identify and selectively manipulate the constituent perisaccadic response components, in ways that cannot be accomplished experimentally, and examine their contribution to specific behaviors using the decoding aspect of the neurons' encoding model. Together, our model-based approach enables us to accurately trace the perisaccadic dynamics of extrastriate neuronal response and provides an unprecedented level of insight regarding how the encoding of sensory stimuli is altered during eye movements and how to link these changes in the visual representation to perisaccadic visuospatial perception.

Collaborator: Dr. Behrad Noudoost, University of Utah

Human age is predicted by the association of multiple brain network and behavioral factors

Brent McPherson, and Franco Pestilli

Psychological and Brain Sciences at Indiana University

Historically results from human behavior have demonstrated that performance improves in a variety of tasks early in life, peaks between the 20’s and 40’s and decreases thereafter. At the same time, several measures of brain network connectivity have also been shown to similarly increase in the early years of life, to peak for young adults and to decrease in older adults. We employed a multivariate approach to relate measures of performance from over 300 behavioral tasks with over 200 measures of brain network connectivity from over 630 individuals' across the lifespan – 10-85 years. We found that a single dimension of covariation strongly associates (r=0.85) measures of performance in five behavioral domains (perceptual, cognitive, emotional and motor factors) with the structural connectivity of individual human brain networks. Importantly, we demonstrate that this single dimension of covariation well predicts the held-out age of the human individuals in the sample (cross-validated r: 0.62). These results demonstrate that human aging is associated with the synchronous changes of both brain networks and behavior.

An autoencoder approach to measuring dimensionality and content of information transmission across cortical processing regions

Megan A. K. Peters
University of California, Riverside / University of California, Irvine

How much information is transferred from one cortical region to another, and what is the nature or content of that information? How can we measure this using available noninvasive neuroimaging tools in awake, behaving humans? Many possible answers to these questions have been developed, ranging from the simplicity of functional connectivity through information theoretic approaches and deep learning algorithms. However, many of these approaches are applied to impoverished brain datasets, in which fMRI measurements of BOLD patterns span only a few simple object categories; large datasets spanning vast representational spaces are rare.

Here, we capitalized on a recently-collected large dataset consisting of 80+ individuals who viewed animals and objects spanning 40 categories for 1 hour while voxel patterns of BOLD response were measured. To evaluate information transmission between two high-level visual and cognitive areas (ventral temporal cortex [VT] and prefrontal cortex [PFC]), we developed a combined autoencoder and neural network decoder to address these questions. We probe the trained autoencoder/decoder network to reveal the dimensionality and feature space topology of the information transmitted between VT and PFC, and to evaluate to what degree these latent spaces are consistent across individuals.

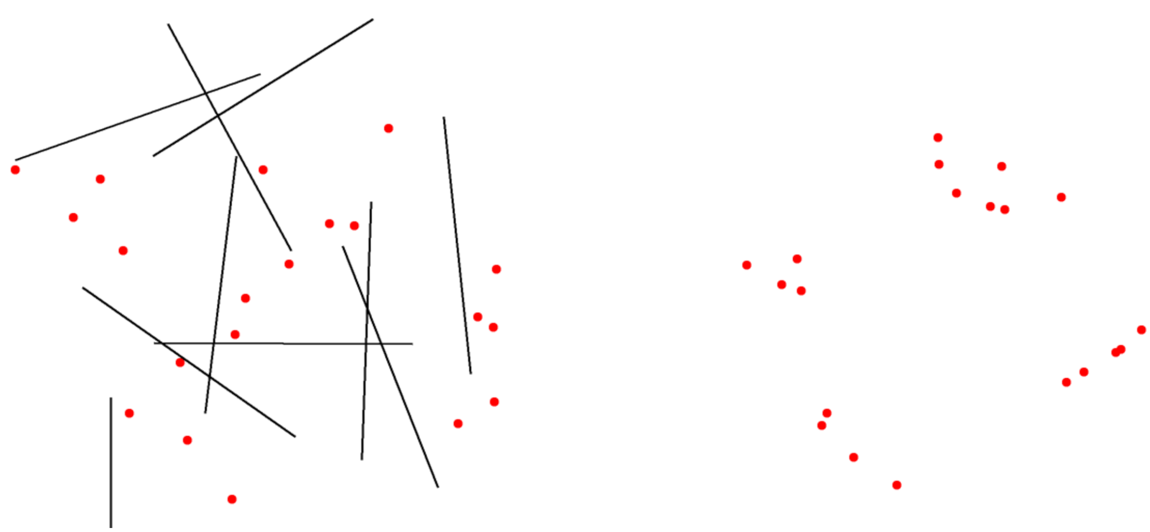
Our approach has advantages over other extant methods, including canonical correlation analysis or hyperalignment (a.k.a. the Shared Response Model framework), because it does not make any assumptions about the shape of the function mapping representations (a) from one region to another, or (b) from a low dimensional latent space to observable brain activity (as in Gaussian Process models). It also avoids challenging assumptions of some information theoretic approaches. We believe this approach can provide a powerful tool upon which to build, to discover and interrogate the information passed among regions of human cortex using noninvasive neuroimaging.

Collaborators:
Mehdi Orouji, Mitsuo Kawato, Hakwan Lau, Vincent Taschereau-Dumouchel, Kazuhisa Shibata

The Status of Mental Representations in Cognitive Functions
Zygmunt Pizlo & Jacob VanDrunen, UC Irvine

Most intelligent human behaviors are goal-directed (purposive). This includes physical behaviors, such as visual navigation, fixing a car, moving furniture, as well as mental behaviors, such as solving a geometry problem, arguing with someone, or reviewing a paper. A *future* goal cannot control *present* actions, so for a goal-directed behavior to occur, present actions must be controlled by a mental model (representation) of the goal and the environment in which the behavior is taking place. This idea was proposed explicitly for the first time by Howard Warren in 1916. It was then used by Edward Tolman (1932) in his studies of rat behavior, by Norbert Wiener (1948) in his Theory of Cybernetics and by Conant and Ashby (1970) in their treatment of Control Systems.

To date, the role of mental representations has been unequivocally demonstrated and accepted in only one cognitive function, namely, problem solving, both human and computer. Problem solving is, by definition, a goal-directed behavior. Following Newell & Simon's (1972) formulation, the problems to be solved are represented by graphs with a start node and an end node, as well as operations that allow the problem solver to navigate the search space. Today, I will discuss the Traveling Salesman Problem (TSP), one of the best known, NP-hard combinatorial optimization problems. I will show the results of human subjects, of an optimal TSP solver, and of our Pyramid Model. I will focus on TSPs that have obstacles where pairwise distances are not Euclidean. Multidimensional Scaling (MDS) is used to produce obstacle-free Euclidean approximations of TSPs with obstacles. This representation is then used by our Pyramid Model to determine the order in which the cities are visited. The stress of 3D MDS was always close to zero, while the stress of 2D MDS was large. Our model's performance with 3D (but not with 2D) MDS approximations is very similar to the performance of the subjects. Below is a simple illustration of a TSP with obstacles and an obstacle-free 2D MDS approximation of the problem with obstacles. During the talk I will show 3D MDS approximation using kinetic depth effect.



Nicholas L Port [1*],Lyndsey Ferris [1], Michael W Collins[2], Anne Mucha[2], Jay Clugston[3], Anthony P Kontos[2]
Indiana University School of Optometry[1], University of Pittsburgh[2], University of Florida[3]
*Presenter

Title: Comparison of the Vestibular/Ocular-Motor Screening (VOMS) and Sport Concussion Assessment Tool-3 (SCAT-3): An NCAA-DoD Concussion Assessment, Research and Education (CARE) Consortium Analysis

Purpose: Vestibular and oculomotor symptoms in concussed athletes are common, with high reports of dizziness (50%), balance (40%) and visual (30%) symptoms. The VOMS tool directly assesses these systems and shows consistent utility in aiding concussion identification and prognosis. However, a VOMS validation study in the acute concussive period of a large sample is lacking. This study aimed to examine VOMS validity among collegiate student-athletes from the multi-site NCAA-DoD CARE Consortium. A secondary aim was to utilize machine learning to compare and contrast the sensitivity and specificity of VOMS to the SCAT-3 and to identify combinations that optimize predictive accuracy during the acute time period.

Methods: Preseason and acute post-injury (6-48 hours) assessments were analyzed for 417 student-athletes and military cadets. Variables included VOMS; and the Balance Error Scoring System (BESS), Standard Assessment of Concussion (SAC) and Symptom Scale (SS) from SCAT-3. Descriptive statistics were computed to compare timepoint results (Table 1). A Kolmogorov-Smirnov test was used to compare the non-normative distributions and effect size was calculated via Cohen's d. Machine learning randomly divided data into training (75%) and testing (25%) sets for analysis. Multidimensional pattern classifiers then tested various variable combinations to determine the predictive value of VOMS and SCAT-3 totals and subcomponents to determine additive and/or substitutive value of various tool combinations. More advanced machine-learning algorithms eg. convolutional neural network) will also be explored.

Results: Both total VOMS scores and SCAT-3 total SS scores demonstrated significant increases post-injury ($d = 1.25$ and 1.10). Changes in BESS and SAC were not significant. VOMS symptoms supported significant post-injury increases. Likewise, symptom increases were detected for all VOMS components ($1.23 < d < 1.36$). Total VOMS score correlated strongly with total SS ($r = 0.83$) but poorly with BESS and SAC. All three correlations were significant ($p < 0.001$). Adaptive boosting machine learning models comparing VOMS, BESS, SAC and SS yielded a predictive accuracy of 80.3%, sensitivity of 76.0%, specificity of 85.0% and an area under the curve (AUC) of 0.89. Removing VOMS reduced predictive power across all categories: accuracy (73.6%), sensitivity (72.0%), specificity (75.0%), AUC (0.80).

Conclusion: Total VOMS and SCAT-3 symptom scores demonstrated significant increases and large effect sizes following concussion. Machine learning predictors suggest that the accuracy, specificity and sensitivity of SCAT-3 would improve with the addition of the VOMS tool. With concussion a growing public health concern, there is greater need for improved concussion diagnosis and care. These results highlight the relations between the visual-vestibular systems and concussion and guide future concussion research and care.

AIC 2020 abstract

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- Secreted synaptic organizers are bridging the gap - C1QL3 orchestrate complex formation between adhesion GPCRs and Neuronal Pentraxins

Our brains rely on neuronal networks composed of a multitude of neurons linked by membrane-bound synaptic adhesion proteins. These proteins form the synaptic cleft, which is the essential molecular interface for fundamental processes at the chemical synapse. This makes a junction of genes and behaviors, and thus associates synaptic adhesion proteins and secreted synapse organizers with complex brain disorders. Fluctuations in neuronal activity induce morphological changes that are orchestrated by synaptically located proteins – synapse organizers. An emerging theme shows that members of C1q/TNF superfamily have been adapted during evolution to act in various physiological roles by binding to specific receptors. Secreted C1Q-like proteins have been increasingly recognized as master-regulators of tissue organization and receptor-triggered pathways for crucial cellular responses and communications in higher organisms.

C1QL proteins are the only known ligands to the adhesion GPCR B3 (ADGRB3) associated with cognitive brain disorders and various types of cancers. By their interaction with receptors, synapse organizers facilitate the process of synapse formation, maintenance and elimination – synapse homeostasis. To investigate the hypothesis that the secreted C1QL proteins may mediate tripartite trans-synaptic adhesion complexes, we conducted an *in vivo* interactome study and identified new binding candidates. We demonstrate that C1QL3 can mediate a novel cell-cell adhesion complex involving ADGRB3 and two neuronal pentraxins, NPTX1 and NPTXR. Single cell RNA-Seq data from cerebral cortex shows that C1QL3, NPTX1, and NPTXR are highly co-expressed in the same neurons, suggesting that all three proteins could be pre-synaptically co-secreted and capable of binding to post-synaptically localized ADGRB3. Identifying new binding partners for C1QL proteins and deciphering their underlaying molecular principles will allow us to understand how C1QL3 protein affects the organization and function of excitatory synapses

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Measuring agency

Novel ways to intervene on brain function raise questions about agency and responsibility. Here, I discuss how to think about direct brain interventions such as deep brain stimulation, and whether they pose a threat to agency. While I argue that these interventions do not constitute a global challenge to our concept of agency, they do have the potential to diminish agency in individuals. I propose that our theoretical understanding of agency and our therapeutic approaches could be improved with a more nuanced, multidimensional view of agency, and describe an approach we are taking for developing such a view.

Disentangling neural mechanisms for perceptual grouping
Thomas Serre
Brown University

Forming perceptual groups and individuating objects in visual scenes is an essential step towards visual intelligence. This ability is thought to arise in the brain from computations implemented by bottom-up, horizontal, and top-down connections between neurons. However, the relative contributions of these connections to perceptual grouping are poorly understood. We address this question by systematically evaluating neural network architectures featuring combinations of these connections on two synthetic visual tasks, which stress low-level gestalt vs. high-level object cues for perceptual grouping. We show that increasing the difficulty of either task strains learning for networks that rely solely on bottom-up processing. Horizontal connections resolve this limitation on tasks with gestalt cues by supporting incremental spatial propagation of activities, whereas top-down connections rescue learning on tasks featuring object cues by propagating coarse predictions about the position of the target object. Our findings disassociate the computational roles of bottom-up, horizontal and top-down connectivity, and demonstrate how a model featuring all of these interactions can more flexibly learn to form perceptual groups.

Joint work with: Junkyung Kim, Drew Linsley, Kalpit Thakkar

Multiple salience maps?

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The centroid task requires subjects to use a mouse to indicate the center of a briefly flashed cloud of, typically, dots. However, subjects can also judge the centroid of a cloud of highly diverse items. Similarly, Ss can judge motion direction in successive frames in which the only thing that changes consistently is an area defined as figure, the nature of both figure and ground changing in each new frame. In a brief flash, subjects can as easily and accurately judge the distance between two totally different objects (defined only by their difference from the background clutter) as between two identical objects. The fact that subjects can make centroid, motion direction, and distance judgments that simultaneously involve the locations of highly different items defined merely as figure versus ground suggests that these computations act on a salience map that records the presence and the location of such items but is indifferent to their nature. In motion and centroid tasks, Ss can also selectively respond to attention-selected subsets of items and ignore distracter items. Here we show that, following a single brief flash of a 24-dot cloud (8 black, 8 red, 8 green, all interleaved), Ss can accurately report the centroids of all three colors. That three centroid computations can occur concurrently suggests that a reformulation of the single salience map concept is required.

Visualizing Uncertainty in Temperature Predictions and Simple Comparisons

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Communicating scientific findings requires communicating about uncertainty. What are the best visual displays for communicating this uncertainty? The current research tackles this question in three domains. One is uncertainty on a spatial scale – such as predicting temperatures around the globe. One is uncertainty on a temporal scale – such as predicting temperature changes across time at a single location. A third is uncertainty in a simple two-point comparison task. All three tasks revealed that the visual system could extract information about uncertainty but sensitivity to this information was far from optimal. Attenuated sensitivity to information about uncertainty is a concern when communicating scientific findings and predictions.