*Interest*: In our everyday life we feel a direct and undeniable connection between attending to something and our clear awareness of it. Despite this feeling and an increasingly deep knowledge of neurobiology, we actually have very little understanding of what is different about information that we perceive *consciously* compared to information that remains unperceived and *unconscious*. We know that the neural correlates of conscious information are processed more deeply, they tend to become synchronized with neural firing in anatomically distant regions, and that they often “recur”, i.e. induce patterns of activation that are self-sustaining.

*Background:* ??

*Impact:* ??

*Interest:* In everyday life we feel a direct and undeniable connection between attending to something and our clear awareness of it. In my own experience rock climbing I have had moments of tunnel vision: an intense focus on just the act of climbing while the rest of my awareness faded temporarily. I became interested in studying this phenomenon during a class taught by Professor Shimon Edelman at Cornell University. Professor Edelman discussed how brains can be looked at through the lens of programming and put forth a view that stood out for me: what brains do is use neurons to *compute* minds. Understanding what computations are necessary to generate perception remains an unsolved problem. For tunnel vision in climbing we would ask: **what computations are the neurons involved in *representing* our awareness performing and how are these *modulated* by attention?** This is a critical issue for our understanding of the mind but it also extends into other domains. If neurons are only a substrate for computation, then we may be able to take the same computations and use them to inform the engineering of new technologies. Several recent efforts have tried to mimic the design of neurons using silicon chips (cell bodies, axons, etc), but another direction is to translate the *computations* themselves into a design.

*Background:* During the past four years I have taken advantage of several key opportunities to gain an understanding of how computational modeling can be used to understand neural activity. As an undergraduate at Cornell I worked with Professor Thomas Cleland on modeling rat behavior in a complex olfactory environment. The rats attempted to identify an odor previously associated with reward among a series of similar odors. One solution to this problem is to act as a Bayesian optimal observer and to take into account prior knowledge about the different odors. This experiment showed me that behavioral measurements can be explained by simple computational models. But more importantly, **the modeling framework made specific predictions about what the rat brain needed to represent and compute to succeed in the behavioral task, an insight I am using in my current work.**

After working in Professor Cleland’s lab I sought out opportunities to work with human participants. I wanted to continue using computational modeling to make predictions about what information we expected to see in the brain, but to also take the further step of isolating that information and localizing it. The most exciting opportunity was a collaboration with Professor John-Dylan Haynes in Berlin, Germany, working on a challenging and controversial project.

**Professor Haynes and I used scalp electrode recordings (EEG) to investigate whether a person’s choices could be predicted in real time and fed back to them**. The project involved using a brain-computer interface (BCI) technique to predict participants’ behavior as they performed a similar experiment to the work of Benjamin Libet (*1*). Summarizing briefly, Libet showed that prior to spontaneous movements a negative deflection, known as the *readiness potential* (RP) appears in the EEG signal. This signal’s onset preceded the time when participants felt they had decided to move, bringing our intuitive sense of *free choice* into doubt (*1*). More recent work by Schurger et al. has shown that a drift-diffusion model of brain activity captures the variability in the RP, suggesting that much of our behavior in this task is driven by random neural activity (*2*). Our experiment showed that participants can be fed back information about their choices as they prepared to choose and despite this feedback they could not learn to *evade* prediction by changing their brain activity. In other words the brain activity producing the RP was the only way to generate these spontaneous movements. **I took on a lead role throughout this project, designing the experiment, implementing the BCI, collecting EEG and behavioral data, and performing analysis**. Our manuscript will soon be re-submitted to PNAS after revisions.

I found the real-time EEG project to be particularly important for me as a researcher. First, it gave me an opportunity to collaborate with researchers in an international setting. Equally important was the impact of our findings for broader human experience. Because of how our brains compute our minds we make a lot of assumptions about the world that, upon introspection, we discover to be illusions. Professor Edelman was fond of pointing out that our “point of view” is a single ellipse extending out from inside of the head (just behind the nose), but all our visual information comes through two separate eyes. This dissociation between what we perceive and what really happens occurs throughout phenomenal experience, and extends to our sense of agency and responsibility for actions. The analysis by Schurger et al. showed that some actions are just randomly occurring—despite our feelings of intention. Our result extends this thread: not only are these *intentional* actions random, but you cannot override the randomness.

With Professor Haynes and two of his graduate students I also pursued a functional MRI experiment where we tried to localize information within the brain. To do this we had to *decode* the representation of *response rules*, for example “press the left button when you see a face”. **Decoding is a multivariate analysis technique which has opened a window into where brains represent knowledge**. Because fMRI takes snapshots of brain tissue in voxels, usually 3x3x3 mm, and each of these voxels can contain millions of neurons, it is easy to presuppose that fMRI has very poor spatial resolution. In the past decade, several labs have shown that by comparing patterns across groups of voxels we can actually get at information which normally would be masked by averaging. This happens because the proportion of neurons which reflect different stimuli, or in our experiment the *rules* kept in memory, differ across voxels. As proportions vary, the pattern of activity across voxels also varies. This computationally driven approach allowed us localize the patterns representing each rule to particular regions in parietal and prefrontal cortex. In my own research **I am using *decoding* techniques to isolate the representation of information in the brain**.

These research opportunities have allowed me to develop an extensive set of skills encompassing fMRI, EEG, decoding, computational modeling, and animal behavior research. Less tangible are my connections with collaborators and experience with experimental design. Combined, these tools and resources put me in a strong position to push my current research projects forward. In addition, **Stanford University provides an ideal environment for research on formalizing the computational aspects of neural processing**. My collaboration with Professor Gardner will take full advantage of these resources as we explore the influence of attention on awareness (see the Research Proposal). Opportunities for future collaboration testing the predictions made by our computational models also exist. Professor Anthony Norcia and I have discussed a potential collaboration using brain stimulation techniques. These are only two highlights of the interdisciplinary nature of the Psychology Dept. at Stanford. I am also exploring opportunities through the center for Mind, Brain, and Computation to find collaborations with researchers in computational fields, such as artificial intelligence. **These opportunities will be foundational in finding solutions to one of my main research questions: whether computations instantiated by neurons can be translated into other mediums**.

*Impact:* My views and research goals have been influenced by a long list of mentors, colleagues, and communities. These opportunities have given me insights into how best to look at formalizing neural-based perception as computation and taught me the value of interdisciplinary work and having a global worldview. Theorizing about brain activity in a computational mindset while conducting empirical studies using EEG and fMRI requires work that spans several fields. Being able to interact with a diversity of researchers and their varying theories has given me the chance to both transmit information across disciplines and to synthesize concepts that would otherwise have remained separate. Understanding brain-based perception will inform our knowledge of perception as a computation and hopefully translate into the field of artificial intelligence. **Whether computers can be set up to mimic the computations the brain performs and be *aware* of their processing is a fundamental question—one that I can only hope to address through collaboration.**

Also exciting are the potential applications of this basic research to education. There is a lot of evidence that our current educational strategies are dysfunctional and there are a diverse set of opinions on what needs to change. The technology industry, driven by an engineering approach to education, has popularized free online education as a possible solution. Complimentary to this I think that there needs to be consideration of *how people learn best*. This line of research is broad and already substantial, but few studies are taking advantage of what we know about how the brain computes and interprets new knowledge. As our understanding of the implementation of mental processes such as awareness and attention grows we can translate this knowledge into better teaching tools. A concrete example of this is the difficulty many people experience with learning mathematics. **Understanding how the brain represents concepts such as numbers or mathematical operations can be turned around to help us more effectively teach people those concepts initially.** In my recent work as a statistics tutor, I have observed students making the same mistakes repeatedly. Often over time the student will reach an understanding, but the process can be very inefficient. Why can’t we teach these students an abstract concept on the first attempt? An engineering solution might be to remove the *teacher* from the equation, but a brain-based solution would be to understand the *format* we should present new concepts in so that the brain can most effectively incorporate them into its existing representations. This is the kind of re-thinking of education that will be beneficial in the next decade.

Translating the outcomes of my research program into these applied results will be a challenge, but it will not be insurmountable. Stanford’s interdisciplinary environment provides opportunities to share ideas and bring in new research tools. My international connections will mean that my projects will reach a global audience and that their thoughts and contributions will in turn benefit my program. My strong preparatory background in neurobiology and computer science is already enabling me to set in motion research projects spanning multiple sub-disciplines of cognitive science (see Research Proposal). Finally, **receiving funding from an NSF graduate research fellowship will further strengthen my position, giving me the freedom to look outside of my department and area to find collaborations throughout the country and globally**.

1. B. Libet, C. A. Gleason, E. W. Wright, D. K. Pearl, *Brain*. 106, 623–642 (1983). 2. A. Schurger, J. D. Sitt, S. Dehaene, *Proc. Natl. Acad. Sci. U. S. A.*, 1–10 (2012).