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 hard 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 which 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 hard—many researchers believe it is premature to study. But more puzzling is the belief that consciousness is a philosophical issue that we cannot address. In the last 20 years this has begun to be replaced by a concrete approach focused on asking which neuronal processes in the brain correlate with consciousness and what is different about those processes compared to non-conscious ones (Crick and Koch, 1992). The search for neural correlates of consciousness (NCC) has succeeded at isolating activity that does not correlate with consciousness, but has yet to identify conscious neural processes. There are a number of possible explanations, but I believe the most compelling issue is that the search for NCC overlooks two important aspects of consciousness: that it has been shaped by evolution and that **consciousness is a** **computation performed by the brain**.

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. For consciousness this comes down to asking why a brain needs to be conscious and what kinds of computations might be important for that function. 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 would not have these important functions. I believe that this kind of thinking translates into a multi-level approach to studying consciousness—never looking at only a single level be it philosophical, computational, or biological.

I believe that to understand consciousness is to understand three questions: how neurons instantiate computations, which neurons are involved in consciousness, and why and how an organism benefits from being conscious. Answering those questions isn’t a research project but rather a research program spanning decades. My own research as a graduate student is pursuing a small piece of this vast program by asking: when we attend to something we become immediately conscious of it, what is the function of attention, which neural processes underlie attention, and where and how are they instantiated?

**Background and Past Research**

Before pursuing graduate work I took time off to improve my skills as a cognitive neuroscientist as well as to pursue a personal interest to learn about and live in a new culture. Prof. John-Dylan Haynes’ research group in Berlin, Germany was an ideal climate for succeeding in both of these goals. Prof. Haynes gave me the opportunity to work on an exciting and challenging research opportunity 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. Surprisingly, 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 and fed back a signal whenever it predicted an upcoming decision (in our task the decision was a movement). 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. In the last 200 ms before movement onset though it became impossible for them 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. At the time of this submission our manuscript is in revisions at PNAS.

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 spanning neurobiology and computer science, combined with my work with Prof. Haynes helped me obtain admission to one of the top psychology departments in the country where I am now developing a research program focused on human cognitive neuroscience. 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. Building on Prof. Gardner’s previous work, which showed that spatial attention introduces a selection bias in the brain’s early visual representations (Pestilli et al., 2011), I am developing a model that can explain 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 research program is only a small step towards a full model of consciousness. But it is also a necessary one: if we want to isolate the NCC we need to be able to separate out neural processes that occur unconsciously from those that induce consciousness. Understanding whether the neural processes that underlie attention are part of the machinery of consciousness, or not, is a step in this direction. 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. Based on the data we have collected and other research I believe a downstream process, likely related to building a model of the current environment, is a more likely candidate for the NCC.

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 had prior exposure to neurobiological techniques, I did not have a rigorous understanding of these. At Cornell I learned to perform microelectrode recording and chemical lesions in the lab of Prof. Thomas Cleland. With Prof. Haynes 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 useful neuroscience techniques. My current list includes learning about convolutional neural networks and incorporating them as neural network models of my experimental tasks, as well as gaining knowledge about transcranial stimulation systems for 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. With that in mind I also have a secondary goal of mentoring and encouraging students to pursue similar research. 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 on students the necessity of looking at problems from a broad perspective. Research in cognition is increasingly part psychology, part biology, and part computer science. Despite this, the majority of incoming graduate students still have little to no training in neurobiology and programming. As I continue to learn about these techniques I hope to refine my teaching to better encourage new students to learn to program, develop quantitative skills, and use neurobiology to augment our understanding of cognitive science. My experience with consciousness research has imparted on me a strong belief that to crack the puzzle we need to be thinking simultaneously at multiple levels of analysis. How 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.

Understanding the neural implementation of consciousness would have far reaching consequences. It would give us a theoretical model of the mind within which all other cognitive models would need to fit. This is a huge goal, but I believe it is one that we can achieve by taking small steps. Understanding why attention acts as a gateway to consciousness is only one of these steps but it inches us closer to a more complete picture of the human mind.

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