**Specific Aims Page:**

While central vision resolves the fine details of discrete objects of interest, peripheral vision plays an outsized role in mapping and monitoring the surrounding space, *capturing rich temporal information about the scene-state of the environment*. It is well-established that the retina does not process light uniformly across its surface. The concentration of spatially-sensitive photoreceptors (cones) is highest in the center of the retina (fovea) and falls off toward in the periphery, where less-spatially-sensitive rods are the dominant photoreceptor. Rods and cones primarily connect to two distinct neural pathways, the magnocellular and the parvocellular pathways, respectively. The parvocellular pathway processes color and fine detail but is comparably slower to integrate temporal changes. The magnocellular pathway is less sensitive to fine spatial detail, but processes motion at a faster rate. Accordingly, while central vision is far more sensitive to spatial information, the gradient of temporal sensitivity follows a much shallower slope toward the periphery. Finally, the distribution of photoreceptor types varies not only as a function of eccentricity, but also as a function of polar angle.

My proposed research aims to address two major gaps in the study of peripheral motion perception. First, we must extend the investigation of peripheral motion perception out of psychophysics and toward naturalistic stimuli and freely-looking behavior. Second, to understand the perception of environmental motion, we must extend study of motion perception beyond rigid-body translational motion, into the domain of complex motion. While the movement of an object of attention is often smoothly tracked in the center of vision, the natural environment seethes with complex motion, such as particle motion, oscillatory motion and turbulent flow.

My *long-term goal* is to accurately model the processing of environmental motion in the human visual system. The *objective of this application*, which is the next step toward attainment of my long-term goal, is to map naturalistic motion sensitivity across the retinotopic field, model these dynamics computationally, and test the relationship between the retinotopic mapping and higher-order (subjective) perceptual judgments in naïve observers. The *central hypothesis* driving this application is that temporal and spatial sensitivities are independently distributed across the visual field, exhibiting distinct patterns of sensitivity that do not conform to a singular, unified gradient. When cortical magnification factor (CMF) is considered, I hypothesize that far-peripheral regions of the visual field will demonstrate enhanced task-related motion sensitivity compared to near-peripheral regions. *The rationale* driving the proposed research is that perception of complex environmental motion is currently a blank spot for perceptual psychology. By characterizing the role of peripheral vision in detecting complex dynamics within natural scenes, our findings promise to address a substantial knowledge gap and provide a behavioral foundation for more detailed neuroscientific investigation of the topic.

I plan to test my central hypothesis by pursuing the following specific aims:

1. *Map the relative spatiotemporal sensitivity across the peripheral visual field, using expert observers and two types of naturalistic dynamic stimuli.* Based on preliminary data, my working hypothesis is that retinotopically-mapped spatial and temporal sensitivity gradients will exhibit independent and significantly different slope and polar angle asymmetries.
2. *Develop a simple computational observer model to bridge behavioral outcomes and neurobiological models of peripheral motion perception.* Based on my understanding of the neurophysiology of the early visual system, my working hypothesis is that a computational observer model of the system will require independent and spatially-accurate representations of both Magno-type retinal ganglion cells and Parvo-type retinal ganglion cells (and their respective pathways) to agree with the behavioral spatiotemporal sensitivity mapping at above-chance accuracy.
3. *Test whether observed spatiotemporal sensitivity maps predict responses in a subjective visual judgement task*. My working hypothesis is that the retinotopic sensitivity map generated in Aim 1 will predict the relative magnitude of subjective aesthetic responses to naturalistic dynamic stimuli, in a group of naïve observers.

The proposed research will use naturalistic stimuli to produce detailed mappings of spatiotemporal sensitivity across the peripheral visual field, and a novel computational model of peripheral motion perception. The research will reveal the relative impact that both eccentricity and polar angle asymmetries in the visual system have on task performance and subjective judgement of naturalistic dynamic stimuli. The anticipated outcomes will not only advance scientific knowledge but stand to inform innovations in virtual/augmented reality, improve therapeutic interventions in that arena, provide insight related to pathologies that selectively affect macular or peripheral vision, and influence the design of both virtual and built environments.

**Research Strategy Section**

**Overall Scientific Premise:** Classic psychophysical studies found little variation in temporal contrast sensitivity as a function of eccentricity (Virsu et al., 1982, Rovamo & Raninen, 1984) where, by contract, spatial sensitivity falls off rapidly. These results indicate highly independent distributions of spatial and temporal contrast sensitivity across the visual field. A recent fMRI psychophysical study on temporal contrast sensitivity in peripheral vision indicated that in the early visual system, peripheral regions of the cortical retinotopic map demonstrate relatively increased temporal contrast sensitivity compared to regions that represent the fovea (Himmelberg & Wade, 2018). However, the same research showed that by visual area hV4, temporal contrast sensitivity appears to be relatively uniform across eccentricities, agreeing with earlier behavioral studies of peripheral temporal contrast (Koederink et al., Wright & Johnston, 1983) that showed little difference in foveal and peripheral performance. These ostensibly conflicting findings have led me to question how peripheral motion sensitivity is mapped in the context of naturalistic stimuli and behavior. While psychophysical methods are an incredibly useful tool for measuring the capabilities of the visual system, they tend to treat behavior as a confound, paring down experiments so that the visual system can be measured separately from the mind and the environment. All the work I have just cited utilized flickering sine wave gratings, an excellent stimulus type for establishing psychophysical thresholds, but far from ecologically valid. The primary motivation of the research proposed in this application is to carefully introduce aspects of naturalistic environmental motion into the study of peripheral motion perception.

**Scientific Premise for Aim 1**: The scientific premise of Aim 1 is that while peripheral sensitivities are well established in the context of critical flicker frequency (CFF), *the visual system does not process all types of motion information uniformly*. While CFF stimuli are an excellent tool to measure temporal contrast sensitivity, they do not represent motion in the ecologically valid sense. A limited number of studies of peripheral motion using translational motion have produced important results. fMRI investigation of motion response anisotropies using 100% coherence RDKs found bias for either centripetal or centrifugal motion that changed systematically with eccentricity in visual areas V1-V3 and hV4 (Maloney et al., 2014). Earlier behavioral psychophysics demonstrated polar angle anisotropies in observer sensitivity to noise stimuli moving in one of eight cardinal directions (De Grind et al., 1992). These studies indicate that there are interactions between motion type and location in the visual field, an exciting possibility warranting further study. To begin to address this gap in understanding, I will retinotopically map observer discrimination of spatial and temporal features of two distinctly different types of dynamic stimuli: coherent motion RDKs and dynamic fractal noise.

**Scientific Premise for Aim 2**: Biologically-inspired computational models of the human early visual system have done well to mimic behavioral results in peripheral spatial discrimination tasks (Kupers et al., 2022). However, we lack detailed computational models of human motion processing. As the *core training component* of my application, I will build a detailed computational model of the early visual system with the aim of mimicking the behavioral results of Aim 1, then test which modeled physiological features of the system best account for the observed behavioral results. I will model the dorsal visual stream from retina to MT+, using a modular architecture that will allow for the selective inclusion and exclusion of particular cell and receptive field types.

**Scientific Premise for Aim** 3: Research by my lab and others on the perception of dynamic fractal noise has shown that observer sensitivity to spatial and temporal fractal complexity follows an inverted-U curve, in which mid-complexity stimuli (statistically similar to natural scenes) are most discernible (Isherwood et al., 2021, Hess et al., 2022). Additionally, this work showed that naïve observers gave slower-moving fractal noise stimuli higher subjective ratings of appeal. However, neither study addressed the role of peripheral vision directly. Results from Hassan et al. (2016) indicate that perceived velocity varies with eccentricity, and that fast-moving stimuli (sinusoidal gratings) can appear faster when viewed peripherally. This fascinating result, in combination with those from the CFF studies of Himmelberg et al. inspired me to test whether subjective ratings of naturalistic stimuli (dynamic fractal noise) vary as a function of eccentricity.

**Preliminary Data:** Collection is in progress.

**Significance of the Expected Research:** The expected contribution of the proposed research is to map the spatiotemporal sensitivity of the visual field as a function of eccentricity, using naturalistic dynamic stimuli. *This contribution will be significant because it will initiate a bridge between traditional psychophysics and naturalistic behavior.*In addition to contributing important empirical results, it is expected to move the field of perceptual psychology vertically by establishing innovative and necessary methods for a more ecologically-valid vision science, and by generating a more comprehensive computational model of human peripheral motion perception. These contributions will open new avenues for the study of environmental motion perception, visual cognition, and for psychology at large.

**Innovation:** While I have taken care to design my experiments rather conservatively, I will take advantage of state-of-the-art VR technology to present stimuli using an innovative method that was not possible until recently. Since the 1960s, psychophysics has been a fruitful field, replete with reliable and increasingly precise findings regarding the mechanisms and capabilities of primate visual perception. In the 1980s, computer-driven stimulus creation and presentation amounted to a huge boost for vision science (Burr & Thompson, 2011). At present, we are on the brink of another flurry of innovation made possible by mainstream technological advancement: *foveated rendering*. Until recently, almost all vision-relevant psychology research has demanded that participants are constrained to a chinrest or head restraint system, then asked to fixate on a centrally located target. Foveated rendering obviates the need for restraint or fixation by precisely tracking the participant’s gaze inside a VR headset*,* allowing precision-delivery of stimuli to specific locations on the retina, regardless of where the participant shifts their gaze. Rather than forcing the participant to lock their gaze in relation to a stimulus, we can now lock the stimulus to the “freely-behaving” participant.

My interest in freely behaving vision science is motivated by my experience in systems neuroscience, where behavioral quantification tools such as DeepLabCut, (Mathis et al., 2018) and continued miniaturization of neural probes (Jun et al., 2017) have allowed freely moving behavioral research to gain momentum over the last decade. Recent findings have indicated that neural activity in the early visual system is richer in freely moving animals than in head fixed ones (Parker et al., 2022, Meyer et al., 2020). It is essential that perceptual psychology moves out of the head fixed era wherever feasible. Foveated rendering enables a new level of ecological validity for psychophysics and perceptual psychology. Not only will foveated rendering allow me to conduct vision science in unconstrained participants, it will allow dense and precise mapping of spatiotemporal sensitivity across the visual field, in a tightly-controlled experimental set up.

**Note on funding:** While considering practical obstacles and limitations, I have taken care to design experiments that do not require additional funding for data acquisition, mitigating expense-related risks associated with ongoing equipment and personnel demands. My lab already has VR headsets (Varjo Aero) on site, and I am in personal control of programming and administering the experiment. This research is not contingent upon funding from my sponsors. My computational modeling work will leverage the Talapas High Performance Computing Cluster at University of Oregon (UO), which provides high-end computing resources to UO labs free of charge.

**Approach:**

**Aim 1: Map the relative spatiotemporal sensitivity across the peripheral visual field, using expert observers and naturalistic dynamic stimuli.**

***Introduction:*** Study 1 is intended determine whether eccentricity and polar angle predict differential behavioral responses when skilled observers are tasked with discriminating features of dynamic stimuli presented to isolated regions of the visual field. In the first task observers will detect coherent motion in an RDK task. In the second task, observers will classify velocity and spatial complexity of dynamic fractal noise stimuli. I hypothesize that in each task, spatial and temporal sensitivity will vary as both a function of eccentricity and polar angle, and that when mapped across the visual field, temporal sensitivity will not have a 1:1 correspondence with spatial sensitivity. The objective of this aim is to map naturalistic motion sensitivity across the retinotopic field. To do so I will measure task performance in relation to accuracy and to reaction time. The rationale behind the study proposed under this aim is to disambiguate seemingly contradictory findings from psychophysics that show both uniform and peripherally graded responses to critical flash frequency (CFF) stimuli. By using naturalistic motion stimuli, I seek to test peripheral motion perception in a more ecologically valid context. Additionally, I will test sensitivity using two separate paradigms related to natural visual behavior: coherent motion detection (in the RDK task) and visual assessment (in the fractal noise task).

I will test my working hypotheses by using in-headset (Varjo Aero) foveated rendering to present stimuli to precise regions of the retina, and test observer sensitivity across the visual field. Stimuli will be presented to isolated retinal ROIs as defined by their angular distance from fovea, and their polar angle. Retinal ROIs will be CMF-compensated regions equal to 10 degrees of visual angle at the center of vision. Ahead of task presentation, I will run a spatial discrimination psychophysics block to estimate CMF separately for each participant and calibrate stimulus size across the visual field accordingly. Stimuli will appear one at a time, at one of 24 positions tiling the retinotopic space between 0 and 30 degrees of eccentricity.

In Task 1, participants will be asked to quickly detect coherent motion in RDK stimuli presented across the visual field. Task 2 will use the same style of presentation, but ask participants to assess the spatial and temporal frequency (on a scale 1-5) of dynamic fractal noise stimuli generated at 5 discreet levels of fractal complexity and played at five speeds. Prior to task sessions, participants will be trained to 95% or greater accuracy on unmasked, centrally-located versions of the stimuli, so that each participant has a strong grasp of the stimulus rating scale ahead of the trial presentation. The study will consist of four 1-hour sessions per participant.

Participants: I will approach study 1 in the style of a traditional psychophysics experiment, relying on skilled observers to remove confounds associated with (undergraduate participant) task engagement. I will use 8 participants total, 4 male and 4 female, drawn from the PhD student body at University of Oregon. Participants will undergo task-specific training prior to data collection.

Analysis and Interpretation: For each task I will I use two 2-way repeated measures ANOVAs with 8 levels of polar angle and 3 levels of eccentricity, one predicting reaction time, the second predicting accuracy. I expect significant main effects of both eccentricity and polar angle, but I do not expect a significant interaction between the two. However, the possibility of an insignificant main effect would be an important finding in that it would suggest the CFF studies that showed uniform temporal contrast performance across eccentricities are predictive of performance in naturalistic motion tasks.

After completing Aim 1, it is my expectation that I will have mapped the relative sensitivity of the visual field to spatial and temporal contrast, in the context of two types of naturalistic motion discrimination tasks. These results will test the relationship between psychophysical findings and naturalistic task performance, establish findings on how complex stochastic motion is processed across the entire field of vision, and build a quantitative armature on which to assess the qualitative aspects of peripheral motion perception (Aim 3).

**Aim 2: Develop a simple computational observer model to bridge behavioral outcomes and neurobiological models of peripheral motion perception.**

***Introduction:*** The objective of Aim 2 is to develop and test a computational observer and validate it against the empirical behavioral data generated in Aim 1. The model will be constructed to reflect the distinct contributions of magnocellular and parvocellular pathways to visual perception, informed by empirical data from neurophysiology and systems neuroscience. The model will be as simple as possible while maintaining spatially accurate representations of cortex and pathway-specific processing characteristics. Validation against behavioral spatiotemporal sensitivity data will test the model's predictive accuracy and evaluate which components have the best explanatory power when compared to behavioral results.

Validation and Refinement: Calibration will leverage existing behavioral outcome datasets, aligning model outputs with empirical motion perception data. Through iterative testing and sensitivity analysis, I will identify critical model components and refine representations to enhance predictive accuracy.

Anticipated Challenges: I acknowledge the complexity of accurately modeling motion perception, and anticipate challenges related to modeling a functional representation of the visual system's many components. Strategies for overcoming these challenges include phased model complexity escalation and active training and collaboration with (unnamed theoretical neuroscientist). Aim 2 represents the bulk of the training component of this application.

After completion of Aim 2 and publication of the related manuscript, I will share the model publicly. I will make a strong effort to release it as a modular, well-documented and user-friendly system, with the goal of advancing understanding of motion perception and offering a novel tool to provide insights into the neurobiological underpinnings of behavioral outcomes.

**Aim 3: Test whether observed spatiotemporal sensitivity maps predict responses in a subjective visual judgement task.**

***Introduction:*** Aim 3 probes the correspondence between spatiotemporal sensitivity and subjective perceptual judgment across retinal ROIs. The objective of this aim is to determine how tightly visual discrimination ability is coupled with subjective assessment of dynamic stimuli. Specifically, I will test three subjective conditions in which participants make visual judgments along *stressful/relaxing, unappealing/appealing, and natural/synthetic* dimensions. I hypothesize that responses related to each dimension will correlate with visual sensitivity, but the relationship will vary depending on the dimension in question; as these judgements rely on high-level processing, whereas visual discrimination (as in Aim 1) can be accomplished using information available in the early visual stream. I will analyze both response and reaction time data to test my hypothesis. The rationale behind this proposed study is to evaluate how visual sensitivity modulates aesthetic impact, particularly in light of evidence that peripheral vision may show enhanced sensitivity to high-speed dynamic stimuli (Hassan et al., 2016).

In each experimental session, the participant will be fitted with a VR headset, then taken through a 10-trial training block in which they will be presented with centrally located dynamic fractal stimuli and familiarized with the subjective rating system. Participants will then switch to a task block in which they will be prompted to respond to one of the three subjective conditions listed above. In each block, participants will be presented with stimuli at all combinations of complexity, speed and eccentricity.

Participants: I will use participants for the University of Oregon Human Subjects Pool (UO HSP). These participants are undergraduates enrolled in psychology or linguistics classes that award class credit for research participation. I will enroll 150 participants. As data collection in this experiment is not constrained by financial or practical limitations, I prefer to opt for a sample size with more than enough statistical power. The participant sample will not be sex-balanced, but I will collect data from enough participants that each male/female sex-divided group will be able to reach statistical significance on its own. While the UO HSP is not particularly ethnically diverse, part of the rationale behind my sample size is to attempt to obtain a sample representative of the whole UO undergraduate population.

Analysis and Interpretation: For each subjective condition, I will use a 3-way repeated measures ANOVA predicting user response by eccentricity x stimulus complexity x stimulus speed. Based on my previous results, I expect main effects of both speed and complexity. While I am hesitant to make a prediction regarding eccentricity (this is what preliminary data will tell me) I expect that eccentricity will explain a different percentage of variance depending on what subjective condition is being measured.

Successful completion of Aim 3 will indicate whether low-level discrimination performance (Aim 1) predicts differences in high-level subjective judgement, and whether subjective judgment changes as a function of retinal eccentricity and polar angle. Additionally, it will probe interaction effects between perceptual phenomena specific to peripheral motion, and subjective responses to wide-field (environmental) motion.

\*I’m skipping Timeline and future directions at the moment, as I still need to figure out my co-sponsor and training strategy.

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