Project Summary

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Area of Study: Cognitive Neuropsychology

Title of Project: "Neural Mechanisms Underlying Perceptual Filling-In of the Human Blind Spot"

Summary of Project:

The phenomenon of visual "filling-in" was first observed medically in patients with retina damage; patients with focal areas of damage in the eye but with intact visual cortex in the brain were often unaware of their retinal damage until the time of diagnosis, and reported no observance of blind spots. This perceptual filling-in is accounted for by plasticity in cortical areas that once corresponded to the damaged retinal areas; in human visual systems, cortical plasticity is readily studied by using the retinal blind spot as a model (Awater, et al., 2005; Spillman, 2006). The blind spot (BS) is the retinal area without photoreceptor cells where the optic nerve passes through the optic disk. Under normal conditions this BS is filled in by information from the partner eye and is therefore not perceived; however, under monocular conditions when the BS lacks partner-eye compensation, the corresponding visual cortex is deprived of input just as it would be if a retinal lesion existed. Recent studies based on this model have used monocular eye-patching to study plasticity around the BS and suggest that reversible visual distortions around the BS can occur as a result of both long-term and short-term sensory deprivation, within mere minutes of deprivation (Dilks et al., 2009). These studies suggest some type of rapid plastic rearrangement in primary visual cortex, but there is currently limited data examining 1) the underlying neurophysiological mechanisms driving these distortions and 2) and the role of higher area feedback in facilitating them (Komatsu, 2006). This study will use electroencephalography (EEG) to examine the electrophysiological response of visual cortices to BS-adjacent stimuli under short-term and long-term deprivation conditions; we anticipate enhanced components of visually evoked potentials (VEPs) from the EEG recordings in conjunction with behavioral reports of perceptual filling-in for both short- and long-term conditions, as in previous studies. These findings will affirm that short-term cortical reorganization does occur in visual systems and that higher information areas like the parietal cortex are involved in these phenomena (Kanai, 2008).

Neural Mechanisms Underlying Perceptual Filling-In of the Human Blind Spot

Cortical sensory areas of the brain are organized in a topographic fashion such that these areas of cortex have an orderly spatial arrangement according to the corresponding sensory organ. For example, visual cortex has a "retinotopic" organization where adjacent areas of visual cortex represent adjacent regions of the retina (i.e., adjacent regions of visual space). Following disruptions to sensory input, the topography of sensory cortices begins to reorganize and remap, adapting to the loss of sensory information (1-2). Such brain mechanisms of sensory remapping are known as cortical *neuroplasticity* and lead to the subjective experience of *perceptual filling-in* whereby missing sensory information becomes "filled in" using the remaining surrounding sensory inputs. Neuroplasticity and perceptual filling-in in the visual system are most often studied under long-term conditions using animal models or human patients studies where neural remapping following retinal damage has occurred over a period of months or years (3-7); however, a number of studies have demonstrated that processes of cortical neuroplasticity and perceptual filling-in begin within minutes of visual deprivation (*short-term neuroplasticity*; 8). For example, many patients with extensive retinal damage are often completely unaware of their condition and fail to report any blind spots because perceptual filling-in following retinal damage occurs over very short time scales (9).

Understanding short-term neuroplasticity and perceptual filling-in is critical to visual neuroscience but has been difficult to study in human subjects because it is not feasible to perform such short-term measurements in patients with retinal damage. One recent approach in humans has been to use the *retinal blind spot* as a model to examine short-term neuroplasticity in healthy subjects (10-11). The blind spot (BS) is a relatively large area in each retina which contains no photoreceptors and thus provides no visual inputs to the visual cortex. Under normal viewing conditions (both eyes open), the BS in one eye is compensated by visual information from the other, partner eye. However, by simply closing or eye-patching this partner eye (monocular viewing), visual cortex becomes deprived of visual input from the BS region of the retina. This mimics the effects of a true retinal

lesion (i.e., loss of sensory input) but is completely harmless, providing a safe and effective method for the study of short-term neuroplasticity and perceptual filling-in in healthy human subjects. A recent study using the BS as a model of neuroplasticity found that after just 15 minutes of monocular deprivation, robust visual distortions were apparent in regions of visual space directly surrounding the BS (12). Though no neurophysiological measures were taken in this study, the effects described by subjects were comparable to perceptual reports of patients with retinal damage and indicate that reversible visual distortions can occur as a result of extremely short-term visual deprivation.

Here, I propose to use EEG recordings in a monocular-viewing BS paradigm to elucidate the neural mechanisms of short-term neuroplasticity and perceptual filling-in in the human visual system. EEG will be used to measure visual cortical brain activity from regions of space surrounding the blind spot under varying conditions of monocular visual deprivation. The results obtained from this study will contribute to a more exact understanding of neuroplasticity in the human brain, which may ultimately advance the development of neural prosthetics (such as artificial retinas) and neurorehabilitation following stroke and aneurism.

Method and Anticipated Results

All procedures described here have been approved by the University of Arkansas IRB as of 10/11/2013 (IRB #13-10-145). Twenty-four consenting participants will be recruited from the University of Arkansas undergraduate population. Upon entering the laboratory participants will be tested for visual acuity, eye dominance, and stereo vision. The boundaries of the BS in the right eye will then be determined using a computer-based task. Following these visual tests, participants will be placed into a 64-channel EEG electrode cap. The quality of EEG data will be checked prior to experimentation and monitored throughout testing. Participants will then be fitted with a custom eye-patch capable of rapid removal and refitting so that the duration of visual monocular deprivation can be readily manipulated.

EEG will be recorded while participants view simple visual stimuli presented on a computer screen and perform basic perceptual discrimination tasks. Participants will be instructed to maintain fixation on a crosshair in the center of the computer screen; fixation will be monitored with electrodes positioned around the eyes. Randomly every 1500 to 2500 ms, a visual stimulus will flash briefly (100 ms duration) in the space surrounding the boundaries of the blind spot. These stimuli will consist of small bars and rectangles that span the blind spot. On each of several hundred trials of such stimulus presentations, participants will provide a perceptual report indicating the extent of perceptual filling-in of the visual stimulus across the blind spot. These reports will be used to measure visual distortions that arise from the induction of short-term neuroplasticity. Averaged neural visual responses evoked by these stimuli will also be derived from the EEG recordings, an analysis approach known as the event-related potential (ERP). These visual ERP responses will provide a direct measurement of the visual neural activity that is associated with perceptual distortion and perceptual filling-in, providing an index of short-term neuroplasticity.

Measurement of visual distortion and visual ERP responses as described above will be performed across three conditions. In a pre-test baseline condition (*Baseline-1*), these measurements will be performed with only two minutes of visual deprivation. After each trial, the eye patch will be removed briefly and subjects allowed to assimilate to binocular vision before the patch is replaced. In a *Deprivation* condition, measurements will be taken after thirty minutes of deprivation. Finally, a post-test baseline (*Baseline-2*) will provide a second control condition to demonstrate that any short-term effects measured in the *Deprivation* condition to return to baseline levels after being exposed to binocular inputs. These conditions allow for extremely short-term deprivation conditions (two minutes in *Baseline 1 and 2* conditions) to be compared with a more extended short-term deprivation condition (30 minutes in the *Deprivation* condition).

Perceptual reports and visual ERP responses will be analyzed and compared between Baseline 1, Baseline 2, and Deprivation conditions using standard EEG pre-processing and analysis

procedures (13). I anticipate that, relative to the two baseline conditions, perceptual reports acquired during the *Deprivation* condition will reveal significant visual spatial distortions. I further anticipate that along with these distortions will be visual ERP responses of greater amplitude, reflecting the increased usage of blind spot neural representations by surrounding representations of visual space. Such a finding would be the first demonstration of a visual neural correlate of short-term visual plasticity within blind spot representations and would provide a convenient model for the future study of the mechanisms of short-term neuroplasticity.

Training Activities, Research Activities, and Project Timeline

My mentor [redacted] and I have established a detailed research agenda, mentorship plan, and project timeline to be carried out from January 2014 to December 2014 (Spring, Summer, and Fall 2014 semesters). The following sections describe the planned mentoring and research development activities.

Mentoring and Professional Development (Duration of award period; 4 hours/week). Mentoring activities will be conducted on a weekly basis for the duration of this project. A major component of mentoring activities will be structured, one-on-one weekly meetings between Dr. [redacted] and myself. During these meetings we will discuss topics pertaining to the proposed experiment, including discussion of theoretical readings, logistics of participant recruitment, computer programming, assessment of data quality, pre-processing of EEG data, and statistical analysis of neurophysiological data. These meetings will also focus on professional development, including building an academic résumé, disseminating results, and preparing academic posters/papers. I will have the opportunity to apply the knowledge gained in one-on-one meetings by attending weekly group lab meetings (~ 10 members) where I will give a monthly oral presentation on the status of my research project and receive critical feedback from Dr. [redacted] and other research assistants. I will also present and discuss my research project with neuroscience professors invited to speak at the Department of Psychological Science. Dr. [redacted] will facilitate these meetings and has arranged visits

by two such speakers by Spring 2014, with more to come in the following semesters. The results of my research project will be submitted as a poster to the 2014 Vision Sciences Society conference where I will present my project in a national, professional arena. Finally, I will serve as a mentor myself, passing on my experience to a more junior student in the lab. Dr. [redacted] has identified such a mentee for me, a sophomore undergraduate research assistant, with whom I have already started to work.

Set-up and Pilot Data (Jan. 2014 – Feb. 2014; 12 hours/week). The first two months of the proposed SURF research project will be devoted to finalizing and testing experimental design. Under the supervision of Dr. [redacted], I will program the experimental tasks, develop demographics and participant recruitment documents, create visual acuity and eye dominance tests, and construct custom monocular eye-patches. I will then collect pilot data to ensure that each of these components functions as intended and that no issues arise during testing.

Data Collection (Mar. 2014 – Sept. 2014; 12 hours/week). During experimental data collection, my responsibilities will consist of collecting data in the described experiment, which includes obtaining consent, affixing EEG electrodes to subjects, explaining and overseeing the experimental tasks, monitoring EEG data quality, debriefing and compensating subjects, and cleaning/disinfecting equipment. I will provide a brief summary of my week's progress at the weekly lab meeting and will give a formal presentation in lab meeting once per month.

Analysis and Write-up (Sept. 2014 – Dec. 2014; 12 hours/week). The final months of this project will be devoted to analysis and interpretation of the acquired neurophysiological data. As the capstone to this project, I will produce a poster for presentation at the Vision Sciences Society conference and a scholarly article to be submitted to a peer-reviewed journal. Dr. [redacted] and his graduate students will closely advise and collaborate with me in the production of these documents.

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