Cognitive science is facing a hard problem (Chalmers, 1995): we have no idea how neural activity generates the rich first-person experience of consciousness. This problem is difficult not only because of our uncertainty about the solution but because we **do not know what a solution will look like**. Because of this I find the hard problem of consciousness particularly compelling—a question that requires a paradigm shift in our thinking. Pursuing an answer has driven me to develop a broad background spanning neurobiology, computer science, and cognitive neuroscience and is pushing me to build a research program that extends across these diverse fields.

Consciousness

It seems ironic that a phenomenon we all experience has yet to be pursued with much rigor, but cognitive neuroscience has largely sidestepped consciousness in favor of studying cognition. This has occurred for several reasons: consciousness is known to be difficult—many researchers believe it is premature to study. But more puzzling is the belief that consciousness is a philosophical issue and that there is something unknowable about consciousness. In the last 20 years this belief has been replaced by a search for neuronal processes in the brain that correlate with consciousness (Crick and Koch, 1992). The search for neural correlates of consciousness (NCC) is based on the assumption that consciousness is a thing in the brain that we need to find, like the gene was for DNA. I believe that assumption is incorrect: consciousness is a distributed neural process and likely has a unique signature for every different experience. Because of this the search for NCC will only succeed at finding neural processes that do not correlate with any kind of consciousness. Instead, I believe **consciousness needs to be understood as a computation**—the brain's solution to a functional problem that we don't yet fully grasp.

Early in my undergraduate career at Cornell I took a course on consciousness. Prof. Shimon Edelman's goal in the class was to impose on us the importance of thinking not only about *what* a cognitive phenomenon is and *where* the brain represents it, but also *why* the brain should bother with it and *how* the brain computes it. This is exactly the kind of paradigm shift in thinking that has occurred for other cognitive processes, such as attention. Attention in the psychology literature used to be invoked as a spotlight that swept through sensory space and highlighted important events. Research in cognitive neuroscience now suggests that although the function of attention differs across sensory domains its implementation is similar in each space. In vision, for example, attention improves the visibility of objects—while at the computational level it acts as a form of sensory enhancement, introducing a gain change on the response to visual inputs. It makes sense to think that in the abstract consciousness may share similarities to attention: consciousness is a computational solution that is shared across brain areas to solve a variety of functional problems.

To understand consciousness as a function requires asking why a brain might need to be conscious and what kinds of computations are necessary to solve those functions. Traditional philosophers have also thought about this issue—and have been stumped by apparent paradoxes. Take the philosophical zombie (or its modern incarnation: the conscious computer), the p-zombie is a perfect copy of a human that simply lacks conscious awareness (Stanford Encyclopedia of Philosophy, 2009). It receives inputs like a human, acts like a human, but lacks conscious experience. While some philosophers consider p-zombies a real possibility the *why* question suggests that **philosophical zombies cannot exist**. If consciousness has a function, a fitness benefit conferred to our predecessor organisms and selected for over evolutionary time, then philosophical zombies are not possible: a p-zombie with no consciousness would lack some essential function. It seems clear to me that we have yet to fully grasp the functional importance of consciousness, and that there may be significant value in searching for and understanding the functional purpose of consciousness.

I believe that to understand consciousness is to understand three questions: what benefit consciousness confers to an organism, what neurons are responsible for computing that function, and how the brain instantiates those computations in neural systems. Answering those questions does not constitute a research project but rather a research program spanning decades. My research as a graduate student pursues a small piece of this program by looking at how attention acts as a gateway to consciousness. When we attend to something we become immediately aware of it: what function does bringing something into consciousness provide for an organism and what neural systems are responsible for this process?

Background and Past Research

Before pursuing graduate work I took time off to improve my skills as a cognitive neuroscientist and to learn about and live in a new culture. I found an ideal climate to pursue these goals in Prof. John-Dylan Haynes' research group in Berlin, Germany. Prof. Haynes gave me the opportunity to work on an exciting and challenging research question looking at whether our intuitions about decision making are reflected in neural processing. When we make a decision we have a conscious experience that the decision occurs at a precise moment. But this intuition does not match the neural activity in our brain: Prof. Haynes had shown in a previous experiment that early brain activity could be used to predict an action 8 seconds in advance of the experienced moment of decision making (Soon et al., 2008). We wanted to further study this process to understand how late a person might still be able to "veto" their decision in real time. To understand this question we devised a predictive brain computer interface which monitored a subject's EEG patterns in real time. The computer then fed back a signal whenever it predicted an upcoming movement decision. We found that up until 200 ms before movement onset participants would see the signal and then entirely cancel their action, showing no overt sign of a decision. This suggests that this earlier EEG activity we pick up is predictive of the decision, but not responsible for it. In the last 200 ms before movement onset though it became impossible for participants to cancel the beginning of their movement, although they were able to stop the movement prior to completion. Comparing our results with a computational model (Schurger et al., 2012) we found strong similarities, confirming that our result may indeed be the last "point of no-return" within the brain before efferent neural activity is sent to the muscles. Our manuscript is in revisions at PNAS at the time of this submission.

The entire research process, from formulating our research question, finding appropriate technological resources to create a brain-computer interface, analyzing data, and finally creating a publishable paper, has been an enjoyable and immensely rewarding experience. Working with Prof. Haynes cemented my goal of becoming a professor and reinforced my belief that academia is the right place to be pursuing consciousness research at this time.

Stanford University

My broad background from Cornell spanning neurobiology and computer science, combined with my work with Prof. Haynes helped me obtain admission to Stanford where I am now developing my research program. With my adviser, Prof. Justin Gardner, I have begun a project investigating the neural process of attention and how it acts as a gateway to consciousness. I am building on the platform of Prof. Gardner's previous work, which showed that spatial attention acts as a selection bias in the brain's early visual representations (Pestilli et al., 2011). My own work is focused on developing a model that explains the impact of feature-based attention on visual perception. My NSF research proposal is a continuation of this research project, looking into the predictions that our model makes through a different research tool: transcranial magnetic stimulation. My prediction is that **attention is a neural process that acts only as a form of sensory enhancement**, but is not ultimately responsible for generating conscious experience.

Working at Stanford is not only an opportunity to collaborate with world class researchers and develop my own research program. It is also an opportunity for me to develop additional quantitative skills. Although I gained considerable research experience as an undergraduate at Cornell and during my time in Berlin, I did not acquire a deep understanding of the techniques I was using. At Cornell I learned to perform microelectrode recording and chemical lesions in the lab of Prof. Thomas Cleland. In Berlin I gained practical experience recording both EEG and fMRI. One of my goals for my graduate career is to become an expert in human neuroscience and eventually teach these same techniques to future students. In my first year I pursued this goal by diving more deeply into understanding functional MRI. I took classes on the physics of MRI and learned about sequence development. Putting my theoretical knowledge to practice I helped develop and test more advanced 'multiplexed' fMRI sequences that allow faster acquisitions without a loss in signal quality. These changes mean that our lab can now collect four to six times as much data, at the same voxel resolution, compared to what was considered standard in fMRI five to ten years ago. In my second year and beyond I plan to continue acquiring a detailed understanding of other neuroscience techniques. My list for this year includes learning about convolutional neural networks as well as gaining knowledge about transcranial stimulation systems and their use as tests of causal neural relationships in the human brain.

Future Goals

My goal is to become a professor of cognitive neuroscience with a focus on understanding the neural mechanisms of consciousness. Given the nature of the hard problem it is clear that this research goal will stretches across decades. The length of this goal highlights the importance of mentoring and encouraging students to pursue similar research. With this in mind my second goal during my graduate career is to improve my abilities as a teacher. This year in the fall I am a TA for the introductory graduate statistics class, and in the winter and spring I will TA for two introductory cognitive neuroscience courses. One course is aimed at undergraduates and the other at graduate students in the neuroscience department. In all of these classes and in my future teaching I hope to impart to students the necessity of looking at problems from a broad perspective. **Cracking the hard problem of consciousness is a multidisciplinary problem**, drawing on psychology, biology, and computer science. Despite this, the majority of incoming graduate students still have little to no training in neurobiology and programming. Developing teaching methods to push students to think in a multifaceted way is an altogether different puzzle for me and I am looking forward to broadening my views with TA opportunities and eventually teaching my own classes. I believe a broad background across disciplines will give students the ability to contemplate cognitive functions like consciousness as simultaneously a computation and an implementation. Ultimately, understanding the hard problem is a question of knowing *what* functional problem consciousness solves and *how* the brain computes that solution.

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