Preliminary research report on the results of Concetta Antico's psychophysical color vision testing and its relation to her photopigment opsin genotype.

Kimberly A. Jameson PhD
Institute for Mathematical Behavioral Sciences
University of California, Irvine

&

Alissa D. Winkler PhD
Department of Psychology
University of Nevada, Reno

Preface:

The current state of color vision testing does not easily permit demonstration of how individuals with a potential for Tetrachromacy may see color in the world compared to other observers with normal Trichromat color perception. The reasons for this are complex, but the net consequence is that (1) standard color vision testing methods (e.g., color sorting, color plates, light mixture methods) are not adequate as tests of tetrachromacy, and (2) no existing method used for testing normal color vision was designed to demonstrate what a tetrachromat difference might be.

For this reason novel methods are needed to test Concetta Antico's (abbreviated "CA") potential for tetrachromatic color vision. Based on a variety of pilot results, we chose not to test whether CA perceives many millions of colors. Rather, we decided to indirectly test CA's color vision using a modified form of a highly reliable method, which, in essence, can be used to measure how CA's perceptions of brightness differ from that of other normal observers across a representative portion visible color space.

Empirical Methods:

Genetic testing: Concetta Antico's color vision genetic sequence was assessed by an independent research laboratory. Those results state that CA has the genetic basis for retinal tetrachromacy. Specifically, genetic analyses suggest that CA's gene sequence for long-wavelength sensitive type cells shows an Exon 3 codon 180 polymorphism in the nucleotide sequence of her L-cone opsin gene electropherogram (personal communication from Concetta Antico, May 28, 2014). The result suggests that CA has the genetic building-blocks, or the potential, for tetrachromatic color vision.

Color perception tests: The empirical measurement method we used employs "minimum-motion" phenomena. Minimum motion is a kind of illusory motion that is perceived when two juxtaposed stimuli are presented using alternating flicker (similar to how motion is created in the movie industry where successively presented frames create a seamless perception of the scene). In such cases, using a simple annular stimulus, when the flicker rate used is just right, and the stimuli are more-or-less equal in subjective brightness, the illusory motion alternates in either one direction or the other. The point of minimum alternating illusory motion is known to reliably identify an observer's point of subjective equiluminance. Such "MM-equiliminance settings" vary greatly across individuals and are not expected to be uniform across color space. Indeed, normal color vision observers may be expected to have different MM-equiliminant settings compared to observers who have the potential for tetrachromacy. This is the empirical approach and question we used to evaluate CA's tetrachromatic potential.

In addition to using this novel MM-equiluminance approach, we chose to examine how viewing complexity might also differentiate a potential tetrachromat from a trichromat observer. We did this because it is well known that color processing depends greatly on the surrounding environment in which a stimulus is viewed. We believe that overly simple, non-naturalistic, viewing circumstances are not complex enough to enlist the kinds of nuanced contributions to color processing that might be conferred by the extra class of photoreceptors that a tetrachromat possesses. For this reason we tested CA using a variety of contexts, with the aim of increasing the chances of detecting a tetrachromat difference that may exist.

Empirical Results:

The results from various viewing conditions tested found, in essence, that CA's observed MM-equiluminance settings differed markedly in certain regions of visible color space compared to that observed for normal color vision female control subjects who do not possess the genetic potential for tetrachromacy.

What does this imply for CA's color vision?

Although we have not confirmed CA's populations of retinal cone classes directly, nor do we know how their signals combine into a neural color code, our psychophysical results suggest that CA has an extra cone class population in her retinas (called L'-cones because they are a variant of the normal L-cone class), and that this extra class of cones contributes to her minimum-motion luminance signal in a way that differentiates her settings from the settings found for normal color vision observers presumed to possess the usual M-, L- and, S-cones.

Moreover, the specific stimulus conditions where CA's settings most differ from the normal settings are consistent with the idea that it is CA's extra L'-cone class that is contributing the luminance signal that significantly differentiates her MM-equiluminance settings from those found for trichromat observers.

Specifically, we found that the regions of CA's deviation involve stimuli with spectra containing substantial "reddish" components, and spectra involving mixtures of "reddish" and "bluish" primaries. The latter point is interesting because it is known that, in general, a negligible luminance signal is carried by the S-cone system and in CA's case this appears to be markedly altered by the additional contributions of her L'-cone class signal.

Based on these results our preliminary conclusions are:

(1) As with normal trichromat observers, across light mixture space CA's MM-isoluminance settings are presumed to be due to first-order motion effects arising from luminance contrast differences signaled by retinal cone contrast signals.

(2) CA's observed MM-equiluminance settings differ markedly in some regions of the visible color space compared to those of normal trichromat controls.

(3) Where CA's MM-equiluminance settings differ from normal settings, they do so in a manner suggesting that CA systematically requires a lesser amount of red-primary contribution to achieve MM-equiluminance. The implication for tetrachromat processing is that possession of both L- and L'-cone classes (both with response peaks in the reddish region of color space) requires a less substantial contribution of red in the primary light mixtures that achieve equiluminance. Or, in other words,

possessing both L-cone class variants lowers the threshold for the detection of luminance contrast in the MM-isoluminance task for reflectance stimuli involving long wavelength components.

Interpretation of Results:

Based on our scientific findings and the genotype results provided, we believe Concetta Antico represents a "perfect storm" for the realization of tetrachromatic color vision. That is, we believe, she has all components that are essential for building the capacity for strong tetrachromacy. Specifically, CA possesses (1) one of the important tetrachromat genotypes required for potential tetrachromacy, (2) a life-history of training in applied color use and color appreciation that, we believe, is important for developing functional tetrachromacy, and (3) color appreciation and expertise that is appropriate for demonstrating a tetrachromat potential under empirical testing circumstances. We believe these factors are all necessary to demonstrate an observer has the ability to use tetrachromatic color vision in everyday viewing circumstances.

Practically speaking, the empirical results found for Concetta Antico would most likely impact an artist's use of color balance, color complementarity, and the uses of color in low light contexts (e.g., shadows, dusk, nocturnal scenes), and perhaps further, yet untested features of color processing, such as the number of colors perceived under naturalistic viewing circumstances.

The possible impacts of these differences for artistic representation may be to provide a systematic alternative to ***structural color relationships*** found in natural visual scenes, which, when interpreted by CA into a painting, could be both (1) aesthetically appreciated by normal observers, and (2) recognized as meaningful, yet somehow "different" from their own internal structural color relations, despite the fact that non-tetrachromat observers may not actually detect the same subtle qualities of color and luminance that CA perceives in the objects, and the representations of objects, that she paints.

Further empirical testing will allow confirmation and extension of these initial results, and will permit elaboration of the consequences of CA's potential tetrachromacy for her color processing.

Notes:
(1) The views and opinions expressed in this article are those of the authors and do not necessarily reflect the official policy or position of any agency of the University of California or the University of Nevada.
(2) This report and its results are made public by request and with permission of Concetta Antico.

Author Contacts:
Kimberly A. Jameson: email – kjameson@uci.edu.
Alissa D. Winkler: email – aliuvthevalley@gmail.com.

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