FORTIETH ANNUAL INTERDISCIPLINARY CONFERENCE

Teton Village, Jackson Hole, Wyoming

February 1 – February 6, 2015

Organizer: George Sperling, University of California, Irvine

ABSTRACTS

Sunday, February 1: 5:00 - 5:30 pm*Reception******Registration, Snacks, and Refreshments*.

J. Busemeyer, J. Wang, R. Shiffrin
Indiana University
A Mysterious Finding About Question Order in Surveys and a Quantum Account

When two questions are asked back to back in a national survey the answers often change depending on the order of the questions. Typically half the respondents are asked the questions in one order, and the other half of respondents asked the questions in the other order. This is a form of 'context effect' and could be part of almost any cognitive model. When looking at all surveys over the last ten years that asked two questions back to back, a peculiar regularity seems to hold for all 70 surveys: The change in the probability of saying yes to both questions plus the change in the probability of saying no to both questions adds to zero. If there are at most small context effects then this result is required, but many of the surveys have large context effects. When there are large context effects, this regularity, called the QQ-equality, is not required mathematically; in fact there are surveys that do not show this result (when, for example, extra information is inserted between the two questions). It is hard to come up with any cognitive interpretation or constraints that would require the QQ-equality. In recent years Jerome Busemeyer and his colleagues have proposed a model of decision making based on the idea that human cognition obeys the laws of quantum probability. The resultant model has been used to explain many findings in the decision making literature that seem to show decisions that are irrational if they are to obey the laws of probability (such as the conjunction fallacy). Although the new model does a good job when applied to such studies, the applications are parameterized and fit the data by appropriate choice of parameters. The quantum model applied to the QQ-equality has no parameters--it predicts that this finding should hold universally, regardless of parameterization. The fact that the results support the prediction should not only lead cognitive scientists to search for alternative models to explain the finding, but also lead cognitive scientists to give the quantum probability theory serious consideration.

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S. L. Ketels, A. F. Healy, M. Jones, L. Lalchandani, D. K. Sasnett-Martichuski
University of Colorado
Testing Two Pedagogical Prescriptions in the Use of Classroom Response Systems

We manipulated the usage of classroom response systems, or clickers, in four statistics classes taught by the same instructor at the University of Colorado Boulder. In the first experiment, we manipulated the schedule of clicker questions in two classes, taught during the Spring 2013 semester. Clicker questions from a given lecture were either all presented at the end of the lecture (delayed), or interspersed throughout the lecture (interleaved). In the second experiment, we manipulated the format of the clicker questions themselves, comparing the standard multiple choice question format (recognition) to a question format demanding recall of information before selecting among response options (recall). In both experiments, conditions were alternated within-subjects for both classes individually, and these patterns of alternation were counterbalanced between the two classes. Performance on midterm and final exam questions was used as the dependent measure for both experiments. In the first experiment, superior test performance was expected for material presented in the interleaved condition. In the second experiment, superior test performance was expected for material presented in the recall condition.

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Wolfgang Pauli
CalTech
fMRI dissociable dopamine systems for appetitive and aversive stimuli.

There is a general consensus that learning during Pavlovian conditioning critically depends on the transient response of dopaminergic neurons to unexpected delivery of reward. Even though the responses of dopaminergic neurons are well characterized, and the uniformity of their response widely accepted, recent data suggest the existence of a subset of dopamine neurons which instead respond to unexpected aversive stimuli. To investigate whether there is a regional specialization within the human dopamine system, we measured BOLD activation in humans while they participated in a Pavlovian conditioning paradigm with appetitive and aversive unconditioned stimuli. Despite the use of high-resolution fMRI imaging, we did not find any region which showed a stronger BOLD signal in response to unexpected aversive stimuli, our results suggest that two regions within the dopamine system are differentially

involved in appetitive and aversive conditioning,and modulate synaptic plasticity in dissociable networks of brain regions.

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T. Busey, J. Vanderkolk, Brandi Emerick
Indiana University
Tracking the Growth of Evidence in Visual Comparison Tasks

Many applied tasks involve a comparison between visual images. For example, the Boston Bombing case was solved primarily through the manual comparison of images of the bombers with faces from other databases. Of course, no two picture or impression are identical, and thus the examiner must make judgments about the likelihood of the two images deriving from the same source. In the present work we collected data from fingerprint examiners when they performed a visual comparison task not unlike a latent print examination. In the first stage we asked examiners to select regions they thought might be diagnostic. In the second stage we showed these regions one at a time and asked for a judgment of whether the two came from the same source (identification) or different sources (exclusion).

We fit models based on signal detection theory to summarize the results. We found that, contrary to a model of holistic or configural processing, evidence seems to grow linearly with the number of regions. We also can track the growth of evidence in favor of exclusion or identification, and I'll present data on this point. The design addresses how weak and strong evidence is interpreted and has some surprising results about how weak evidence is evaluated.

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Bas Rokers
University of Wisconsin
Visual Motion Perception in the Human Brain

Perception is inherently limited by our sensory systems. I will demonstrate two ways in which these limitations lead to systematic misperception of visual motion. First I will show that a large proportion of the normal population (> 50%) have blind spots (scotomas) in their visual field in which observers are unable to judge the direction of object motion (towards or away), even when those observers are perfectly able to judge object position in the same visual field location.

Second, I will turn to another curious finding: Human observers are reported to systematically misperceive motion trajectories, so that an object that moves towards an observer is perceived to move more laterally (Harris & Dean 2003). We tested this finding by systematically manipulating stimulus contrast, which effectively varied retinal noise.

As would be expected, lower contrast negatively affected observer's estimates of motion direction. However, we did not find evidence for the previously described biases. Instead, observers increasingly confused motion direction, such that motion toward the observer was reported as away, and motion away from the observer was reported as towards. We subsequently developed a Bayesian model in which these misperceptions can be understood as a natural consequence of optimal inference under sensory uncertainty.

These results extend models of motion perception, produce novel predictions for the effects of sensory limitations on behavioral performance, and build toward understanding visual perception in a three-dimensional world.

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Jenny Read
Newcastle University, UK
Developing a Stereoscopic 3D Display System for an Insect

The praying mantis is the only non-vertebrate which is known to have binocular stereopsis. Although several pieces of circumstantial evidence, such as their wide binocular overlap, suggest the presence of stereo vision, the proof comes from a series of experiments by Samuel Rossel in the 1980s and 90s. Rossel used prisms and occluders in order to display different images to the two eyes. However, these techniques are extremely limited in the kind of disparities they can present. Almost none of the classic human experiments on stereopsis can be performed by these means. To date, Rossel's remains the only lab to have demonstrated stereopsis in any non-vertebrate species.

Our team is investigating the computational algorithms insects use to achieve stereopsis, and the neuronal mechanisms by which these computations are carried out. For this purpose, we need a way of displaying arbitrary left and right images to the two eyes of a mantis. In this paper, I will discuss how we have achieved this.

We used beeswax to glue two tiny pieces of film to the mantid's face, in such a way that the front-facing portion of each eye is covered by a different piece of film, effectively forming insect 3D glasses. We discovered that, after a short recovery period, mantids appear to behave normally while wearing the glasses: for instance, they will hunt for prey in their home cages, and will track and strike at images of prey presented on a computer screen. Initially, we

constructed the 3D glasses from "passive stereo" circularly polarizing filters used for human 3D, in conjunction with a 3D monitor of the patterned retarder type. However, a long series of experiments failed to provide any evidence that the mantids were perceiving objects presented on this system with the depth indicated by the screen parallax (the physical separation between the left and right images on the screen). Possible reasons for this include (i) the mantis is free to move in these experiments. As it moves its head up and down, it can vary the angle at which it views the object on-screen. Cross-talk in this kind of 3D display is highly dependent on viewing angle, so this means cross-talk is poorly controlled. (ii) The polarizing filters were damaged by the tweezers used to place them on the mantid's face, which could have increased cross-talk independent of head angle. (iii) Light emerging from the circularly-polarizing filters is linearly polarized, and it was impossible to ensure that the axis of linear polarization was the same in both eyes when the glasses were affixed. Any sensitivity to linear polarization in the mantid's eye would therefore result in a luminance mismatch between the two eyes' images. To address both concerns, we repeated many experiments with the mantis fixed in place, viewing the 3D monitor through 3D filters fixed in front of the relevant eye, aligned such that the light arriving in each eye was linearly polarized along the same axis. This failed to produce any improvement. The reason for the failure of the polarizing filters remains unclear.

We therefore moved to anaglyph glasses, i.e. using spectral filtering. Conveniently, mantids are unusual among insects in being monochromatic, so their nervous systems cannot detect spectral differences between left and right images. Luminance mismatches remain a possibility, but we attempted to minimise these by using green and blue filters with a pass-band on either side of the mantid's peak spectral sensitivity, and presenting stimuli on the green and blue LEDs of a 3-LED LCD monitor. We measured the electrophysiological response in the mantis retina to light flashes presented on green/blue LEDs, and viewed through green/blue filters. We then adjusted the luminance in order to equalize the responses evoked by each color.

Using this technique, we were able to confirm that praying mantids (Sphrodromantis lineola) use binocular disparity to judge the distance of prey. Like Rossel, we used the mantids' strike response to demonstrate this. Mantids strike at prey only when they are within catching range of their raptorial forelegs: within about 4cm in our species. In our experiments, we presented simulated prey objects on a computer monitor at a variety of distances from 5-15cm, all out of the catch range. We found that mantids would strike at the simulated prey when these were presented with a screen parallax indicating a virtual object within the catch range. However, mantids would not strike when the prey was presented with zero parallax (i.e. on the screen plane) or with the opposite screen parallax, indicating a virtual object further away than the screen. This represents the first independent replication of non-vertebrate stereopsis. Our anaglyph 3D glasses technique allows us to present arbitrary images to the two eyes, in a freely behaving mantis, without changes in cross-talk due to head orientation or viewing angle. We now plan to use this technique to probe the nature and capabilities of mantis 3D.

Author contributions: VN developed the 3D glasses technique and carried out most of the behavioral experiments as well as analyzing the behavioral data. RR carried out the electrophysiology experiments and analysed the corresponding data. GT wrote the computer code for visual stimulation and interfacing with the electrophysiological recording system. JN did some of the behavioral experiments as part of her MRes project. JR led the research.

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***Monday, February 2*: 4:00 - 8:00 pm Psychophysics and Physiology**

David Heeger
New York University
Reliability of Sensory-Evoked Activity in Autism

Autism has been described as a disorder of general neural processing, but the particular processing characteristics that might be abnormal in autism have mostly remained obscure. I will present evidence of one such characteristic: poor evoked response reliability. We compared cortical response amplitude and reliability (consistency across trials) in visual, auditory, and somatosensory cortices of high-functioning individuals with autism and controls. Mean response amplitudes were statistically indistinguishable across groups, yet trial-by-trial response reliability was significantly weaker in autism, yielding smaller signal-to-noise ratios in all sensory systems. Response reliability differences were evident only in evoked cortical responses and not in ongoing resting-state activity. I will also present electrophysiological measurements of response reliability differences in a mouse model of autism. These findings reveal that abnormally unreliable cortical responses, even to elementary nonsocial sensory stimuli, may represent a fundamental physiological alteration of neural processing in autism. The results motivate a critical expansion of autism research to determine whether (and how) basic neural processing properties such as reliability, plasticity, and adaptation/ habituation are altered in autism.

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Nicholas Port

Indiana University

Eye Movement Dynamics: A Rapid Objective Involuntary Measure of Concussion/MTBI

Critical decisions are made daily about whether to bench athletes who might have suffered mild traumatic brain injury (mTBI). Unfortunately, the low-level, diffuse damage underlying sport-related mTBI has proven difficult to measure, especially on the sidelines where initial decisions must be made quickly. The most widely used tool, beyond self reported symptoms, for diagnosing and tracking sports-related mTBI is the ImPACTTM test1, a neuropsychological battery. This test is not viable as a rapid sidelines test because of its length (30 minutes) and the need for a controlled testing environment. It is also susceptible to motivational factors; one's performance can be manipulated to increase or decrease the chance of being cleared to play. The ideal instrument for measuring mTBI would be sensitive to low-level diffuse damage, would be easily and rapidly administered on the sidelines after a potentially injurious hit, and would be unaffected by human bias. Based on a body of research documenting the sensitivity of ocularmotor performance (e.g., eye movements such as saccades and smooth pursuit) to mTBI damage, we have built five sideline eye tracker and are currently evaluating its clinical utility as a rapid, objective, and accurate sideline test of sports-related concussion/mTBI. I first present our a review of our original ~50 concussed athletes and how their pursuit and saccadic system were impaired by concussion. I will then present a summary of our new sideline eye tracker which is currently in use with the entire IU athletic department and two local high schools with an enrollment of over 1600 athletes in the study.

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Tania Pasternak

University of Rochester

Unilateral Prefrontal Lesions Impair Memory-Guided Comparisons of Contralateral Visual Motion

The contribution of the lateral prefrontal cortex (LPFC) to working memory tasks is a topic of active debate. On the one hand, it has been argued that the persistent delay activity in LPFC recorded during some working memory tasks is a reflection of sensory storage, the notion supported by some lesion studies. On the other hand, there is emerging evidence that LPFC plays a key role in the maintenance of sensory information not by storing relevant visual signals but by allocating visual attention to such stimuli. In this study, we addressed this question by examining the effects of unilateral LPFC lesions during a working memory task requiring monkeys to compare directions of two moving stimuli, separated by a delay. The lesions resulted in impaired thresholds for contralesional stimuli at longer delays, and these deficits were most dramatic when the task required rapid reallocation of spatial attention. In addition, these effects were equally pronounced when the remembered stimuli were at threshold or moved coherently. The contralesional nature of the deficits points to the importance of the interactions between the LPFC and the motion processing neurons residing in extrastriate area MT. Delay-specificity of the deficit supports LPFC involvement in the maintenance stage of the comparison task. However, because this deficit was independent of stimulus features giving rise to the remembered direction and was most pronounced during rapid shifts of attention, its role is more likely to be attending and accessing the preserved signals rather than their storage.

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Kenneth H. Britten

University of California, Davis

Neural Control of Steering in Monkeys

Authors: K. Britten, S.W. Egger, X. Li

Optic flow is the term given to the pattern of motion that results from our motion through the environment. Most of the study of the processing of this kind of information has been done using conventional two-alternative, forced-choice tasks. This approach has been productive, uncovering a network of areas that contribute to such perception, and elucidating a number of their properties in some detail. However, the perceptual tasks used in these studies differ in significant ways from normal locomotion: the stimuli are usually briefly presented and the behavior is open-loop. Locomotion, however, unfolds over time and is closed-loop. We have developed a behavioral task where

monkeys steer through a virtual environment in pursuit of a distant target, being guided by continuous dynamic feedback from optic flow. Behavior in this task is reliable and well described by simple control-system models. While the animals are performing this task, we recorded from the dorsal subdivision o f the medial superior temporal area (MSTd), one of the cortical areas known to be involved in optic flow processing. Neuronal responses to both of the behaviorally relevant cues (the motion of the distant target and the optic flow) are robust. One surprise is the strength of the responses to the motion of a small target; MSTd neurons are thought to not respond very well to such stimuli. Also, the responses to the two cues also interact: optic flow responses depend on the location of the target and vice versa. This reveals a hitherto un-suspected complexity of MST motion responses. We have also analyzed both behavioral and neuronal responses for their fidelity of representation of a time-varying stimulus, using a stimulus-reconstruction approach. We find that neurons in MSTd are, on average, relatively poor at representing the stimulus, relative to behavioral fidelity. However, a few neurons approach the precision of the behavior. This suggests that relatively simple population readout would allow the signals in MST to support active steering behavior.

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John H. Reynolds

The Salk Institute

Using Optogenetics to Probe Neural Circuit Mechanisms Underlying Attention

Authors: A.S. Nandy, J.J. Nandy, J. H. Reynolds

A typical visual scene contains more information than our visual system can process at any moment in time. The brain utilizes attention to preferentially process behaviorally relevant stimuli. The physiological signatures of spatial attention have been well-studied in cortical area V4 of the macaque, where increases in gain, reductions in low-frequency correlated activity and a biasing of competition between nearby stimuli have all been implicated with attention. Together, these effects are thought to increase the signal-to-noise ratio of behaviorally relevant stimuli at the attended location, while largely filtering out activity associated with behaviorally irrelevant distracters. The neural circuit mechanisms underlying these effects remain poorly understood. Here, we describe experiments in which we have used optogenetic depolarization of excitatory neurons in macaque V4 to probe the circuitry of attention.

Michael Landy

New York University

A Model of Contingent Adaptation in Cortex

The literature on sensory adaptation has been dominated for many years by a model of adaptation in which individual neurons (or psychophysical channels) reduce their gain in response to overstimulation. This "fatigue" or gain-control model is not consistent with recent physiological evidence showing that (1) neural orientation-tuning curves are repelled away from an over-represented orientation in an adapting stimulus ensemble, and (2) adaptation results in neural spiking covariances that are restored to their pre-adaptation values in such a biased stimulus ensemble. We have developed a new model of cortical adaptation that can account for these physiological data. The model is based on the normalization model of cortex in which the response of a given neuron is divided (normalized) by the responses of other neurons having different orientation preferences and/or receptive-field locations. We extend the normalization model with a learning rule in which the weight of neuron i for the normalization pool for neuron j is modified so as to homeostatically control the product of the firing rates of this neuron pair, pushing that product toward its expectation, pre-adaptation, for an unbiased stimulus ensemble. This "contingent-adaptation" model makes several predictions that we have tested psychophysically. (1) Adapting to an orientation-biased stimulus ensemble leads to a tuning-curve shift measured psychophysically (a variation on the typical tilt aftereffect). (2) Adaptation to center-surround displays with center and surround grating orientations that covary modulates surround masking effects. (3) Adapting to a plaid, as compared to adaptation to plaid components alternated sequentially, leads to stronger cross-orientation overlap masking. A model of adaptation, in which sensory neurons with greater covariance than is expected update to inhibit each other more, explains the coding of biased

stimulus ensembles and may provide a canonical learning model applicable to a wide variety of learning and adaptation phenomena.

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Randolph Blake

Vanderbilt University

Visual Competition

Conscious visual awareness seems to occupy center stage in our perceptual world, but is that just an illusion? To rephrase that question in a tractable form, what aspects of visual processing transpire outside of awareness? One very useful tool for answering that question is the beguiling phenomenon called binocular rivalry â€“ fluctuations in perceptual dominance between conflicting visual images presented separately to the two eyes. My talk highlights some surprising discoveries that have been made using rivalry to dissociate physical stimulation from perceptual awareness.

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Bill Geisler

University of Texas, Austin

Dimensions of Masking Measured by Constrained Natural Scene Sampling

Vision science has identified a number of factors that affect detection threshold for spatial targets in backgrounds. Typically, simple stimuli are used to allow precise experimental control and rigorous hypothesis testing. However, an ultimate goal of vision science is to understand performance under natural conditions, where multiple factors are varying simultaneously in complex ways. We have developed a direct experimental approach for identifying and quantifying the factors that affect detection performance in natural scenes. First, we obtain a large representative collection of calibrated natural images. Next, we divide the images up into millions of background patches and sort them into narrow bins along dimensions of interest. For example, in the present study each bin represents a particular (narrow range of) mean luminance, contrast, and similarity (spatial correlation of the background to the target). Next, we measure detection thresholds in humans parametrically for a small subset of bins spanning each dimension. The psychometric function for each bin is measured by randomly sampling (without replacement) background patches from that bin. Finally, we analyze the residual variation of the background patches within each bin for other factors that strongly correlate with the measured performance. In our initial measurements with a 4-cpd Gabor target in five subjects, we find that threshold amplitude is a linear function of mean luminance (Weber's law for luminance), threshold power is a linear function of background contrast power (Weber's law for contrast), and threshold amplitude increase linearly with similarity once above a base level of similarity. Each of these dimensions (when the others are held fixed) has a large effect on threshold (greater than a factor of 10) over the range of values that occurs in a typical natural gray scale image. We also identified another dimension (contrast-contrast) that explains much of the residua l variance in the thresholds. We argue that these results may form the foundation for a general model of detection in natural scenes. Also, this general approach should be applicable to other natural tasks as long as a sufficiently large set of natural stimuli can be obtained.

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***Tuesday, February 3*: 4:00 - 8:00 pm Perceptual Organization, Attention**

Roger Ratcliff

Ohio State University

Modeling the Go/no-go Task

Authors: R. Ratcliff, C. Huang-Pollack, G. McKoon

The go/no-go task is one in which there are two choices, but the subject responds only to one of them, waiting out a time-out for the other choice. The task has had a long history in psychology and modern applications in the clinical/neuropsychological domain. We present a diffusion model that assumes there are two decision boundaries for the go/no-go task and termination at go boundary leads to a response and for termination at the no-go boundary, the subject simply waits out the trial. First, we fit the standard two-choice model to two-choice data and then fit the go/no-go model to RTs from one of the choices from the two-choice data. Results showed parameter values that were similar between the two models with high correlations between the parameter values across subjects. The go/no-go model was also fit to data from a go/no-go version of the same task with the same subjects. Most model

parameters differed from the two-choice values, in particular, drift rates were lower for the go/no-go task. A simulation study with ranges of parameter values that are obtained in practice also showed similar parameter recovery between the two-choice model and the go/no-go model. The results show that a diffusion model with an implicit (no response) boundary can be fit to data with almost the same accuracy as fitting the two-choice model to two-choice data.

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Zhong-Lin Lu

Ohio State University

Visual Perceptual Learning: How Experience Shapes Visual Perception

Practice or training in perceptual tasks improves the quality of perceptual performance, often by a substantial amount. This improvement is called perceptual learning, in contrast with learning in the cognitive or motor domains. Perceptual learning has been a very active area of research of both theoretical and practical interest. Research on perceptual learning is of theoretical significance in illuminating plasticity in adult perceptual systems, and in understanding the limitations of human information processing and how to improve them. It is of practical significance as a potential method for the development of perceptual expertise in the normal population, for its potential in advancing development and supporting healthy aging, and for noninvasive amelioration of deficits in challenged populations by training. In this talk, I will discuss the special challenges of perceptual learning that balance the competing goals of system stability and system adaptability, and a potential account of the broad range of perceptual learning through the theoretical framework of incremental learning of reweighting evidence that supports successful task performance.

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Barbara Dosher

University of California, Irvine

Perceptual Learning: Plasticity, Stability, and the Integrated Reweighting Theory

Perceptual learning improves how we see visual stimuli and is the basis of visual expertise. This talk considers whether and how the Augmented Hebbian Reweighting Model and its extension, the Integrated Reweighting Theory, relate to plasticity and stability of visual representations, and how they account for broad phenomena in perceptual learning, such as mechanisms, feedback, and induced biases.

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Aaron Seitz

University of California, Riverside

Better Batting through Perceptual Learning

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Steve Shevell

University of Chicago

Color Motion Feature Binding Without Color: An AIC Story

Authors: S. Shevell. N. Stepien

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George Sperling

University of California, Irvine

Visual Attention Filters for Color

Authors: G. Sperling, P. Sun, C.E. Wright, C. Chubb

An attention filter is a top-down instruction-initiated brain process of feature-based attention that allows selected visual information to pass but attenuates unselected information. A centroid-judgment paradigm enables the quick measurement of such human perceptual filters. The paradigm as used here enables measurement of human attention filters for single colors as precisely as physical measurements of photographic color filters. Subjects view a briefly presented cloud of colored dots, use a mouse to position a pointer at the centroid--the center of gravity--of the cloud, and receive comprehensive feedback after every trial. In attention conditions, a subset of dots is designated by some characteristic, such as a particular color, and subjects judge the centroid of only the distinguished subset, e.g., dots of the attended color. The analysis determines the precise weight (according to its color) that each colored dot (attended and unattended) contributes to the judged centroid, i.e., the attention filter for the attended color in that context.

We measured attention filters in stimuli that contained 24 dots, 3 dots in each of of 8 colors. Subjects estimated the centroid of the 3 dots of the attended (target) color while attempting to ignore the 21 other (distracter) dots. Four 8-color sets were studied: isluminant hues in a hue circle embedded in an isoluminant plane in 3D color space, and sets of dot colors positioned on the three "axes": red-green, blue-yellow, and black-white.

Results: The 32 measured attention filters (plus attention filters measured in control conditions) show that attention filters for one color among the 7 isoluminant hues are extremely selective, achieving attended/unattended weight ratios >30:1. For equally discriminable colors along the 3 color axes, attention filters are much less selective.

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***Wednesday, February 4*: 4:00 - 8:00 pm Higher-order Perception**

Zygmunt Pizlo

Purdue University

Spatially-Global Interpolation of Closed Curves
Authors: Z. Pizlo, T. Kwon, K. Agrawal, Y. Li

Most previous methods focused on spatially local interpolation using rules such as proximity, co-linearity, co-circularity and relatability. We propose a spatially global model based on finding the shortest path in the log-polar representation of the image, which is a good approximation to the topographical map of the retina in the area V1. The shortest path in a log-polar representation corresponds to a smooth, convex and closed curve with a small number of interpolated segments in the retinal image. As such, our method implements four fundamental rules of Gestalt perceptual organization: closure, convexity, proximity and good continuation. Producing the shortest path is computationally simple. At the same time the shortest path interpolates missing parts of the target contour and

ignores pieces of contours that are likely to represent noise. These features of our model are critical considering the fact that spatially-global interpolation is a combinatorial optimization task with exponential complexity. Three subjects and the model were tested with synthetic stimuli composed of 300 noise and 30 target edges (straight line segments). The target was a convex or a concave fragmented polygon. Orientational jitter of the target edges was used to move the subject's performance from nearly perfect to nearly chance. Performance of the three subjects was very similar across the stimuli and jitter levels. The model, whose performance depended on only one free parameter, emulated the subjects' performance very closely.

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James H. Elder

Centre for Vision Research, York University

Generative Shape Trees
Authors: J. H. Elder, I. Frund, A. Yakubovich

Intermediate areas of the primate object pathway in visual cortex appear to represent object shape in some form of sparse code, although the precise nature of this code remains unclear. While this representation must serve to support object recognition, it may also play a role in perceptual organization through feedback pathways to early visual cortex. This possibility suggests a generative framework for shape representation. I will review a selection of generative models but will focus on an approach originating with the GRID framework of Grenander et al (2007), used to model incremental growth in medical imagery, which has the significant advantage of preserving topology. I will show how this framework can be used to model natural shape as the result of a sequence of localized deformations called formlets, applied to an embryonic elliptical form. Although formlets are formally sequential, we show that a simple inner product measure of formlet independence can be used !
to restructure this representation into a hierarchical tree that corresponds closely with our intuitive notion of parts and introduces opportunities for parallelizing and thus speeding shape coding and decoding.

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Richard Murray

York University

Lightness Constancy via Bayesian Anchoring

Lightness constancy is the remarkable ability of human observers to perceive surface reflectance accurately despite variations in illumination and context. Two successful approaches to understanding lightness perception that have developed along independent paths are anchoring theory and Bayesian theories. Anchoring theory is a set of rules that predict lightness percepts under a wide range of conditions (Gilchrist, 2006). Some of these rules are counterintuitive, e.g., a rule that large surfaces tend to look lighter than small surfaces. Bayesian theories are formulated as probabilistic assumptions about lights and objects, and they model percepts as rational inferences from sensory data (e.g., Adelson, 2000). Here we reconcile these two seemingly divergent approaches by showing that many rules of anchoring theory follow from simple probabilistic assumptions about lighting and reflectance. We describe a simple Bayesian model that makes maximum a posteriori interpretations of luminance images, and we show that this model predicts many of the phenomena described by anchoring theory, e.g., anchoring to white, scale normalization, and articulation effects. Thus anchoring theory can be naturally formulated in a Bayesian framework, and this approach shows that many seemingly idiosyncratic properties of human lightness perception are actually rational consequences of simple assumptions about lighting and reflectance.

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Casper Erkelens

Utrecht University

The Extent of Visual Space Inferred From Perspective Angles

Retinal images are perspective projections of the visual environment. Despite this, it is not self-evident that visual space is a perspective representation of physical space. Analysis of underlying spatial transformations shows that visual space is perspective only if physically parallel lines vanish at finite distance in visual space. Three subjects judged the perspective angle, i.e. the angle perceived between parallel lines in physical space, between real rails of a straight, disused, railway track. The subjects also judged the perspective angle from pictures taken from the same point of view. Perspective angles between real and depicted rails ranged from 27% to 83% of their angular size in the retinal image. Perspective angles prescribe the distance of vanishing points of visual space. Computed distances were all shorter than six meters. This extent of a hypothetical space inferred from perspective angles does not match the depth of visual space, as it is perceived. The incongruity between perspective angles and depth of visual space is huge but apparently so unobtrusive in human vision that it has remained unnoticed. The current results argue against methods that have been used to measure visual space. The mismatch between perceived angles and distances casts doubt on the concept of a consistent visual space.

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Tim McNamara

Vanderbilt University

Cue Combination in Human Spatial Navigation

This project investigated the manner in which visual cues and self-motion cues are combined during navigation. Participants walked from a starting location to three successive waypoints and then attempted to walk back to the first waypoint using (a) only self-motion cues, (b) only visual cues, (c) concordant visual and self-motion cues, and (d) conflicting visual and self-motion cues. Cue reliability was manipulated for each cue independently. The primary dependent measure was response precision. The results showed that navigators were able to combine visual and self-motion cues in an optimal or near optimal manner. Participants varied widely in their apparent abilities to use each type of cue, and this variability was reflected in the weighting of cues when combined. False feedback affected navigators' performance in the task, not simply their weighting of cues. We propose a new framework for understanding the role of cue reliability in human navigation.

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Keith A. Schneider

York University, Canada

Quantized Time Perception and Illusions of Motion

Much of the spatiotemporal input to the visual system is redundant. Retinal circuits remove spatial redundancy, and this process continues in the cortex, akin to compression techniques used to reduce the file size of digital images. The temporal mechanisms used by the brain are less clear, but temporal compression necessarily involves temporal subsampling. Such discrete perception has long been speculated, suggesting that the brain processes snapshots of the visual world similar to the frames of a motion picture, but has never been definitively proven. I will show that the assumption of discrete processing simply and quantifiably accounts for many illusions of motion, including the Fröhlich effect and the various manifestations of the flash-lag effect, which have defied a coherent explanation.

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***Thursday, February 5*: 4:00 – 8:00 pm Visual, Photonic, and fMRI Assessment**

Jeffrey B. Mulligan
NASA Ames Research Center

Assessment of Sensory and Cognitive Performance using Mobile Touch-screens

In recent years, mobile touch screens have become ubiquitous, with the widespread acceptance of smart phones and small tablet computers. These devices offer new ways to collect data in the field. In this talk, I will demonstrate two applications: the first is a novel method for the measurement of visual contrast sensitivity, in which the subject is presented with a "sweep grating" depicting a range of contrasts and spatial frequencies in a single image, on

which the subject indicates the threshold contour with a single swipe with a finger. The second is an implementation of the Psychomotor Vigilance Test (PVT), which measures simple reaction time to a visual stimulus, and has been previously validated as an indicator of fatigue. The implementation of PVT was combined with a set of daily questionnaires and was used in a fatigue study conducted with the European airline EasyJet in 2013. Both applications were constructed using a software framework called QuIP (QUick Imag! e Processing), originally developed for UNIX platforms, which allows rapid prototyping of new applications, and a degree of portability between desktop computers and mobile devices.

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Laurie Wilcox

York University

On the Benefits of Disparity-Based Grouping: Improved Detection in Visual Search

Stevens and Brooks (1988) proposed that degraded depth percepts from slanted surfaces are due to an impoverished disparity signal. They argued that the visual system is insensitive to linear disparity gradients, and (as in the case of brightness) instead extracts surface discontinuities or point discontinuities in otherwise smooth surfaces. As a result, estimates of slant in depth from linear disparity gradients are imprecise. While this proposal is consistent with much of the data concerning stereoscopic depth from slanted surfaces, our research supports an alternative explanation. Using line and dot stimuli presented stereoscopically we have shown that configural cues to perceptual organization, such as closure, strongly modulate the amount of relative depth seen in figures with smooth disparity gradients. We argue that the degraded depth percepts reported previously are well explained by object-based disparity smoothing operations (Marr & Poggio, 1976). That is, degraded percepts for stimuli that are slanted in depth are obtained when there is implicit or explicit spatial support for interpretation of the two features as a single object however, when this support is removed or reinterpreted, depth from disparity increases. Local relative depth information is sacrificed for the sake of cohesion in these slanted stimuli. However, we have also shown that this perceptual grouping phenomenon results in improved detection for these cohesive stimuli in a visual search paradigm.

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Justin Halberda

Johns Hopkins University

Clustering and Number Perception in Random Dot Arrays

In this talk, we propose that rapid extraction of approximate number may occur based on perceptual groups as units, rather than single individual items. We introduce a modeling approach relying on a modified k-means clustering algorithm to formally describe human observers'grouping behavior (quantitatively fit as a grouping window size). Next we studied the impact of grouping on human estimation of the number of elements in an array; we found that human observers tend to underestimate the number of dots in a display as a function of the "clusteredness" within the display (i.e., the greater the proportion of items falling within the critical inter-item distance of 4˚ the greater the underestimation). We suggest that, in some situations, the representation of numerosity may be based on perceptual groups as units, allowing for the rapid extraction of ensemble features from briefly flashed visual scenes.

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Lawrence Cormack

University of Texas, Austin

(Almost) Continuous Psychophysics: Using Real-Time target tracking to measure sensitivity

In a target tracking task, an observer attempts to follow a moving target with a cursor, their finger tip, or their gaze. Intuitively, the greater the visual sensitivity for the target, the better an observer should be able to follow it. Not only does this intuition hold, but a Kalman filter model fit to tracking data yields sensitivity estimates directly comparable to those from traditional push-button psychophysics. Overall efficiencies for tracking are slightly worse that for button pushing (understandably), but the two techniques yield fundamentally the same answers. Tracking, however, is more fun. We will show a few example applications of this technique, and also show that robust results can be obtained without requiring a full Kalman filter model of the observer.

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Bosco S. Tjan

University of Southern California

A Forward Model of BOLD fMRI for Multi-Voxel Decoding in Human V1

Authors: B.S. Tjan, R. Millin

Pattern classifiers have been used to decode multi-voxel fMRI activity of V1 with respect to visual stimuli. When decoding is successful, how much of the success can be attributed to the retinotopic projection of the visual field on to the cortex? More importantly, when decoding fails, is the failure due to properties of the spatiotemporal response of fMRI BOLD signal, or can it be attributed to the neural computation? To answer these questions, we built a realistic forward model of multi-voxel fMRI BOLD response for human V1, which includes the consensus models of cortical magnification of V1 (Rovamo and Virsu, 1984), spatial point spread function of the BOLD signal (Engel et al., 1997), and nonlinear hemodynamics (Buxton et al., 1998). For a given subject, we empirically estimated the responsiveness of each V1 voxel to a calibration stimulus. We also characterized the â€œnoiseâ€ in the BOLD signal by estimating the spatiotemporal spectrum of the non-stimulus-related signal fluctuation and a ratio that describes an additive mixing of response-dependent and response-independent noise. Once calibrated with a small data set, the model was able to predict voxel-wise BOLD signal time courses to new stimuli that are similar in spatiotemporal characteristics to the calibration stimuli. Applying pattern classification to the model output, we found that for large peripherally presented letters, the accuracy of pattern classification with human V1 data is comparable to that with modeled BOLD response, suggesting the decoding result in this case is mostly due to the retinotopic projection of the stimuli on to V1. Our model can be used as a simulator to optimize the design of a pattern-classification experiment with respect to the spatiotemporal limitations of the BOLD signal in V1.

Cory Miller

University of California, San Diego

Optogenetic Photostimulation in Marmoset Cortex

Marmosets are emerging as a powerful model for investigation of primate neurologic systems. Optogenetics offers relatively precise temporal and spatial control of neuronal activity. We employ awake, behaving head-fixed marmosets performing auditory discrimination tasks to evaluate marmoset cognition, auditory processing, and social behaviors. More could be learned about the underlying neural mechanisms of these complex primate features using optogenetic manipulations of neurons to perturb the brain during auditory tasks. Here we sought to develop an optogenetic photostimulation preparation for marmoset cortex. This project comprised two components. The aim of the first component was to determine which viral constructs were most suitable for use in marmosets. Using various adeno-associated viral (AAV) capsids containing channel rhodopsin genes with varying promoters, we systematically examined various methods for creating a marmoset optogenetic preparation. We investigated the utility of AAV 1, 5, and 9, the promoters synapsin, CAMkII, and CAG, and we varied injection rate and volume into the marmoset cortex. The viruses were allowed to express for 6 weeks after injection and brains were harvested and examined microscopically using immunofluorescence. The channel rhodopsins also had fluorescent protein tags such as GFP, YFP or mCherry. Primary antibodies against NeuN, GABA, CD68, and GFAP were applied to fixed brain slices prior to application of secondary fluorescent antibodies. The results demonstrate excellent expression of channel rhodopsin for particular serotype/promoter combinations. Particular constructs expressed notably well in the long-tract axons of the corpus callosum and in white matter coursing through internal capsule and brainstem. The aim of the second phase of the project was to optimize photoexcitability in marmoset cortex using these constructs.

We are currently refining these parameters in marmoset neocortex and will present these results. Our results here indicate that using optogenetic techniques in marmosets is a feasible and useful method of correlating neural activity with behavior in awake marmosets.

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***Friday, February 6*: 4:00 – 8:00 pm Friday Miscellany**

Dirk Bernhardt-Walther

University of Toronto

Local, not global Structure Drives Human Scene Categorization
Authors: D. B. Walther, H. Choo

People can categorize scenes accurately and rapidly. Which visual properties do people use to categorize scenes with such efficiency? Here we provide conclusive evidence from computational analysis, behavioral testing, and decoding from neural activity that intact local structure of scenes is essential for human scene categorization. (1) We extracted structural properties of contours (orientation, length, and curvature) and contour junctions (types and angles) from line drawings of natural scenes. Of these properties, orientation contained the most information about scene category that can be exploited computationally. We found, however, that junction properties (requiring precise localization of contours, thus only available locally) generated prediction errors most similar to errors made by humans in a six-alternative forced-choice scene categorization task. (2) To further test their role in scene categorization, we selectively perturbed junctions (by randomly shifting contours) and orientation (by randomly

rotating the image). Participants categorized rotated scenes more accurately than contour-shifted scenes. More importantly, error patterns of rotated but not contour-shifted scenes correlated with error patterns of intact scenes. (3) How do these manipulations affect the neural representation of scene categories? Using functional magnetic resonance imaging we recorded brain activity of participants passively viewing intact, rotated, and contour-shifted scenes. We could decode viewed scene category from intact and rotated but not from contour-shifted scenes in the parahippocampal place area (PPA), retrosplenial cortex, and the occipital place area. Furthermore, decoding errors in PPAmatched behavioral errors if and only if local structure was preserved, i.e., for rotated and intact scenes. We conclude that local structure is essential for scene categorization by humans. Disruption of local structure degrades scene categorization performance and affects category-specific neural activation patterns in PPA. In light of these results, the view that scene perception is chiefly determined by global properties needs to be revised.

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Kerry Jordan

Utah State University

The Nature of Impulsivity

Authors: K. Jordan, M. Berry, M. Sweeney, J. Morath, A. Odum

Visual exposure to natural environments benefits human stress reduction, mood improvement, and attention restoration, but the effects of natural environments on impulsive decision-making remain largely unknown. We evaluated differences in impulsivity when humans were exposed to one of the following image sets: natural (e.g., mountains), built (e.g., buildings), or control (e.g., triangles). We employed a delay discounting task requiring participants to choose between immediate and delayed hypothetical monetary outcomes. Participants viewed the images before and during the delay discounting task. Participants made more self-controlled decisions in the condition providing visual exposure to natural scenes compared to built and geometric scenes. Results suggest that exposure to natural environments decreases impulsive decision-making relative to built environments.

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Jane E. Barker

University of Colorado

Children's Time Use Predicts Developing Self-Directed Executive Function

Authors: J. E. Barker, Y. Munakata

Young children who typically have no difficulty achieving a goal when given a timely reminder (e.g., interrupting the morning routine to grab a coat on a chilly day, after a cue from mom), often struggle when they must behave in a more self-directed way (e.g., stopping to grab the coat when mom is absent). In each scenario, children engage executive functions (EFs), the cognitive processes that regulate thoughts and actions in support of goal-directed behavior. However, children who can successfully engage externally-driven EFs in the presence of reminders may struggle to engage self-directed EFs, where they must decide what to do and when. Externally-driven EFs can be improved via structured, adult-led training, but it is less clear how children's experiences relate to their development of self-directed EF. In this work, we build on recent findings showing that the way in which 6-7 year-olds spend their leisure time predicts their self-directed EF. Specifically, children who spent more time in less-structured activities displayed better self-directed EF, as indexed by a verbal fluency task (in which children generate members of a category and can decide on their own when to switch from one subcategory to another) (Barker et al., 2014). By contrast, children who spent more time in structured activities exhibited marginally poorer self-directed EF. These relationships were specific, as time use did not predict performance on two standard measures of externally-driven EF: Flanker and AX-Continuous Performance (AX-CPT) tasks. In this talk, we will present new analyses of this rich dataset and new findings from follow-up studies targeting potential mechanisms underlying links between leisure time and EF. Our more-detailed analyses reveal that less-structured activities vary greatly in their relationship with self-directed EF. For instance, social, rather than solitary, activities show strong positive relationships with self-directed EF. In contrast, time spent multitasking with media (e.g., watching TV and eating dinner) predicts worse self-directed EF. Also, in contrast with impressions that the availability of less-structured time for children may be a luxury associated with the presence of a stay-at-home parent, we find that children with a stay-at-home parent did not differ from children without a stay-at-home parent in their amounts of less-structured time ($p>.5$); moreover, positive links between less-structured time and child self-directed EF are not explained by the presence of a stay-at-home parent ($p>.4$). We present possible interpretations of these findings and others, and discuss their relationships to diverse literatures, including those emphasizing the benefits of experiences where children can plan, play, or mind-wander.

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Xiaoping Hu

Emory University

Modeling Brain State Switching with Hidden Markov Model

The resting state brain is known to be dynamic and believed to be switching between states. Functional MRI of the resting state has provided us a means to examine the dynamics of resting state brain noninvasively and over an extended period of time. However, existing approaches for analyzing the dynamics of rsfMRI data do not account explicitly for sequential switching between states. For example, spatial Independent Component Analysis or Co-activation Patterns treat all the temporal samples as independent and ignore the sequential information in the data. As a dynamic approach, the sliding window correlation method has a constraint of the fixed time window length, which would mix signals from multiple states together. In this work, Gaussian Hidden Markov Model (HMM) is adopted to model the brain state switching process. In our model, we modeled the switching as a markov process and used multi-variate Gaussian distributions to represent brain states. In our results, we detected 9 reproducible brain states from the experimental fMRI data. The resultant states are consistent with brain networks well described in the literature. We further calculated the occurrence and duration of each state and derived the states sequence for each subject. These temporal characteristics provide additional insights in the resting state brain and may allow to examine it in normal and pathological conditions.

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Steven Silverstein

Rutgers University

Reduced Susceptibility to Depth Inversion Illusions in Schizophrenia But Not Bipolar Disorder

Authors: S. Silverstein, B. Keane, T. Papathomas

People with schizophrenia have demonstrated more veridical perception than healthy control subjects when viewing stimuli that normally create depth inversion illusions (DIIs). The purpose of this study was to determine whether this effect depends on: 1) the type of stimulus used (e.g., face or scene); 2) the presence of texture; 3) viewing condition: monocular or binocular; 4) diagnosis: is it specific to schizophrenia or does the effect also occur in another serious mental illness, namely bipolar disorder; and 5) acuity of present illness. To address these issues, 30 schizophrenia patients, 30 bipolar disorder patients, and 25 well-matched healthy controls performed a depth inversion illusion (DII) task that involved making convexity judgments on physically concave faces and scenes. Patients were selectively sampled from three levels of care to maximize symptom heterogeneity. Subjects viewed the objects with one eye while laterally moving in front of the stimulus (to see depth via motion parallax) or with two eyes while remaining motionless (to see depth stereoscopically). For each group, DIIs were stronger with textured stimuli, and weaker with stereoscopic information than without, indicating that patients responded normally to stimulus alterations. However, patients experienced fewer illusions than controls irrespective of the face/scene category, texture, or viewing condition (parallax/stereo). The most pronounced reduction in the DII effect occurred among schizophrenia patients, with bipolar disorder patients performing roughly midway between the control and schizophrenia groups. Within the latter group however, resistance to the DII (i.e., more veridical perception) was most evident in patients with more psychotic symptoms, who required more structured treatment, and who were closer in time to their last hospitalization. These data are consistent with Bayesian models of psychotic symptom formation in schizophrenia, and suggest that DII tasks – by indexing the effects of stored knowledge on modulation of sensory signals - could potentially be used to predict symptom emergence and/or treatment response in this population.

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Peng Sun

New York University

Visual Attention Filters Act at Very Early Perceptual Stages

To judge the mean location (centroid) of only a set of black dots when they are spatially intermingled with white dots, one needs a mechanism that passes information carried by the to-be-attended visual feature (black) across space (all locations of black dots) onto further mental processes while blocking the passage of the information carried by the to-be-ignored feature (white). This global, selective process, Feature-Based-Attention (FBA), can be quantitatively described as an attention filter (Drew, Chubb and Sperling, Journal of Vision, 2010). The filter's properties are derived from the observer's responses. Here, we measured the improvement of attention filters as a function of the time-duration available for subjects to process the stimuli. Method. A brief flash of the dot-containing stimulus was followed, at various Stimulus-Onset-Asynchronies (SOAs), by a post-stimulus masking array. Stimuli were random clusters comprising 1-, 2-, 4-, 6- or 8-each of black and white dots, randomly interleaved in blocks of different SOAs ranging from 12ms to 300ms. Control trials with stimuli composed of only black dots were interleaved in each block. Subjects mouse-clicked the mean location of all the black (target) dots. Results. (1) Judgment accuracy improved as SOA increased and reached an asymptote at 80ms whether or not white (distractor) dots were present. (2) Remarkably, the improvement in accuracy as a function of SOA for black-plus-white and black-only conditions was almost identical. (3) Attention filters, at their optimum, were very effective, giving a more than 4:1 transmission advantage to black versus white dots. Conclusion. The nearly equivalent performance with black dots alone (no attention filter) and with intermingled black and white dots (attention filter required) over a wide range of stimuli and SOAs indicates that FBA takes place at a very early stage prior to the computation of the mean of multiple locations.

Charles Chubb

University of California, Irvine

Most People Cannot Hear the Difference Between Major vs. Minor Musical Modes

Authors: C. Chubb, C. Wright, C. Dickson, T. Dean, D. S. Mann

This talk will describe new research in perception of musical tonality. Our main goal is to understand how tonal variations give rise to the qualities of majorness vs minorness. Most of the stimuli we use are "tone-scrambles," randomly ordered sequences of pure tones presented at a rate of around 15 per sec. At the outset of this work, we discovered something strange: Most participants (65%) are utterly deaf to any difference between strongly major vs strongly minor tone-scrambles whereas nearly all of the other participants are highly sensitive to this difference. We documented this effect with an experiment in which the stimuli were tone-scrambles that combined eight each of four pure tones: Low and high tonics (G5's and G6's), dominants (D's), and either major thirds (B's) or minor thirds (B-flats). After training, participants strove to classify stimuli (with trial-to-trial feedback) as major vs minor. The distribution of proportion correct across 275 listeners tested over the course of three experiments was strikingly bimodal, with one mode very close to chance performance, and the other very close to perfect performance. Skill in classifying major vs minor tone-scrambles showed only a modest correlation of around 0.5 with years of musical training. Further experiments reveal that analogous results are obtained for tone-scrambles that include major vs minor sixths (E's vs E-flats) instead of thirds suggesting that sixths and thirds activate the same perceptual mechanism in generating the distinctive qualities of majorness vs minorness. If time permits, I will describe other experiments that focus on listeners who are sensitive to the difference between major vs minor. In revealing the statistical properties of tone-scrambles that control the responses of these participants as they strive to classify more complicated tone scrambles as major vs minor, these experiments begin to shed light on the mysterious "happiness" vs "sadness" of music in the major vs minor mode.

Misha Pavel

Northeastern University

Behavioral Informatics: Mathematical Models of Behavior Change

Authors: M. Pavel, H. Jimison, B. Spring

Improvements of health-related behaviors are particularly important as a part of proactive and preventive healthcare, where behavioral interventions are likely to play an important role in mitigating costs, loss of quality-of-life and increased morbidity caused by poor health behaviors. Health-related behaviors such as smoking, poor-quality diet, excessive intake of food and alcohol, and sedentary life style seem to be acquired effortlessly, but getting rid of them is difficult often requiring behavioral intervention. Fortunately, recent advances in sensing, monitoring and inferring behaviors – behavioral informatics – enable continuous assessment of behaviors. Augmented with with continuous monitoring, behavioral intervention can be viewed as closing the loop in an optimal control system, but its implementation requires quantitative models of the behaviors and behavioral change. We will describe mathematical models of behaviors and behavior change that have the potential to characterize and predict individuals' behaviors based on the dual process theoretical framework. This framework involves two processes: Type 1 is automatic and fast, triggering habitual (overlearned) behaviors. Type 2 evokes executive functions, reasoning and problems solving and is therefore slow in responding. We developed a simple computational model based on the dual process framework and used it to analyze recently published experimental data from the Make Better Choices Study (Spring et al 2012). The model was able to capture the main aspects of the data dynamics.

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