Exploring a Possible New Mechanism of the Predictive Coding Theory of Consciousness with a Binocular Rivalry Experiment

Sai Kiersarsky
Portland State University

Madison Cho-Richmond
Oregon State University

Exploring a New Possible Mechanism to the Predictive Coding Theory of Consciousness with a Binocular Rivalry Experiment

Sai Kiersarsky[1] and Madison Cho-Richmond[2]

1 Department of Psychology, Portland State University

2 Department of Biochemistry and Biophysics, Oregon State University

Please contact ak36@pdx.edu with any questions, or for a paper-sized format for more convenient reading.

Abstract

Predictive Coding Theory is a theory of brain function in which consciousness is a model generated by higher brain regions that constantly update its predictions about the cause of upwards flowing data – often but not always sensory perception data. Binocular Rivalry is a phenomenon where, when each eye is presented with a completely different image in an experiment, consciousness alternates between one image and the other rather than attempting to fuse both images into one. Despite this, when an individual with myopia wears only one contact lens, it results in unified vision favoring the eye wearing the contact lens rather than alternating between clear and blurry visual streams.

Proposed here is a novel binocular rivalry experiment which presents the same image to both eyes, but with each image partially blurred in differing areas, to test if consciousness weaves together the clear areas to synthesize a single crisp image. In our pilot study, participants report a consistently crisp image, supporting predictive coding theory because the similar images produce input similar enough to be reconcilable by the conscious model, whereas completely different images usually used in binocular rivalry experiments are irreconcilable causing alternation between images and complete regenerations of the model.

In preliminary testing of our hypothesis, we discovered an overall clear image was seen despite two images with blurry portions. This capability indicates a possible new fundamental mechanism of visual information processing, which is delineating patterns of signals and synthesizing them accordingly. In our proposed experiment, the use of frequency tagging would indicate the possible location the blurry signals ended in the visual pathway and the clear signal continued to be propagated through the network.

The most interesting aspect to this micro-level pattern detection system is its potential generalizability. Its most apparent function in the brain is for sensory systems, but it's possible that these micro-level pattern detection systems are employed at many levels of the predictive-coding hierarchy in many parts of the brain. We speculate that other facets of cognition such as abstract thought and language might use similar techniques, which is an area ripe for future research.

Introduction

A popular theoretical framework of neural processing is Predictive Coding (also known as Predictive Processing) which posits that the brain constantly generates a model of the world. This model is updated by the differences between its predictions about what sensory input it should be receiving compared to actual sensory input, and this discrepancy (the prediction error) is used to update the model. It draws strong parallels with Bayesian inference in statistics.

Binocular Rivalry is an experimental setup and phenomenon within perception in which each eye is presented with a completely different image – for example an image of a house is presented to one eye and a face to the other. One might expect that the two images somehow fuse into one image. However, in typical binocular rivalry experiments the conscious perception instead alternates between the two images. This is useful for studying consciousness in the brain because it separates the stimuli from the perception and allows for examining the difference between sensation and perception in the brain.

Our experimental setup is different from most binocular rivalry experiments. Instead of presenting two different images to either eye, we present two copies of the same image but with certain areas being blurry in one image but clear in the other, so that each area is clear where it's blurry in the other image. In our pilot study, our participants found that instead of alternating between the two partially clear images which would be similar to most binocular rivalry experiments, the two images neglected the blurry areas fused the clear areas into one cohesive clear image in perception.

This preliminary finding was quite striking, and as we will elucidate in the conclusion section of this poster, it might be revealing a new fundamental mechanism of predictive coding and brain function in general, which could be generalized to other regions of the brain beyond vision. In order to study this in a more robust way, we propose a similar experiment with EEG equipment in order to utilize frequency tagging to explore where this fusion of images is taking place in the brain.

Frequency tagging is an experimental methodology that utilizes stimuli that has been configured to flash at differing frequencies. In the case of visual stimuli, the images are displayed on a screen that flickers them at the specified frequency. Neuroimaging techniques, often electroencephalography (EEG), are employed to monitor the neural response in the sensory visual pathway. In binocular rivalry experiments each image can flicker at a different frequency and it's then possible to observe which image is being processed at which regions of the brain. Often in binocular rivalry when one image is being subjectively perceived by the participant, neurons farther along the visual pathway are activated in similar frequencies as the perceived image, whereas the suppressed image's frequency does not advance along the visual pathway. Thus, frequency tagging can inform how far along the visual pathway an image is processed, and at what point a suppressed image is no longer processed. Frequency tagging has enjoyed usage in Binocular Rivalry experiments in the past.

Poster created and presented by the authors at Portland State University Student Research Symposium in April 2021.

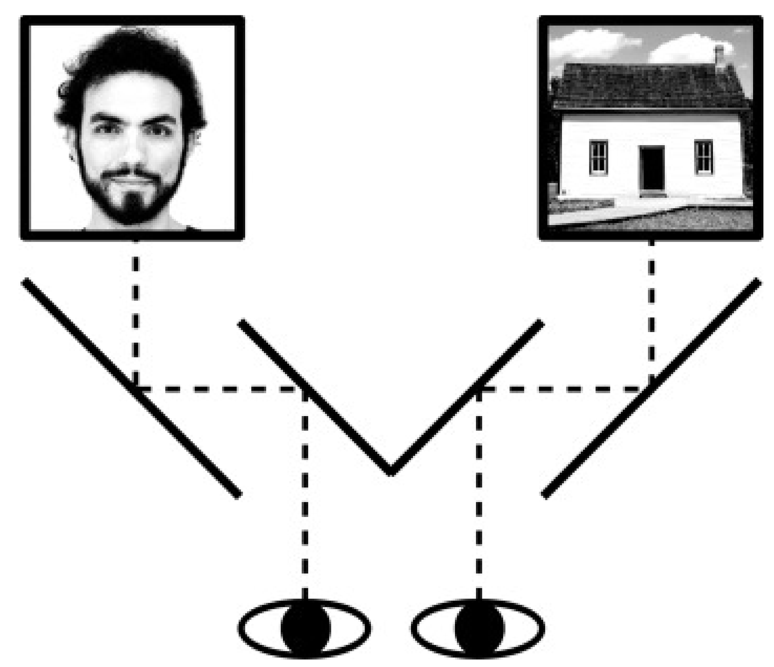
Methodology

Pilot Study

A preliminary pilot study was undertaken. The results suggest that the clear portions of each image do in fact converge to make one clear mental image.
And will be succeeded with a more formalized rigorous experiment environment.
Even when looking at the composite image (partially blurred images side by side), our minds still favor the clearer image.

Our crude setup with two tubes sequestering each visual stream made for a slightly unnatural viewing process and sometimes it image took some time for the images to converge into one, but we hypothesize that with a more robust viewing setup involving stereoscopic mirrors will make a more natural viewing experience, and thus a more rapid image convergence.

Participants reported crescents of blurriness around the circles which were clear within and without. This could be due to parallax distortions because of the equipment used that may not be present when an actual mirror stereoscope is used during the proposed study.



Typical binocular rivalry experiment with the two eyes presented with two completely different images – a face and a house.

Proposed Study

In the proposed study, n > 30 participants will view images in a setup that utilizes mirror stereoscopes to induce binocular rivalry. The presented images will flash according to predetermined frequencies in order to achieve frequency tagging conditions detailed below. An EEG will be used to record the results of the frequency tagging. Each Image Configuration (1 and 2) will be undertaken for each Frequency Tagging Condition (A and B) so that each participant views each combination in random order.

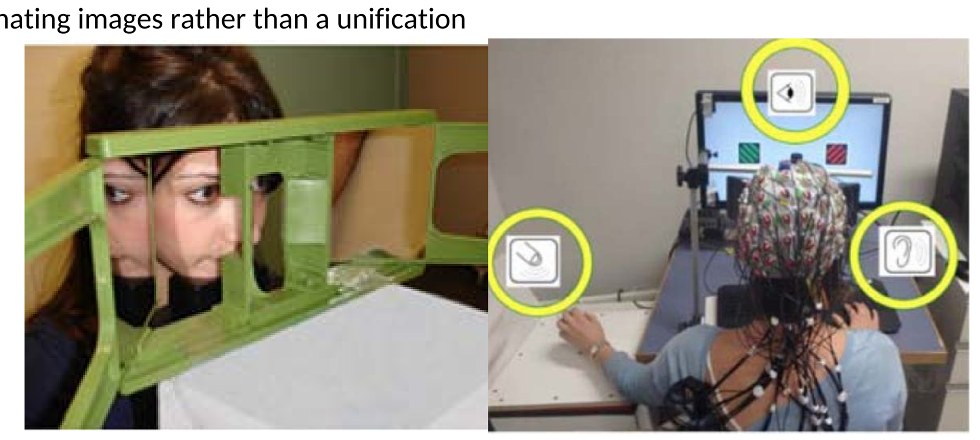
Image Configuration 1: Each eye is presented with either a completely clear or completely blurry image.

Image Configuration 2: Each eye is presented with an image that is blurred in opposite areas as the image presented to the other eye (see figure)

Frequency Tagging Condition A: The more traditional binocular rivalry configuration where the left and right eye view a image which each have their own frequency.

Frequency Tagging Condition B: A different approach where the blurry areas presented to both eyes flash at one frequency and the clear areas of both images are amplified.

As stated, an aspect to this experiment that is different than the usual binocular rivalry studies is that most others use completely different images, whereas this one uses similar images. In the pilot study, the two images were identical but had differing areas of clarity and blurriness. The two images converged for the participant into one unified cohesive clear image. An interesting additional piece of data from this experiment would be to quantify the average degree of difference between images where the images would no longer unify, at which point the participant reports alternating images rather than a unification



Participants in binocular rivalry studies, with and without EEG.

Example images with opposite blurry and clear regions which fuse into one clear image in conscious perception when presented to each eye individually, rather than alternating between images like in most binocular rivalry experiments.

References

Alp, N., Kogo, N., Van Belle, G., Wagemans, J., & Rossion, B. (2016). Frequency tagging yields an objective neural signature of Gestalt formation. Brain and Cognition, 104, 15–24. https://doi.org/10.1016/j.bandc.2016.01.008

Feldman, H., & Friston, K. J. (2010). Attention, Uncertainty, and Free-Energy. Frontiers in Human Neuroscience, 4. https://doi.org/10.3389/fnhum.2010.00215

Hohwy, J. (2012). Attention and Conscious Perception in the Hypothesis Testing Brain. Frontiers in Psychology, 3. https://doi.org/10.3389/fpsyg.2012.00096

Hohwy, J., Roepstorff, A., & Friston, K. (2008). Predictive coding explains binocular rivalry: An epistemological review. Cognition, 108(3), 687–701. https://doi.org/10.1016/j.cognition.2008.05.010

Rubin, J., Ulanovsky, N., Nelken, I., & Tishby, N. (2016). The Representation of Prediction Error in Auditory Cortex. PLOS Computational Biology, 12(8), e1005058. https://doi.org/10.1371/journal.pcbi.1005058

Weilnhammer V, Stuke H, Hesselmann G, Sterzer P, Schmack K (2017) A predictive coding account of bistable perception - a model-based fMRI study. PLoS Comput Biol 13(5): e1005536. https://doi.org/10.1371/journal.pcbi.1005536

Conclusions

The conclusions we draw from this pilot study and our hypothesis for the more robust proposed study goes far beyond an additional mechanism for enhancing visual acuity. We see potential for an undiscovered general principle of brain function.

Predictive coding selects signals based on error from the model. We are proposing that the coherence of the pattern of the signal plays a role in the signals that are selected. This pattern delineation can be generalized as a general fundamental computational principle of brain function and cognition.

It is well known that the visual system has many features which functionally discern patterns from visual information, such as receptive fields and other network architecture which act as feature detectors for visual features such as lines, curves, movement, and colors. However, based on the results of our pilot study and our hypothesis for our future study, there appears to be another element of the network architecture that automatically selects for and later assembles more clear elements of the visual scene into one cohesive optimally clear conscious visual percept.

Conclusions

A. A new, unknown fundamental component of predictive coding which involves selecting patterns that are most clearly delineated from other signals. Potential functional mechanisms for this pattern delineation are:
1. A bottom-up mechanism in which the network architecture automatically favors more clearly delineated patterns for further processing, or
2. A top-down mechanism in which the model being generated uses reciprocal connections to select for more clearly delineated patterns as its input.

In both cases, this could be a formerly unrecognized fundamental mechanism of predictive coding. The more well-known functional mechanism is propagation of prediction error, but this facet of coherent pattern selection may be a new element in selecting the prediction error signal.

B. This generalizable principle of signal selection that might be utilized in other parts of cognition, and may be observable in the physical network architecture in other regions of the brain on both micro and macro levels.

The results of a successful frequency tagging experiment would furnish a great deal of information about the location of the point where the blurry signals ended in the visual pathway and the clear signal continued to be propagated through the network. This may provide evidence for either a bottom-up signal selection process (Conclusion A1) or a more top-down process (Conclusion A2).

If either A1 or A2 is true, the brain is even more active than we currently believe in selecting relevant stimuli to build an accurate model. The current paradigm in predictive coding centers around prediction error in updating the model on both micro and macro levels, but if these conclusions were true, it might suggest that the brain has a mechanism to select not only for novel stimuli, but also for higher quality stimuli. This could be an attentional mechanism akin to the cocktail party effect for selecting relevant signal from noise, but in every aspect of cognition and perception.

In this view, predictive coding would have at least two fundamental functional mechanisms – the traditional Bayesian functioning in which a model is modified by incoming prediction error, and this new proposed function in which the prediction error is codified and selected according to its distinction from the noise as well as its novelty/difference from the currently generated model. In other words, the traditional view is that prediction error is selected and amplified based on its discrepancy with the currently generated model, and the new proposition is that the difference between the selected signal and the surrounding noise is also a fundamental aspect of the selection of the prediction error.

Future Directions

This has broader potential implications for our understanding of consciousness and cognition in general.

Part of the impetus of this project is to explore how the brain sequesters useful signals to process among the vast noise that exists both exogenously and endogenously - within our environment and within our brains. It's unclear how such a mechanism for detecting and synthesizing coherent patterns in neural signaling might be used for the generation of abstract thought and language.

We seek in the future to not only further examine the functional and physical mechanisms of this automated pattern detecting system, but to generalize it to other systems. If portions of the visual fields are chosen to be processed and developed into conscious perception regardless of the eye that the input entered, then there must be neural network mechanisms that select for clearly delineated and coherent patterns within the ambiguous and noisy signals that come from within and without. It's clear that on a global level that our brains are adept at pattern discernment, but this study suggests that our neural networks are capable of pattern discernment on a much more fundamental micro-level.

Within Complexity Science there are measures of complexity that may account for how much of a cohesive pattern the signal represents. If a fitting measure of complexity does not currently exist that could account for this signal selection, a new model may be built capable of predicting outcomes in other neural systems.

One possibility for an underlying neural mechanism might be detecting the mutual information that is propagated through the signal. An information stream that is largely uni-directional or bi-directional such as the ventral visual stream has signal propagation through multiple parallel circuits simultaneously. A salient signal will be somewhere between spatiotemporal homogeneity and heterogeneity. – for example, a plain white background will be extremely ordered and the parallel circuits will propagate the same exact signal. On the other hand, too much variation in the signal such as the case of random static will cause the opposite to occur, and there would be very little mutual information in the signal. A salient signal will be somewhere between the two poles of spatiotemporal homogeneity and heterogeneity. In the case of our experiment, a blurry region has less variance than a clear region.

A rudimentary example of such a formulation might look something like the following:

Variance of signal x mutual information in parallel circuits x discrepancy with current model's prediction = likelihood of signal propagation

Mathematically formalizing this measure of complexity in a network-based information-theoretic methodology and applying it not only to sensory signals but eventually to abstract thought is a future ambition of the authors.