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Experimental Approaches to Exploring Visual Consciousness

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1 Introduction

Throughout explorations of the brain and neuroscience, researchers have been provoked by the question of "consciousness", whatever that might entail. Early endeavors to understand this topic were more confined to the realm of philosophy, but as neuroscience develops it becomes increasingly capable of addressing these many issues. In particular, the vast literature on visual psychophysics in addition to the large body of work in comparative anatomy and physiology of the visual system makes vision a prime target for the bulk of this early exploratory work. In this paper, I will explore past explorations into this topic, and focus in particular on ideas championed by Francis Crick and Christof Koch regarding visual consciousness as a whole. I will examine and critique their ideas in the context of the present literature, and present what I feel are relevant courses for further explanation. As we transition into this new period of studying consciousness from a neurally plausible and neurally informed perspective, it is crucial that we focus our efforts on relevant experiments that will yield insight into this perplexing phenomenon.

2 A Theoretical Underpinning

2.1 A Stab In The Dark

After a long period of inactivity in addressing the questions of consciousness, recently there has been a strong resurgence of interest in this topic. One important body of modern work that has generated interest in exploring consciousness further was developed by Crick &

Koch in the 1990s. These explorations not only attempted to show the utility of studying consciousness, but also that it could be done scientifically and yield interesting results. When Crick & Koch [2] began these explorations of consciousness, their primary goal was to reduce this question to one that could be addressed in a scientific fashion. One important contribution, perhaps the most important of the paper, was to avoid defining consciousness entirely, instead relying on an abstract assumed "rough idea" of what consciousness is. Additionally, they choose not to address the question of who or what is conscious, and they also ignore the notion of self-consciousness, shrugging it off as a special case. By doing so, they manage to sidestep a large number of philosophical dilemmas many of which are almost innately unproductive, and move on instead to defining a set of principles by which they constrain their search. In particular, they state that they will only focus on visual consciousness, as vision is the most studied (even if not the most well-understood) of the senses and has already yielded a tremendous amount of psychophysical data to be used as fodder in constructing both new experiments and new theories.

Having restricted their view to vision, they agree to focus on what they deem the Neural Correlates of Consciousness, or NCC. These are the cells that have a causal relationship with conscious activity, and in the visual case, visual percepts. In order, once more, to simplify their search, they postulate that consciousness arises from specific areas of the brain as opposed to a distributed pattern of activity. Having thus delimited what they consider the most important and immediately examinable components of studying consciousness, they present a few overarching theories to help ground further efforts. In particular, they propose that the NCC must have a direct connection to the frontal lobes, while having access to visual information. This proposal stems from the notion that planning and free will are key in our conscious experience, and that the components that innervate them are themselves likely to be conscious.

Consistent with this theory is their further argument that V1 is *not* amongst the neural correlates of consciousness. To begin with, there are no direct connections from V1 to the relevant frontal areas identified as involved with planning. Moreover, there is important experimental evidence that V1 does not directly cause visual percepts. This is an important idea, and one that goes against many traditional notions of the underlying mechanisms of vision. In particular, most neuroscientists are familiar with the generation of phosphenes as a result of electrical stimulation of V1. Yet as Crick & Koch quickly point out, it is important to not confuse such correlation with causation. Because V1 is highly interconnected with other cortical areas, any one of them could be responsible for the actual *generation* of the perception itself. Instead, there are multiple cases (which I will address individually in subsequent sections) in which phenomenological visual perception is present in the absence of activity in V1. Such evidence supports the notion that V1 is not conscious, because although correlation does not equal causation, causation should certainly imply correlation.

Crick & Koch focus then on describing experiments that should be undertaken in order to glean information regarding the NCC. In particular, they point out that bistable phenomena (such as the Necker Cube) give a window to the study of visual perception. Because these displays are perceived in two distinct states, there is presumably some neural correlate to each particular representation that can be identified in awake and behaving monkeys. This and similar experiments are considered by the authors to be the most important way to address the Neural Correlates of Consciousness, in the framework that they present.

2.2 Beyond Crick & Koch

Mysteriously, although Crick & Koch decline to address questions of whether certain other creatures are conscious, they do their best to describe *why* we are conscious, which does not fit in with their general framework of addressing the most fruitful questions first, and leaving the deeper philosophical issues to a later date. Other philosophers are considerably less shy of addressing these more controversial issues. A large number of researchers and philosophers believe that self-consciousness is not some curiosity of consciousness, but rather one of its central tenets [11],[8]. In particular, they hold that without some sort of notion of identity, it is impossible to judge whether or not stimuli are important in meaningful. Evidence for this comes from the neurology literature, specifically the codevolution of self-identity and sensory experience in disorders such as Alzheimer's.

Of course, self-identity itself seems to be intricately tied to planning, especially in a motor domain, and a considerable number of theories identify similar requirements for what their authors consider to be important aspects of consciousness itself. Alva Noë, for example, considers not planning, but rather the sensorimotor loop itself[12]. By his argument, what is necessary to develop conscious perception and visual phenomenology is exercising some measure of control of the sense itself. That is, by moving objects in the world, you can identify that they have moved, and by correlating these, the brain is able to construct a conscious percept.

This notion is modified and extended by others, such as Andy Clark, who propose instead a skill-based account of vision. This notion is a response to a more simple sensory-motor account, and references evidence that not all visual pathways are conscious. In particular, the dorsal stream is thought to not relate to conscious processing [12], and regardless of the quality of the visual pathways, it is probably safe to assume that there are differences between them, and some may not contribute to this Neural Correlate of Consciousness, so to speak. As such, we must approach with caution arguments based on connectivity, as these loops between unconscious visual areas and motor areas most likely are not directly related in conscious processing. Thus, Clark's proposal that our experiences and memory have a strong influence on the very quality of the conscious percept of vision.

All of these, however, fall within the same general context, and as a whole present strong opposition to a view that excises the influence of the entity itself. This view is, simply stated, that vision is essentially a "snapshot" encoded in neural activity somehow, one that is present regardless of the experience of the individual in question. Explorations of consciousness, then, must focus not only on these visual areas alone, but additionally on the possible role of frontal areas, motor areas and memory in shaping this visual percept.

Another important metatheoretical viewpoint is presented by Stoerig and Cowey, whose viewpoint can be curtly summarized as "aim low"[11]. What they mean by this is that explorations of consciousness are not going to be particularly satisfying when it comes to a definite explanation of, for example, how physiological processes can possibly lead to a phenomenological perception of the world. Perhaps this is the most important guiding principle of exploring consciousness - to select questions for which we are confident that we can discover an answer, and to eschew discussion of the deeper issues that plague the field. Stoerig and Cowey proceed then to outline what they think are possible neuronal correlates to consciousness in a general sense. If we are in search of these, then, it is important to first identify which cells have this overarching property, and then to discover what these cells have in common. For example, these cells may share firing characteristics, neurotransmitter or receptor types, locations in the layers of cortex and so on. But until we can identify these correlates, which can be done in a fairly straightforward way, these deeper questions cannot be addressed.

3 Experimental Techniques

Having established a basic theoretical framework by which it is possible to guide the search for a scientific approach to consciousness, we may now identify patterns of exploration and discuss their role in the literature as a whole.

3.1 Dominant Experimental Paradigms

A large number of scientists have been in search of the neural correlates of visual consciousness, and most take a fairly straightforward approach. Specifically, they try to identify the difference between vision that is conscious and vision that is not conscious. In particular, researchers tend to focus on the region of the brain that is activated in the conscious case, but not in the unconscious case.

The argument goes that if area A is differentially active for both the conscious and unconscious case, it is certainly not part of the NCC. Moreover, if B is differentially active in the conscious case but not the unconscious case, this lends support to B being part of the NCC. Of course, this logic must be exercised with restraint, because not all areas associated with consciousness are visual in nature. Consider a task in which a subject sees a particular stimulus and makes a motor response - although the area for the visual representation will be active, so too will be areas correlated exclusively with motor responses. Thus, it is necessary to bring external knowledge of any relevant visual areas into play when trying to describe its role in conscious vision. Another caveat to this particular line of reasoning is that there simply may not be any single area A that is always correlated with conscious vision. Most neuroscientists seem to avoid using such fierce terms as "always", but it is simply necessary to concern oneself with the question of whether anything in the brain can be *always* correlated to anything at all.

One example of this is present in the work of Rees et al., whose work focuses on attentional disorders in vision. In particular, they consider the difference between stimuli in the left hemifield that are attended to by patients with visual neglect and stimuli that are extinguished, and thus not reported as seen. Using fMRI and comparing trials, it is possible to determine which areas are differentially active, and Rees et al. were able to conclude that the supposedly conscious ventral pathway (the fusiform face area, in fact) is active even during unconscious vision [9]. Of course, one important caveat is that, in addition to using only a single subject, this particular subject has damage to right parietal cortex, leading to his peculiar condition. Thus, it may be difficult to generalize from this to brains that are on the whole undamaged.

Single-cell recording has also been employed in the search for correlates of consciousness, even in humans. In particular, subjects with epilepsy that is pharmacologically intractable are implanted with electrodes over a fairly long period of time to identify the location of the malfunctioning brain region. Krieman et al. used such patients to study correlates of visual consciousness using a flash suppression paradigm [5]. In this paradigm, subjects are presented with an image to a single eye, then an image is flashed to the other eye, at which point subjects only perceive the novel stimulus. The advantage of such a system lies in that an image is presented to the retina, and is yet not consciously perceived. Cells recorded from the medial temporal lobe (MTL) tended to respond to only the perceived stimuli, and not the suppressed stimuli, indicating that MTL may be part of the NCC. This is exactly the sort of experiment proposed by Krick & Coch, and indeed it has contributed to the body of work regarding which parts of the brain are correlated with conscious activity.

Another important mechanism used to explore the same vein of research stems from explorations of stimuli present exactly at the threshold of detection. At this threshold, roughly 50% of the stimuli are detected, which means that the effects of the detected stimuli can be contrasted with undetected stimuli. Pins and ffytche used this particular method along with both fMRI and EEG to develop an understanding of the neurobiology of visual perception [7]. In particular, they cite the importance of investigating the precise timing of these events, which is conspicuously absent from fMRI research. Their findings have indicated that correlates of consciousness are distributed across the brain, and in particular, distributed temporally. In fact, they can be broken into two distinct groupings, a speedy initial response in the first 100ms, and a slower set of activations 150ms after that.

This generalized paradigm of a comparison of conscious/unconscious stimuli is clearly a very productive one, and it indeed lends itself to a great number of different experiments. The goal is both to perform new and innovative experiments, but also to construct working hypotheses of how this data fits together.

3.2 Other Paradigms

There are many alternatives to comparing consciously perceived displays to "unconscious" displays, which yield equally interesting results pertaining to the neural correlates of consciousness.

One such experiment type focuses on studying the neural correlates of hallucinations. Because hallucinations are conscious, but can be dissociated from any retinal activity, they are an important window to the generation of visual perception. ffytche et al. investigated these issues using fMRI, and observed activity in ventral extrastriate cortex [4]. Of course, the poor temporal resolution of fMRI makes it difficult to draw definitive conclusions from this data, and a coupling to EEG in the style of Pins and ffytche [7].

An entirely different approach is proposed by Pollen, to identify to importance of recursive connections [8]. In the context of many theories of consciousness, recurrent connections are necessary to tie the ever-important planning, motor and higher-order areas back to the visual areas. In general, it is difficult to identify the roles of these connections, because their anatomy is only beginning to be explored, and it is exceptionally difficult to selectively alter them. Pollen, however, believes that selectively blocking such recurrent projections is an essential component of investigating the neural correlates of consciousness, and he suggests several mechanisms of doing so. In particular, he believes that pharmacological agents may eventually be developed to selectively inactivated receptors for recurrent connections, and he maps out a few potential outcomes. Of course, none of these are particularly simple, and I will excise them for the sake of brevity.

3.3 Summary of Present Research

The research in visual consciousness is quite complex, and yields many interesting but often contradictory results. Some experiments propose that particular visual areas are not part of the NCC, while others propose that these same visual areas are, and both offer compelling evidence for this claim. One example presented above is that of the ventral processing stream, which is generally associated with conscious visual perception, but is not necessarily deactivated in the absence of awareness. Interpreting these findings is an exceptionally difficult task, and a new class of scientist is necessary to integrate this disparate data in a compelling way to come up with a convincing theory of consciousness.

Of course, a good deal of this research has focused exclusively on visual cortex, without addressing a fairly fundamental question, namely *why* is visual processing localized to the striate and extrastriate cortex? Is it possible to obtain visual perceptions as a result of activity in other areas of cortex individually? Answering this and similar questions may not be simple, but in the following sections I will outline a mechanism for their study and the impact that answering these questions can have on our basic understanding of visual consciousness.

4 A New Look: Sensory Substitution

4.1 Introduction

Sensory substitution refers to the phenomenon in which one sense is used to simulate another sense, often substituting for a sense that has been lost somehow. The canonical example of this is given by a blind man who uses a walking stick and begins to use this stick to “see” the world in front of him. This concept has been extended to many other senses, and is in fact quite general. That is to say, touch and audition have been used as a means to substitute vision, and even to add new senses. One prominent example of this is a belt that gives its users cues regarding orientation in space, which, after training, they are able to use quite naturally [6].

The most compelling set of results, however, is a tactile substitute for vision that is applied to the tongue, as was pioneered by Paul Bach-y-Rita [1]. The system is set up such that a camera gives input to a matrix of electrodes, which stimulates the tongue in a stereotyped way. After sufficient training, the user begins to develop a qualitative sensation of the information presented via the camera, in a manner comparable to vision itself.

While this in and of itself is an exciting result, it has other qualities which make it even more interesting and relevant to further studies of the brain. To begin with, in order to obtain this "visual" percept, users must have control of the camera and its various quantities, such as the zoom and focus. Without control of the camera, the tactile sensation is never interpreted as representative of the visual world. This, of course, relates to the work of Alva Noë, who postulates that a complete sensory-motor loop is always necessary for conscious perception to arise. Additionally, this particular substitution paradigm is interesting because once the mechanism is learned, the location of stimulation may be changed. That is, if you learn to use the system through stimulation of the tongue, stimulating the abdomen in the same way will lead to exactly the same percept. And finally, what is perhaps most stunning about this system is that both sighted and congenitally blind subjects can learn to use it, and both are able to perform to a fair degree of accuracy, as is measured by visual acuity [10].

4.2 Possible Experiments

Much to my surprise, very few experiments have been carried out using this system to study visual phenomenology. There are many clear advantages to using such a sensory substitution system to study consciousness as opposed to very nearly any other method. The components of a tongue brain-machine interface, for example, are very simple, and most likely comparable in cost to systems such as EEG. Additionally, studies of this type may be carried out very quickly and simply, such as psychophysical tasks, requiring relatively little training and few sessions in order to demonstrate important qualities of the system. Perhaps most importantly, a research paradigm such as this one does not inherently require any unique patients - blind individuals are much easier to come by than chronically implanted epileptics, or subjects recovering from visual neglect. Even normally sighted individuals can be used in studies that take advantage of this system. Of course, the true reason to use a system such as this one is the incredible insight it provides to the development of new sensory systems, and the components that are necessary to generate this conscious sensation.

Thus, I will present a series of relevant experiments to probe the neural correlates of consciousness, as well as important issues regarding plasticity and learning. Addressing the question of fruitful experiments to be carried out, it is clear that our suggestions will be constrained by a number of methodological factors. Perhaps the most immediate experiment that could be suggested is a simple fMRI study to identify the regions of activation during use of this device. The use of fMRI could also elucidate changes in regions of activation over time as a function of learning, and the learning parameters could be varied to observe the relevant effects. In general, it would be impossible to use a system such as this one within an MRI scanner, because of the ferromagnetic components and the electrical currents needed. Recently, however, Zappe et al. have developed a similar sensory substitution system that can be safely used within a scanner [13]. This opens the window to a large set of relevant experiments. Presumably, trained subjects will exhibit differential activity patterns as compared to untrained subjects. This subjective experience could then be mapped to a certain component of the brain, much as past experiments have done with vision, and the relevant brain region can be explored in depth. Is, for example, this area the same in sighted subjects as in congenitally blind subjects? The implications of this particular experiment are particularly striking, and they hinge on a description of the qualia of the substituted perception itself. Do blind and sighted subjects even perceive the same thing? If so, and different brain regions are active, this has crucial implications for the study of consciousness.

Another extremely useful tool in examining the function of this particular sensory substitution system comes in the form of TMS, or trans-cranial magnetic stimulation. Applying TMS to specific areas of the cortex over short periods of time can induce, for example, twitching and other phenomena also capable of being induced via direct stimulation by electrodes. Could, then, the equivalent of phosphenes in this new "visual" sense be evoked by TMS? This would indicate a strong change in the underlying connectivity, surely, but also a change in the meaning of different neural elements, which is a crucial question in examining consciousness.

TMS can also be used over longer periods of time to induce temporary lesions across relatively specific areas of cortex, allowing for selective deactivation of accessible regions. Fernández and colleagues describe an experiment in which TMS is applied to the striate cortex of blind subjects, and they note that these subjects lose the ability to read braille [3]. This style of TMS can be applied appropriately in two very interesting ways. After the system has been learned, TMS can be applied to the active part of the cortex, for example, the occipital portions, and the effect of this on both sighted and blind subjects may be identified. Specifically, what will be the effects of this on perception? Even more interestingly, however, would be the effects of using TMS while the subject is being trained. If visual cortex is in fact used in this particular mapping, but is deactivated prior to learning, then what would be the effects of this on learning, and in particular, the development of the expected perception? If the subjects are able to use the system anyway, and report similar subjective experiences, then this has interesting implications for the localization of consciousness. In particular, it would perhaps remove the extreme emphasis on localizing particular areas as "associated with consciousness" and shift instead to models focused more strongly on patterns of connection and the capacity for adaptation.

Bach-y-Rita mentions the possibility of using time-division multiplexing to take advantage of the increased temporal resolution of skin. One alternative to this method that would also be quite informative would be to present non-contiguous stimulation to the skin and identify the extent to which subjects can integrate this into a unified percept. This can help compare the importance of early processing to late processing, and again probe the effects of plasticity. Skin, for example, is also thought to exhibit shunting properties, much the way the retina does, so what is the result then of stimulating different areas of the skin? Consider the right hemifield being presented to the abdomen, and the left hemifield to the back. First off, can this be learned, and if so, what visual information can be integrated across the boundary? Additionally, how does the spatial invariance property of this system apply to multiple areas of stimulation? How is this affected by the absence of motor control of the camera?

The initial studies mention congenitally blind subjects, but fail to mention late blind subjects at all. Are these subjects capable of learning to use this sensory substitution system? If so, are the utilized brain regions more in line with congenitally blind subjects or sighted subjects, and what would they report in terms of visual experience? These observations could be quite useful in identifying neural correlates of consciousness, and in particular ascribing some rationale to how they are formed and how they can change with experience, something that has not been adequately addressed thusfar in the literature.

Even simple measures such as EEG may be simply applied to such a system, as long as the stimulation on the tongue can be adequately shielded from the electrodes on the scalp, but under such circumstances it could yield very interesting data. Are stereotyped signals also present for users of this system? Do they occur at the same times, and perhaps most interestingly, does the timing of these events change? Such questions can be examined simultaneously with training, and in particular in conjunction with psychophysical studies assessing the changes in performance over time.

To the best of my knowledge, none of these experiments have been undertaken, and indeed, no experiments have examined the details of the sensory-substitution system developed by Bach-y-Rita. Doing so is advantageous because is gives insight into the development of a “visual” percept over time as a function of training. This is, it seems, a crucial piece in the puzzle of understanding the neural correlates of consciousness, in direct opposition to simply identifying which areas are active. This system gives the opportunity to test hypotheses of the development of conscious percepts, as are provided by Noë, Clark and other neurophilosophers. Even aside from the concerns of the development of this perceptual phenomenon, sensory substitution gives another mechanism to investigate the same principles that are currently being explored, albeit in a simpler and more straightforward way. Instead of going to great detail to fool the visual system, one merely needs to compare somatosensory input alone (either prior to learning, or outside of the learned parameters) to these new sensations. As far as I can tell, sensory substitution is the single most promising and most unexplored outlet for the exploration of the development of perception and the neural correlates of consciousness.

5 Conclusion

Throughout this paper, I have described general approaches to examining the neural correlates of consciousness (NCC). Overall, a large body of theoretical work has been done to establish the constraints of these correlates, and hand in hand with this a large, complex and oft-contradictory set of research has begun to unravel the regions correlated to conscious awareness of visual stimuli. I also presented an important alternative to this mode of exploration, namely experiments based on sensory substitution systems. Such systems allow a surprising amount of control over the development of perception, and also a good deal of control of what is perceived after training. As we learn more about the adaptive nature of the brain and consciousness, it will become increasingly important to explore these novel mechanisms as models for the function of more “natural” sensory systems. With luck, the problems discussed in reference to the neural correlates of consciousness will be able to be more adequately addressed with such systems, and eventually lead to a greater understanding of all levels of consciousness itself.

References

[1] Paul Bach-y-Rita. Tactile sensory substitution studies. *Annals of the New York Academy of Sciences*, 1013, 2004.

[2] Francis Crick and Christof Koch. Consciousness and neuroscience. *Cerebral Cortex*, 8, 1998.

[3] E Fernández, F Pelayo, S Romero, M Bongard, C Martin, A Alfaro, and L Merabet. Development of a cortical visual neuroprosthesis for the blind: The relevance of neuroplasticity. *Journal of Neural Engineering*, 2, 2005.

[4] D.H. ffytche, R.J. Howard, M.J. Brammer, A. David, P. Woodruff, and S. Williams. The anatomy of conscious vision: An fmri study of visual hallucinations. *Nature Neuroscience*, 1, 1998.

[5] Gabriel Kreiman, Itzhak Fried, and Christof Koch. Single-neuron correlates of subjective vision in the human medial temporal lobe. *Proceedings of the National Academy of Science*, 99, 2002.

[6] Saskia K. Nagel, Christine Carl, Tobias Kringe, Robert Martin, and Peter Konig. Beyond sensory substitution - learning the sixth sense. *J. Neural Eng. 2*, 2, 2005.

[7] Delphine Pins and Dominic ffytche. The neural correlates of conscious vision. *Cerebral Cortex*, 13, 2003.

[8] Daniel A. Pollen. Explicit neural representations, recursive neural networks and conscious visual perception. *Cerebral Cortex*, 13, 2003.

[9] Geraint Rees, Ewa Wojciulik, Karen Clarke, Masud Husain, Chris Frith, and Jon Driver. Neural correlates of conscious and unconscious vision in parietal extinction. *Neurocase*, 8, 2002.

[10] S. Maris. Sampaio, E. and P. Bach-y-Rita. Brain plasticity: 'visual' acuity of blind persons via the tongue. *Brain Research*, 908, 2001.

[11] Petra Stoerig and Alan Cowey. Visual perception and phenomenal consciousness. *Behavioural Brain Research*, 71, 1995.

[12] Steve Torrance. The skill of seeing: Beyond the sensorimotor account? *Trends in Cognitive Science*.

[13] Anne-Catherin Zappe, Thorsten Maucher, Karlheinz Meier, and Christian Sheiber. Evaluation of a pneumatically driven tactile stimulator device for vision substitution during fMRI studies. *Magnetic Resonance in Medicine*, 51, 2004.