Studying the Neural Substrate of Attention and Visual Awareness

Consciousness appears to be a bi-stable phenomenon: you are either aware of something, or you aren't. In addition we have an undeniable feeling that attending to something brings it immediately to awareness. Attention appears to act as a gateway to consciousness and I believe that studying attention is a way to probe the specific mechanisms that translate visual inputs into conscious awareness. To clarify these mechanisms I am building a model of feature-based attention as a part of my research program with Prof. Justin Gardner at Stanford University. Our goal is to build a model of the neural process of feature-based attention that accounts for the evident changes that attention causes for conscious visual perception.

Inattentional Blindness

In the early 1990s Arien Mack and Irvin Rock showed that attention to one feature in an image was sufficient to abolish conscious awareness of other features. They coined this phenomenon "inattentional blindness" noting that it even occurred when participants were specifically fixating (i.e. their eyes were directly centered on) the feature of which they had no perception. However, it was later shown that some features survive inattentional blindness, in particular natural images and faces (Li et al., 2002; Reddy et al., 2004). This finding led researchers like Christof Koch to announce that attention and conscious awareness were two separable processes in the brain (Koch and Tsuchiya, 2007). More recent research has re-opened the debate by suggesting that even scene perception is subject to inattentional blindness when attention is engaged by a sufficiently difficult task (Cohen et al., 2007). I propose that this mixture of results is largely due to an imprecise understanding of attention. **Attention is a specific neural process**. If we knew precisely how attention acts on other neural processes in visual cortex we would have a better grasp on understanding why attention manipulates our conscious awareness.

Current and Proposed Studies

Over the past year I have collected data to begin building a model of the effect of feature-based attention on neural processing in the visual cortex. Using an inattentional blindness paradigm I combined two well understood image features: image contrast and motion coherence. We know that the BOLD fMRI signal in early visual cortical areas such as V1 is sensitive to contrast intensity, but not to motion coherence. The reverse is true in the later cortical areas V3a and hMT, where there is response sensitivity to motion coherence but not to contrast intensity. Importantly, visual cortex is organized in a hierarchy such that V1 projects more strongly to V3a and hMT than the converse. Based on this knowledge I expected that due to the feed-forward connections in visual cortex attentional effects would be fed to downstream cortical regions, potentially corrupting the downstream representations. Specifically, I expected that attention to contrast, which is known to affect V1, would corrupt or suppress signals in the downstream areas V3a and hMT. In contrast, I expected that attention to motion, which we expected to affect V3a/hMT, would not result in any change in the signals in V1. If discrimination of contrast depended only on V1 and motion only on V3a/hMT, then the behavioral results are clear: **attention to contrast should affect the perception of motion** but not vice versa. This is precisely the effect that we observed. Our BOLD fMRI results show that the responses in area hMT and V3a are modulated by the type of attention, whereas responses in V1 are not. In parallel we found that discrimination of motion in our task was affected by attention, whereas discrimination of contrast was not.

The model is currently incomplete—although we know from our data that the perception of contrast and motion are asymmetrically related to attention and that BOLD fMRI responses reflect and possibly drive perception, we still have not specified the causal process of attention. My hypothesis is that **attention to contrast corrupts the representation of motion** in the downstream regions. I will test this hypothesis in two ways: First by using a computational model of our current dataset to look at what effect of attention best explains our data, and second in a new experiment using transcranial magnetic stimulation. TMS is a technique that can be used to either abolish neural activity in a region, akin to a temporary lesion, or to boost or suppress activations that are near perceptual threshold. We can take advantage of both of these techniques to test our hypothesis in the following ways: **(1)** as a test of causality, using temporary TMS lesions to test the involvement of each area in contrast and motion perception, and (**2)** by using low-threshold pulses to mimic corrupting attentional signals.

My prediction is that if corruption is indeed the cause of our effect than a low-threshold pulse to V1 should introduce similar corruption in downstream regions, mimicking the behavioral effects I have already observed. In this way TMS is a test of the casual process of motion and contrast perception. This is the ideal technique for testing my corruption model and the data I collect will allow me to understand exactly how attention impacts perception. Specifically: it helps answer the question of whether feature-based attention modifies conscious neural processes directly, or only indirectly due to downstream effects.

Impact

This research project will help clarify the debate surrounding attention and inattentional blindness, and help clear up a literature that is full of conflicting effects. Attention is clearly an integral part of our own conscious experiences, but how attention interacts with consciousness remains unclear. In addition we have no predictive model of when we should expect attention to influence perception. My hypothesis is that attention is a form of sensory enhancement that is fed-forward through the visual cortex, boosting some representations but corrupting other representations. These representations then have an effect on conscious perception via other neural processes. If my hypothesis is correct and I find that attention only introduces sensory enhancement, then we can safely consider the neural processes of attention as only indirectly related to consciousness itself. This would be a large gain for the inattentional blindness literature, which has struggled with pinning down a specific definition of attention and visual perception. By clarifying that attention is a computation (sensory enhancement) and visual perception is a separate neural process, we can start to discuss the complexity of inattentional blindness in more detail and generate a hypothesis about why there are so many asymmetrical and unexpected effects.

Ultimately, understanding attention is an indirect solution: it doesn't directly address the question of how consciousness is evoked by neural processes. That said, building a computational model of attention is a foothold into the neural processes that contribute to consciousness. Eventually, as my research program develops, I hope to expand my projects to include experiments that focus on consciousness directly—looking at the functional role of consciousness and the neural processes that underlie those functions.

References **1** Mack, A., & Rock, I. (1998). *Inattentional blindness* (p. 288). Cambridge, MA: MIT press. **2** Li, F. F., VanRullen, R., Koch, C., & Perona, P. (2002). Rapid natural scene categorization in the near absence of attention. *Proceedings of the National Academy of Sciences*, *99*(14), 9596-9601. **3** Reddy, L., Wilken, P., & Koch, C. (2004). Face-gender discrimination is possible in the near-absence of attention. *Journal of Vision*, *4*(2), 4. **4** Koch, C., & Tsuchiya, N. (2007). Attention and consciousness: two distinct brain processes. *Trends in cognitive sciences*, *11*(1), 16-22. **5** Cohen, M. A., Alvarez, G. A., & Nakayama, K. (2011). Natural-scene perception requires attention. *Psychological science*. **6** Pestilli, F., Carrasco, M., Heeger, D. J., & Gardner, J. L. (2011). Attentional enhancement via selection and pooling of early sensory responses in human visual cortex. *Neuron*, *72*(5), 832-846.