**Interest:** **What neural activity is required to generate perception?** In many studies of neural function over the past two decades, researchers have taken the approach of correlating neural activity with measures of perception, such as visibility. One intriguing finding from this line of research is that the brain does not use modular representations such as the activity of a single neuron or region to represent a feature. Most perceptual representations appear to be distributed and are hypothesized to be bound together into awareness. **These studies have characterized the importance of a variety of neural regions in perception, but so far they have failed to capture the underlying computations responsible for perception**. One way to investigate this is to look for close links between behavior and neural activity. Success in a behavioral task, for example by reducing reaction time, depends on computing the solution to the task efficiently. This might involve comparing two stimulus objects and choosing which matches a rule, such as “identify faces, but not cars”. The link between stimulus and decision is complex. Large populations of neurons perform these non-linear integrations but **these neural dynamics can be formalized as computational models giving us insight into the neural computation that produces perception.**

Many researchers consider attention and awareness to be controlled by different neural processes. Consider the commonly used dual task paradigm: participants are asked to focus on a demanding task at the center of the screen and simultaneously perceive stimuli in the periphery. If attention and awareness are implemented by a single large process tapping into a pool of attentional resources, then we would expect that as attention increases in the center, awareness would drop in the periphery. Instead many studies show that while we are focused on the center we are still aware of the surroundings (1). Even during extremely complex tasks, such as motion tracking, we remain aware of peripheral stimuli (2). I consider these experiments to be misguided. They suffer from a misunderstanding of attention as an “operational” phenomenon, rather than a set of computations implemented by neurons, a view that is more common in neurobiology (3). I believe that to fully understand the complexity of perception we need to look at three levels simultaneously: the neurobiological implementation, the psychological/perceptual level, and the computational aspects.\*\*\*FIX\*\*\*

Over the past year I have investigated one aspect of this issue by looking at how visual awareness is modified by attention in a feature discrimination task. We found that when people attended to the intensity of contrast in an image their perception of motion was diminished, but that attention to motion had little effect on the perception of contrast. This asymmetry is a good example of the complex link between stimulus features and perception. At the level of psychological analysis this asymmetry would be difficult to disentangle—we would need a satisfying explanation for why contrast is privileged over motion. But by looking at the level of brain anatomy and computational principles an explanation quickly becomes clear: the areas that are thought to represent contrast and motion (cortical areas V1 and MT, respectively) are linked hierarchically. This link causes most of the projections to extend from V1 to MT, but not back. Our perceptual observations then match perfectly with the anatomical

**Research Proposal:** My research program will disentangle the impact of attention on neural activity and awareness. I propose that neural representations are modulated when we pay attention to specific spatial regions or features. Awareness is an extension of attentional modulation, but not a distinct brain process. Instead, the dissociation in dual task paradigms is an artifact observed when an attentional task does not engage the same neural substrates as the awareness task. I hypothesize that a few criteria will be met by any area that is modulated by attention: **1:** **the modulations will be limited by the processing capability of neurons** **in that region**. This predicts that even when we are engaging our full attention at the center of our vision we may not be over-loading neurons responsible for attention and awareness in the periphery. **2:** **A computational model will capture how neural activity, behavioral changes, and shifts in awareness are linked.** My hypothesis that awareness and attention are linked suggests that a single computational model will delineate the link between behavior, neural activity, and awareness for one feature in one brain region. Testing this has previously been confounded by using tasks where attention was spread across multiple different features or where neural activity was not tested within only one brain region. Finally, **3:** **the model will make testable predictions about the impact of attention on awareness**.

**Project 1 will specify, through quantitative psychophysical measurements and fMRI, how behavior and neural activity are linked (1-2 above)**. In these experiments participants will be shown faces which sometimes change perceptually (more or less contrast (4)) or conceptually (amount of noise disturbing face identity (5)). Professor Justin Gardner has shown that contrast discrimination success depends on whether participants are given prior knowledge that reduces the uncertainty in their judgments (6, 7), as well as that the variability in success is well accounted for by neural responses in early visual cortex. Building computational models linking both contrast and noise discrimination will allow me to quantify the role of different brain regions in each of these tasks.

These computational models will allow me to assess the role of attention in terms of neural activity. They will also enable me to test whether attention and awareness are linked. **In Project 2, we will investigate whether attention impacts awareness of faces (3 above) by asking participants to judge the gender of faces in the periphery.** Because both noise embedding a face (5) and gender (8) are represented in the fusiform face area (9), but contrast is represented in early visual cortex, I predict that performing the noise discrimination task will have a greater impact on awareness than performing the contrast discrimination task. If attention and awareness are linked then awareness should suffer as representations become more overlapping.

**Impact:** The significance of the results from these studies will extend far beyond visual cortex. Understanding the computations which result in visual perception will enable us to translate the underlying computations into algorithms with applications in a variety of domains, computer vision in particular. Programming computer vision algorithms to perform basic tasks, such as face identification, has proved incredibly difficult. This seems to be due in part to a misunderstanding of how neural representations gather information about faces. Designing artificial vision algorithms that mimic neural activity may inform robotics, self-driving vehicles (which need to scan the region around them), and will also help enlighten issues critical to the field of cognitive neuroscience.

These experiments also have implications beyond vision science. In education there has been a considerable struggle in the past decade to improve the quality of our basic math, science, and engineering curricula. One assumption that should be questioned is the idea that our current methods are the only and best methods for teaching. In statistics many students find visual presentation of concepts to be intuitive, but find the mathematical jargon indecipherable at first glance. Taking into account the means by which the visual system generates perception and understanding may take us a long way in improving the quality of our education system.

1. F. F. Li, R. VanRullen, C. Koch, P. Perona, Proc. Natl. Acad. Sci. U. S. A. 99, 9596–601 (2002). 2. M. a Cohen, G. a Alvarez, K. Nakayama, Psychol. Sci. 22, 1165–72 (2011). 3. E. I. Knudsen, Annu. Rev. Neurosci. 30, 57–78 (2007). 4. J. L. Gardner et al., Neuron. 47, 607–20 (2005). 5. B. S. Tjan, V. Lestou, Z. Kourtzi, J. Neurophysiol. 96, 1556–68 (2006). 6. Y. Hara, J. L. Gardner, J. Neurophysiol. (2014), doi:10.1152/jn.00729.2013. 7. F. Pestilli, M. Carrasco, D. J. Heeger, J. L. Gardner, Neuron. 72, 832–46 (2011). 8. G. Loffler, G. Yourganov, F. Wilkinson, H. Wilson, Nat. Neurosci. 8, 1386–90 (2005). 9. K. Grill-Spector, N. Knouf, N. Kanwisher, Nat. Neurosci. 7, 555–62 (2004).