Perception is shaped along the (L+M)–S axis (and possibly confused with a memory color effect)

Ifedayo-Emmanuel Adeyefa-Olasupo ^*#!

^Department of Psychological and Brain Sciences, Johns Hopkins University,
**Berlin School of Mind and Brain, Humboldt-Universität zu Berlin*
 # Department of Psychiatry and Psychotherapy, Charité Universitätsmedizin Berlin,
! Department of Neuroscience, Yale School of Medicine

Address for Correspondence:
Ifedayo-Emmanuel Adeyefa-Olasupo
Email: first.last@yale.edu
Mailing address:
200 S Frontage Rd
Yale School of Medicine
New Haven, CT 06511

Running Head: Perception is shaped along the (L+M)–S axis.
Key words: Color vision**,** Perception, Achromatic, Top-down effects**,** Daylight illumination
Word count: 4967incl. Abstract; 8 Figures.

Abstract

What shapes perception? Does what we know and remember actively affect what we see? Perhaps the most intuitive example of something remembered or known possibly affecting perception is the case of objects with canonical hues. Since people are aware of the typical colors of certain objects, are those objects perceived differently? All other reflectance and lighting properties held constant, do such objects elicit color appearances that are different from those that would arise for surfaces without canonical color associations? The question is difficult to answer empirically because it is one precisely about one's phenomenological experience. But in the last two decades, a small number of studies have supplied rigorous evidence of canonical memory modulating color appearance. I sought to extend these studies to cases of objects with more than one canonical color association (e.g. grapes). But I failed to obtain a memory color effect for any of the stimuli, even those intended to replicate the original effects. Results however demonstrate the shaping of perception along the (L + M) – S axis, the axis which daylight illumination is known to vary along, in what normal trichromats judged to be a neutral, achromatic point. Specifically, subjects typically adjusted familiar objects in the opponent direction of their achromatic points. These biases may explain the appearance of effects in past studies. More broadly, these results point to a need for replication in order to establish a consensus around whether cognition (e.g. memory) does in fact modulate perception.

Introduction

Does knowing that certain objects tend to possess certain colors affect the color appearances of those objects under normal conditions? If one has learned through direct experience that bananas are reliably yellow, for example, then shouldn't this knowledge, alleviate some of the ambiguity inherent in disentangling surface color from lighting properties whenever the object in view is a banana? An effect of canonical object color on appearance is often called a memory color effect (MCE); it is a deeply intuitive place where higher-level cognition ought to modulate perceptual appearance and it has a long history in psychophysics (Hering 1920 [1878]; Adams, 1923; Duncker 1939; Bruner et al., 1951; Harper 1953; Fisher et al., 1956; Newhall et al., 1957. Bolles et al., 1959; Delk and Fillenbaum 1965; Siple and Springer 1983; Yendrikhovskij et al., 1999). Compelling positive evidence for such an effect is harder to obtain than one might at first expect. This is because the effect sought is specifically based upon the subjective color appearance of a surface, what it looks like to an observer. Many behavioral measures may reflect that a participant knows an object's canonical color, without supplying evidence one way or another about how the object looks in that participant's phenomenological experience. (See Firestone & Scholl, 2016 for a discussion of challenges associated with disentangling appearance from other factors in experimental research).

However, a landmark study in 2006 is often cited as overcoming these challenges (Hansen et al., 2006), and it has reinvigorated interest in the memory color effect over the last decade (Olkkonen et al, 2008; Witzel et al, 2011; Kimura et al, 2013; Witzel, 2016) as well as studies and philosophical discussions purporting the influence of cognition on perception (Lupyan and Spivey, 2008; Mitterer and Ruiter, 2008; Prinz & Seidel 2012; Radel & Clément-Guillotin 2012, Banerjee et al. 2012, Cole et al. 2012, Maier at al.,2014; Wakslak & Kim 2015, Léger & Chauvet 2015;

Macpherson, 2012; Stokes, 2013; Gatzia, 2017; Lammers et al., 2017). The foundational insight in the Hansen and colleagues (2006) study involves the use of an adjustment task that always requires participants to adjust a stimulus to a neutral or 'achromatic' gray. In the control trials of the experiment, a participant sees a homogenously colored disc that appears in a random hue, and they are instructed to adjust the color of the disc until it appears colorless, (achromatic, devoid of any hue). In this way, a participant's preferred achromatic locus (PAL) is identified. In the critical trials, the same exact procedure is carried out with a stimulus shaped like an object with a canonical color, a banana for example. The result: participants adjust these stimuli to an achromatic locus that is significantly different from their baselines, one that is in the direction opponent to the object's canonical color. In simple terms, a neutral gray for a banana is not the same as the participant's baseline neutral gray; instead, it is a slightly bluish gray, presumably one selected to erase the vestiges of yellow imposed on the appearance of the object by knowledge and or visual memory of its canonical color (see Figure. 1).

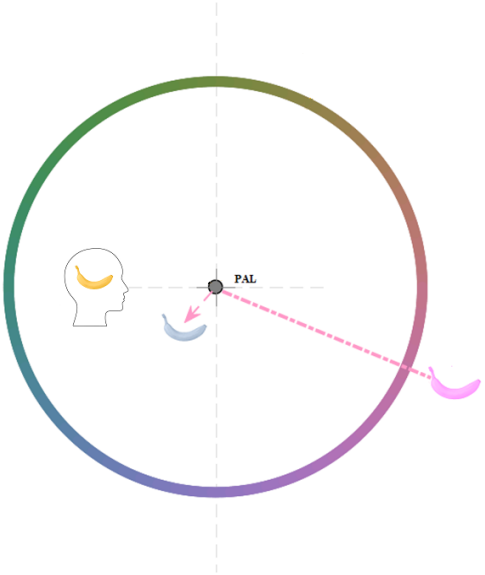


Figure 1. The memory color effect. The circular color wheel represents the hues which can be achieved in an isoluminant color space (DKL color space) upon adjustment. Here, an example of

memory color effect for a banana. At the onset of the trial the banana is presented in a purplish hue. The task is for the participant to adjust the banana until it becomes achromatic, a point that should be close to the origin of the color space. But as the subject adjusts the surface of the banana, the banana's canonical hue –yellow– is activated, causing the subject to adjust the banana towards a slightly bluish hue thereby cancelling this subjective activation.

The memory color effect, while intuitive, is mechanistically difficult to reconcile with the modular view of color perception in general, and color constancy in particular (Fodor 1983; Pylyshyn 1999; Granzier and Gegenfurtner 2012). Recent experiments have begun the process of assimilating the effect into a broader understanding of color perception (Olkkonen et al., 2008; Bae et al., 2015). Here, I sought to further this process by addressing two issues while utilizing the methods of Hansen and colleagues' (2006).

First, I sought to examine the memory color effect for objects with more than one canonical color. Consider grapes for example. Typical supermarket grapes in the West are both green and purple. How do these dueling canonical hues modulate the perception of these stimuli? How does a route that provides for canonical memory to influence perception incorporate more than one canonical association, particularly given highly canonical objects which reliably appear in a secondary canonical (deuterocanonical) color? Ripe bananas are yellow, although seeing green bananas in the store is not unusual. The perceived achromatic locus for objects with two canonical colors, such as grapes, could constrain hypotheses about the mechanisms by which memory influences color appearance.

Second, I sought to examine the perception of achromatic locus for canonical objects appearing from the outset with little chromaticity. In the study of Hansen and colleagues (2006)

the to-be adjusted objects always appeared in a randomly chosen but highly saturated color. Those methods therefore identify what looks achromatic after being exposed to a heavily saturated stimulus. I sought to consider the possibility that something like a conflict signal between the canonical expectation and the random appearance of the object activates the influence of memory on color appearance. Accordingly, I presented objects at starting points with only slight shading, including canonical ones. For example, in these experiments, a banana could appear in a slightly yellow shade of gray. The question was whether participants would still adjust such a stimulus in the blue direction, or whether they would perhaps not find a need to compensate.

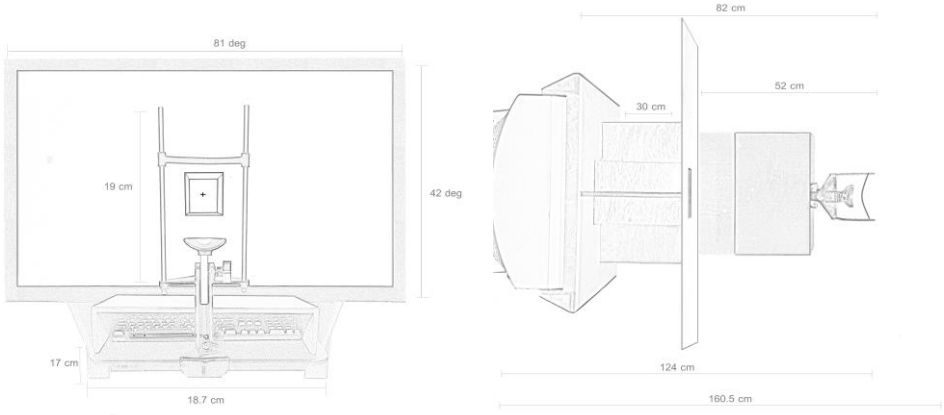
To foreshadow, I ultimately failed to find a memory color effect in any of the conditions I tested, including for the banana, which was measured in order to replicate Hansen and colleagues (2006). I did however find general biases in participants' achromatic adjustments, including for control stimuli, that were projected along the (L + M) – S (blue-yellow) opponent axis, which daylight illumination is known to vary along (Shepard, 1992; Lee, 1999; Wyszecki & Stiles, 2002). I discuss these results in the broader context of a need for high-powered replication of the memory color effect and the interaction between achromatic biases and color perception.

Methods

In general, the methods of this experiment followed closely those of Hansen and colleague (2006).

Apparatus. Stimuli were presented on a Dell D1526HT cathode ray tube (CRT). Color calibration and gamma correction where accomplished using standard procedures (Krauskopf & Li, 1999, p. 3347; Rinner & Gegenfurtner, 2000, p.1815; Hansen et al 2008, p.3), and utilizing a UDT Instruments model 370 optometer with a model 265 photometric filter (mounted atop a Dolica 68" Lightweight Tripod) and a Lighting Passport Pro spectroradiometer. The CRT was

firmly positioned 30cm behind a neutral wall which subtended 81 x 42°, allowing the concealment of the light source. CRT was driven by a NVIDIA Quadro FX 580 graphics card with a color resolution of 8 bits per channel. The spatial resolution of the CRT during the duration of the experiments was 1280 x 1024 pixels with a refresh rate of 85 Hz (11.76 ms per frame). The contrast and brightness were set using the procedures of Poynton (2002). Directly at the center of the wall was an opening which subtended 10.6 x 9° (cf. Rinner & Gegenfurtner, 2000). A rectangular truncated aperture was designed with its exterior and interior homogenously painted using a Clarke and Kensington deep matte black acrylic paint, thereby inhibiting any unsolicited shadows or light reflectance, later connected to the posterior region of the neutral wall directly to the center of the CRT's phosphorescent surface. At the anterior base of the wall extended 17cm horizontally a trapezoid-shaped hand chamber with the exterior and interior pained deep matte black to prevent any reflectance of keypress or any glossy or self-illuminating objects worn by subjects. Inside the hand chamber was fixedly placed a black Dell L100 keypress. Attached to the base of the hand chamber was a black adjustable head and chin rest. The chin rest not only allowed a standardized viewing distance for all subjects at 52 cm, but also a natural demarcation between the left and right-hand. Figure 2. presents detailed drawings of the experimental set up.



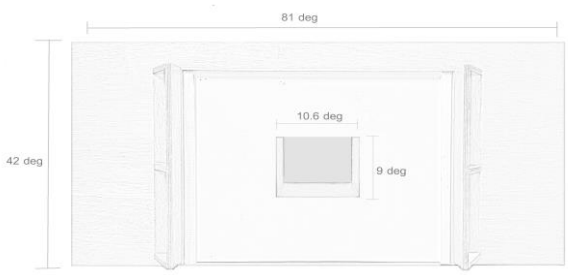


*Figure 2***.** Drawings of the experimental apparatus used in the study and their associated measurements. (a) Observer's view during the experiment (b) an overhead view of the aperture (c) the aperture which was attached to the CRT monitor in order to control the lumaince being emitted to the foveal region of each observer.

Stimuli and procedures. In each trial of part one of the experiment, participants (with normal color vision measured using Ishihara color plates) observed a homogenously colored disc (3x3°). The luminance of a disc was set to 30 cmd−2 while the background was set to 28.632 cmd−2 in order to avoid any color blending strategies (cf. Olkkonen et al., 2008). The disc appeared with a slight hue chosen randomly from within the DKL color space. Note that this color space is modelled the second stage color perception, thereby reflecting the preferences of neurons in the magnocellular, parvocellular and koniocellular pathways of Lateral geniculate nuclei (LGN) in macaques (Derrington et al., 1948). Furthermore, the participant's task was to adjust the hue of the disc until it appeared void of any hue. Adjustments were made by keypress, along the isoluminant L – M (red-green) color opponent axis, using the left arrow and right arrow, or along the isoluminant (L + M) -S (blue-yellow) axis, using the up and down arrows. Participants were also able to modify the pace by which they preferred to move along each axis, toggling between finer and coarser changes by pressing the 'v' and the 't' keys, respectively. In the event a participant was lost within the color space they could press the "q" key, which would reset the

object to the initial color it was presented in. Finally, upon the completion of an adjustment (pressing the "a" key), the chromaticity of each individual pixel – was scaled to the stimulus' new chromatic positions (see Hansen et al., 2006, pg.2, supplementary methods).

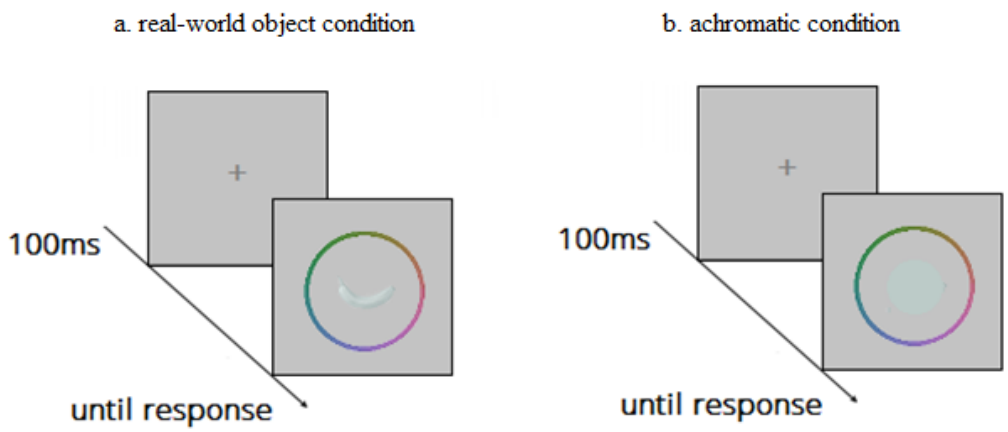


Figure 3. General procedure for Experiment 1 and Experiment 2: A. achromatic condition and B. real-world object condition. Depending on the condition, recruited trichromats were presented with a stimulus and allowed to adjust its surface. The circular ring which was not present during adjustments, denotes the color space which subjects traversed using the assigned keypress.

Trials in part two of the experiment were identical to trials in part one, with the exception that each trial included one of four digitalized photographs of an object (either banana, pear, autumn leaf or grapes) instead of a disc. The banana subtended 6.20° x 4.07°. The grapes and autumn leaf subtended 4.66° x 4.57° and the pear was subtended 4.41° x 5.56°. These images always were set to have the same mean luminance values across their surfaces as the background (28.632 cmd-2). Upon first appearance in a trial, these objects did not appear in a random hue. Instead, they appeared with a slight hue chosen from one of three conditions: In the 'canonical' condition, an object appeared with a slight canonical hue (e.g. grayish yellow in the case of the

banana). In the ‘deuterocanonical’ condition, an object appeared in with a slight hue of a secondary association (e.g. green for a banana). And in the ‘opponent’ condition the item had a slight hue in the opponent direction from its canonical association (e.g. blue in the case of the banana). Although I call them ‘part 1’ and ‘part 2’ their order was counterbalanced in practice across participants. Each participant completed 5 trials in part 1 and 36 trials in part two (equally distributed across objects and conditions). I tested a total of 26 participants. The protocol for this study was approved by the Johns Hopkins University Homewood IRB.

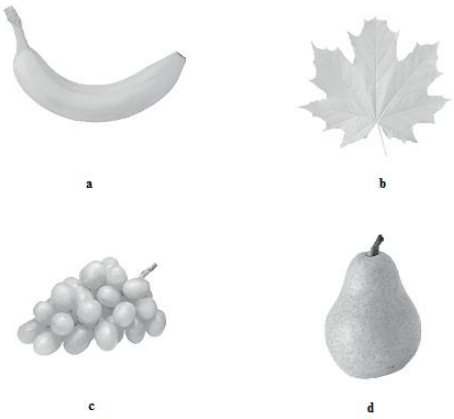


Figure 4. The color diagnostic stimulus used in the study. a. banana. b. autumn leaf. c. grapes and d. pear. Each stimulus was photographed under standard daylight illuminant with the white balance set to 6,500 Kelvin. This prevented any undesired color casting on the photographs.

Results

Consistent with previous studies, in part 1, participants preferred achromatic loci (PAL) were shifted away from the origin of the color space, the expected achromatic locus (EAL). Specifically, 65% of participants reported a PAL biased toward a bluish hue (see also Hansen et al., 2006, pg.1368, figure 2A gray diamond, Olkkonen et al., 2008, pg.5 figure, 3A black squares

and Witzel et al., 2011, pg.38, figure 4A, black stars). However, unlike in previous studies PALs for 34% of participants were yellow biased (see figure 5). To quantitatively measure whether this deviation is projected along a specific chromatic axis (e.g. opponent or orthogonal), a simple linear regression was performed. If for example, chromaticities are projected along the red-green opponent axis, I would expect a negative linear relationship, with a fitted line projected along quadrant IV to quadrant IV of the color space. For all 26 subjects, a line of best fit was projected along the blue-yellow opponent axis. Specifically, $r^2 = 0.81$, $p = 0.022$.

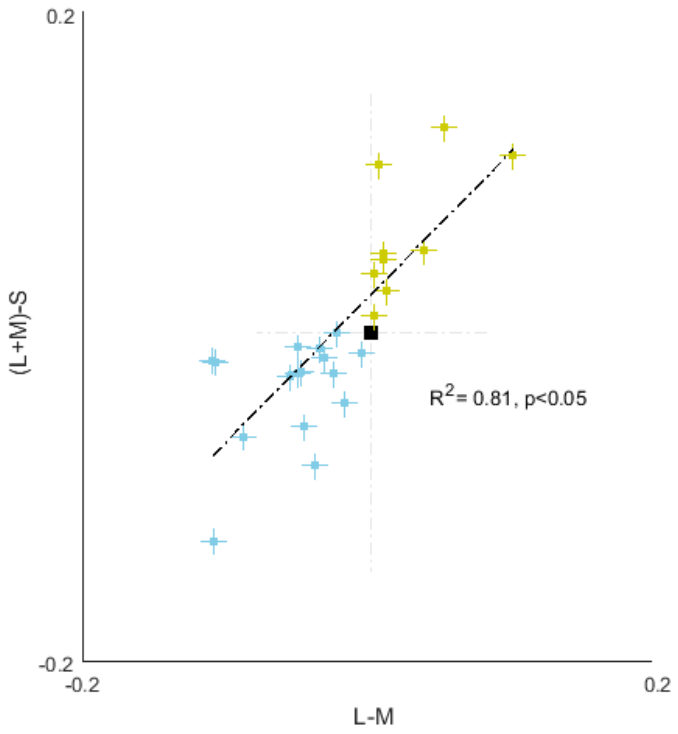


*Figure 5***.** Neutral adjustment for all participants who participated in part 1. bPAL are participants whose PAL were shifted towards a bluish hue, yPAL denote the cohort of participants whose PAL were shifted towards a yellowish hue.

Inconsistent with previous studies, I unable to replicate the memory color effect for any of the measured objects, even those where an effect had been previously reported (see Figure 6).

These results are surprising for two reasons. One, because I was able to replicate PALs biased towards a bluish hue for most participants (n=17), I expected, at least for this cohort, canonical effects similar to those previously reported for participants who also had a PAL shifted towards a bluish hue. Second, because the theory states that when a subject arrives at their PAL, a subjective canonical activation should occur, by carefully tinting the initial hue of each stimulus to a canonical, deuterocanonical opponent-canonical grayish hue, an even stronger effect should have been observed. Instead of the expected results, I observed once again biases along the blue-yellow opponent axis. Here $r^2 = 0.7669$, $p = 0.0096$.

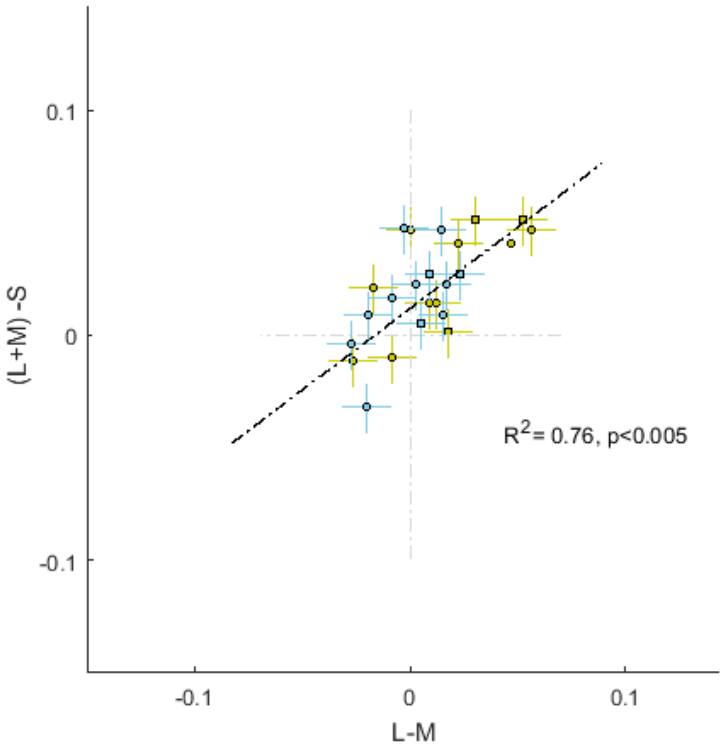


*Figure 6***.** Neutral Adjustments for participant with a shifted for bPAL (blue circle) and yPAL (yellow circle) participants for the four-color diagnostic objects measure in part 2.

I did observe one effect which differentiated again the yPAL and bPAL groups. Specifically, adjustments for *all* objects appeared to be projected in the opposite direction from

the PAL. Thus, yPAl subjects made more blue adjustments for the canonical objects, while bPal subjects made more yellow trending adjustments. (see figure 7a and 7b). This is the only study to date where such effects have been reported.

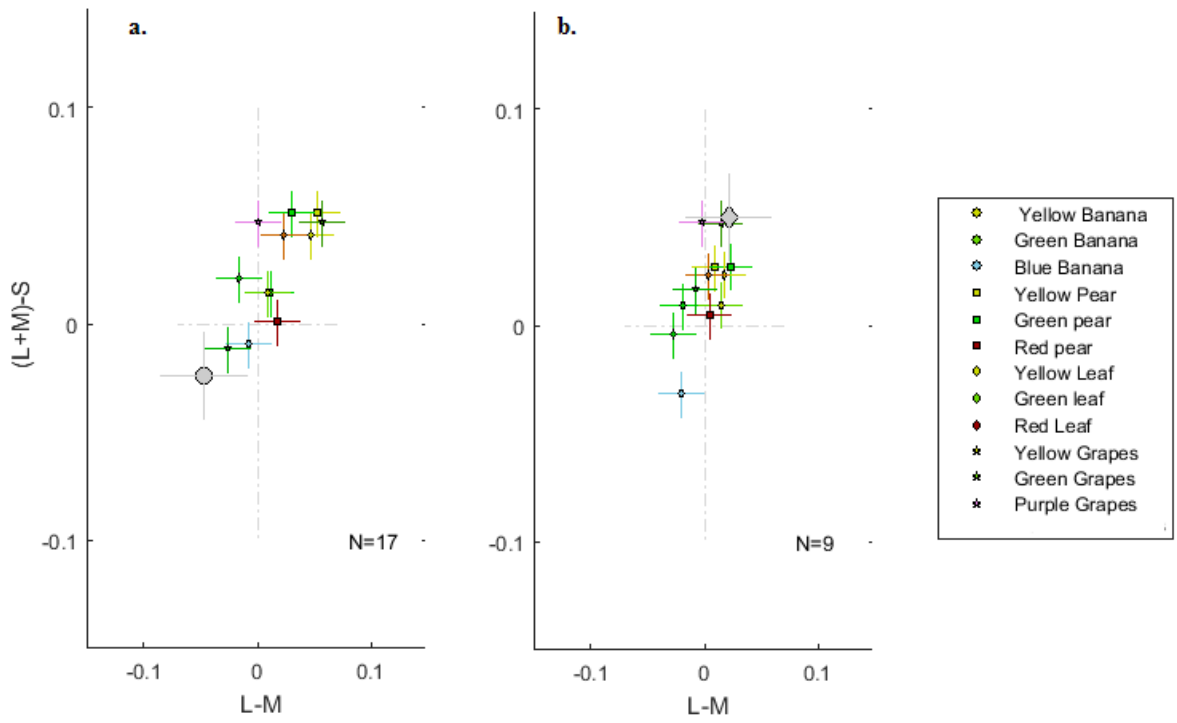


Figure 7. Neutral adjustments for a. bPAL and b. yPAL with respect to the average PAL (gray circle for blue cohort and gray diamond for the yellow cohort) across participants in each cohort.

Illustrated in figure 8, across all objects for the yPAL, a change of 0.0941 away from the average PAL with a SE of 0.0112 was computed. For yPAL a change of 0.0542 with an SE of 0.0110 was observed respectively. To directly measure if this difference is statistically significant, a t-test was conducted which yielded a t=2.5338 with a p value of 0.0191. Because participants

had biased PALs, and canonical object adjustments away from their PALs, their canonical adjustments were also *more similar* to neutral gray, the EAL. Indeed, there was no significant difference for either group between canonical object achromatic loci and the origin of the color space (t = 2.5338 p= 0.4053 for the bPAL group; t= 0.4097 p= 0.6857 for the yPAL group).

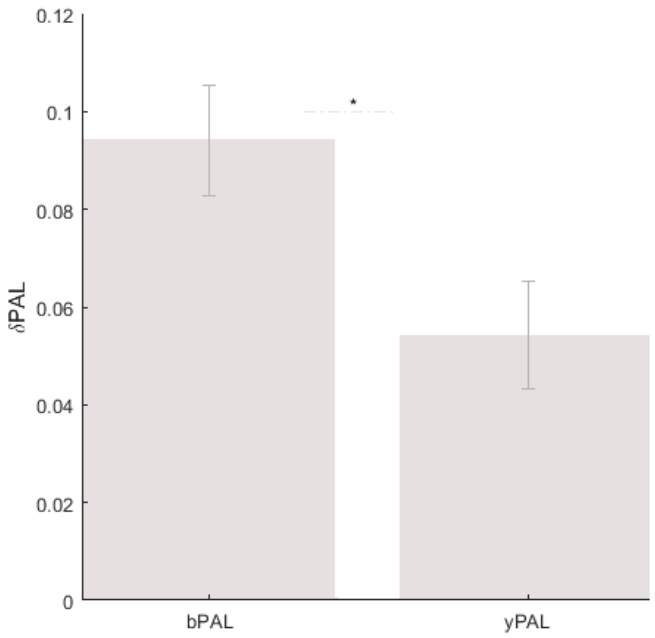


Figure 8. Change in PAL for yPAL and bPAL in part 2.

General Discussion

I sought to extend research on the memory color effect. Here the hypothesis was that the memory color effect could be modulated by the starting color that a canonical object is shown in. In particular, I hypothesized that weakly hued deuterocanonical colors might activate conflicting canonical representations, producing a memory color effect, while weak random or canonical hues might not produce an effect. The hypothesis was based on the possibility that memory color effects

are in a sense, compensatory, active when unlikely or especially ambiguous inputs are present. Unfortunately, I did not observe a clear memory color effect for any of the four objects I tested (see Gross et al., 2014 of another failed attempt to replicate classic memory color effects). This was true even for the banana stimulus for which an effect has been reported previously.

However, I did observe significant bias in the preferred achromatic loci among observers, a bias along the blue to yellow daylight axis. And in surprising contrast, a participant's achromatic locus for an identifiable object of any kind, was biased in the opposite direction from that participant's PAL, i.e. the locus identified with a control disc as the stimulus. Thus, although I did not observe a memory color effect differentiating between the objects and their canonical hues, I did find a change in the perceived achromatic point for control compared to canonical stimuli overall, a change in the canonical cases that seemed to reflect and compensate for an individual's biased preferred achromatic locus.

What should I make of these results? The failure to obtain a memory color effect using previous methods and one of the same stimuli as before suggests a need for direct replication. Note that I did not use highly saturated randomly colored starting positions as Hansen and colleagues (2006) did. However, the results I obtained in the conditions I did run are potentially consistent with the results of Hansen and colleagues in an unexpected way. Scrutinizing those results (see Figure 2b in Hansen et al., 2006) reveals that all the achromatic points for canonical objects in their study fell in quadrant III, specifically along positions that are on the blue-yellow axis. Indeed, all the achromatic canonical end points in that study appeared to be 'bluish'. For example, they included grapes in their study, a green object that should have produced a reddish achromatic final adjustment in the presence of a memory color effect (quadrant IV). The observed color was actually bluish though, albeit a more reddish blue than the blue elicited by some of the other objects

in that study, such as the yellow banana. If, in general, people tend to possess biased achromatic loci, sampling error with small numbers of participants could produce the appearance of a memory color effect where it is actually just a bias, especially if differences in effect sizes between objects are written off as noise. Hansen and colleagues (2006) tested 14 participants. A high powered registered replication would therefore be a welcome addition to the literature on the topic.

What about the biases observed along the blue-yellow axis? These are ultimately the more important, albeit unexpected results of this experiment. Achromatic biases in the blue direction have been documented elsewhere (Brainard, 1998; Olkkonen et al., 2008 Chauhan et al.2013). However, biases in the yellow direction has never been observed, until now. They are predicted however under the theory that biased achromatic loci reflect an attempt to discount a daylight illuminant. Recently, differences between observers in their implied assumed illuminants have attracted attention because of the famous ‘dress’ illusion, where some observers see blue and others see yellow (Winkler et al., 2015; Gegenfurtner et al., 2015; Brainard and Hurlbert, 2015; Lafer-Sousa et al., 2015).

Considering these novel results, a number of unknowns emerge about blue-yellow biases, all of which should be the focus of future studies. One, why do some people possess a bias in one direction and some in the others and are these biases stable over any period of time (see study by Werner and Schefrin, 1993 on achromatic loci across different life spans). Two, how elastic is one’s achromatic locus; can those who possess a blue bias be trained to develop yellow bias or even a bias along the orthogonal axis, where red-green color-blind observers are known to show strong biases. Three, because the human visual system evolved under terrestrial illumination, which is known to shift from bluish illumination in the mornings towards yellowish illumination as the night approaches, what is the relationship between the direction of achromatic biases and

one's cardician rhythm (see study by Wallisch, 2017 on illumination judgments between self-described early birds and night owls). Four, what role does the amount of exposure to sunlight (e.g. Icelandic vs Ecuadorian observers) play in modulating people's achromatic bias? The achromatic adjustment procedure developed for the study of the memory color effect now appears to be a useful for tool for further research into these novel questions, and more generally, for investigating possible interactions between top-down and bottom-up effects on perception.

Ethics

This study was approved by the Johns Hopkins University Homewood IRB and conducted in accordance with the principles noted in the Declaration of Helsinki. Informed consent was also obtained for all participants.

Competing interests

I have no competing interests.

Authors' contributions

I-E.A-O designed the study, conducted and analyzed the research data and wrote the manuscript.

Funding

This research was supported by the Berlin School of Mind and Brain.

References

Adams, G.K. (1923). An experimental study of memory color and related phenomena. *The American Journal of Psychology*, 34, 359–407.

Bae, G.Y., Olkkonen, M., Allred, S. R., Flombaum, J. I. (2015). Why some colors appear more memorable than others: A model combining categories and particulars in color working memory. *Journal of Experimental Psychology: General*, 144, 4, 744-63.

Banerjee, P., Chatterjee, P., Sinha, J. (2012). Is it light or dark? Recalling moral behavior changes perception of brightness. *Psychological Science*, 23, 407– 409.

Brainard, D. H., & Hurlbert, A. C. (2015). Colour vision: Understanding #TheDress. *Current Biology*, 25,13, R551–R554.

Bloj, M., Weiss, D., Gegenfurtner, K.R. (2016). Bias effects of short- and long-term color memory for unique objects. *J. Opt. Soc. Am. A Opt. Image Sci. Vis*, 33, 492–500.

Bolles, R. C., Hulicka, I. M., Hanly, B. (1959). Color judgment as a function of stimulus conditions and memory colour. *Canadian Journal of Psychology/Revue canadienne de psychologie* 13, 175–185.

Bruner, J. S., Postman, L., Rodrigues, J. (1951). Expectation and the perception of color. *The American Journal of Psychology*, 64,216–227.

Cole, S., Balcetis, E., Dunning, D. (2012). Affective signals of threat increase perceived proximity. *Psychological Science*, 24, 34–40.

Delk, J., Fillenbaum, S. (1965). Differences in perceived colour as a function of characteristic colour. *The American Journal of Psychology*, 78,290–93.

Derrington, A. M. Krauskopf, J. Lennie, P. (1984). Chromatic mechanisms in lateral geniculate nucleus of macaque. *The Journal of Physiology*, 357, 241–265.

Duncker, K. (1939). The influence of past experience upon perceptual properties. *The American Journal*, 1939,52, 255–265

Firestone, C., Scholl, B. J. (2016). Cognition does not affect perception: Evaluating the evidence for 'top-down' effects. *Behavioral and Brain Sciences*, 39, 1–19.

Fisher, S.C., Hull, C., Holtz, P. (1956). Past experience and perception: memory color. *The American Journal of Psychology*, 69, 546–560.

Fodor, J. A. (1983). Modularity of mind: An essay on faculty psychology. MIT Press.

Gatzia, D. (2017). Cognitive Penetration and Memory Colour Effects. *Erkenntnis*.

Gegenfurtner, K. R., Bloj, M., Toscani, M. (2015). The many colours of 'the dress'. *Current Biology*, 25,13, R543–R544.

Granzier, J. J. M., Gegenfurtner, K. R. (2012). Effects of memory colour on colour constancy for unknown coloured objects. *i-Perception*, 3, 190–215.

Gross, S., Chaisilprungraung, T., Kaplan, E., Menendez, J., Flombaum, J. (2014). Problems for the purported cognitive penetration of perceptual color experience and Macpherson's proposed mechanism. *Thought and Perception*, 1–30.

Hansen, T., Giesel, M., Gegenfurtner, K. R, (2008). Chromatic discrimination of natural objects. *Journal of Vision*, 8, 1–19

Hansen., Olkkonen, M., Walter, S., Gegenfurtner, K. R., (2006). Memory modulates colour appearance. *Nature Neuroscience*, 9, 1367–1368.

Harper, R. S. (1953). The perceptual modification of colored figures. *The American Journal of Psychology*, 66, 86–89.

Kimura A., Wada Y., Masuda T., Goto S., Tsuzuki D., Hibino H., Dan I. (2013). Memory color effect induced by familiarity of brand logos. *PLoS One* 8, e68474.

Krauskopf J, Li, X. (1999). Effect of contrast on detection of motion of chromatic and luminance

targets: retina-relative and object-relative movement. *Vision Research*, 39, 3346–3350.

Lammers, N.A., de Haan E.H., Pinto, Y. (2017). No Evidence of Narrowly Defined Cognitive Penetrability in Unambiguous Vision. *Front Psychol*. 10, 8, 852.

Lee H. C. (1990). A computational model for opponent color encoding. *Advances Printing of conference summaries, SPSE's 43rd Annual Conference, Rochester*, 1990**,** 178–181.

Lafer-Sousa, R., Hermann, K. L., & Conway, B. R. (2015). Striking individual differences in color perception uncovered by 'the dress' photograph. *Current Biology*, 25(13), R545–R546

Léger, L., Chauvet, E. (2015). When canary primes yellow: Effects of semantic memory on overt attention. *Psychonomic Bulletin and Review* 22:200–205.

Lupyan, G., Spivey, M. J. (2008). Perceptual processing is facilitated by ascribing meaning to novel stimuli. *Current Biology*, 18, R410–12.

Macpherson, F. (2012). Cognitive penetration of colour experience: Rethinking the issue in light of an indirect mechanism. *Philosophy and Phenomenological Research* 84:24-62.

Maier, M., Glage, P., Hohlfeld, A., and Abdel Rahman, R. (2014). Does the semantic content of verbal categories influence categorical perception? An ERP study. *Brain Cogn.* 91, 1–10.

Mitterer H, de Ruiter J P. (2008). Recalibrating colour categories using world knowledge. *Psychological Science*, 19, 629–634.

Newhall, S. M., Burnham, R W., Clark, J. R. (1957). Comparison of successive with simultaneous colour matching. *Journal of the Optical Society of America*,47, 43–54.

Prinz, J. & Seidel, A. (2012). Alligator or squirrel: Musically induced fear reveals threat in ambiguous figures. *Perception*,41,1535–39.

Poynton, C. (2002) Frequently asked questions about gamma, Available at: http://www.poynton.com/PDFS/GammaFAQ.,pdf.

Pylyshyn, Z. (1999). Is vision continuous with cognition? The case for cognitive impenetrability of visual perception. *Behavioral and Brain Sciences*, 22,3,341– 65.

Radel, R. & Clément-Guillotin, C. (2012). Evidence of motivational influences in early visual perception: Hunger modulates conscious access. *Psychological Science*, 23, 232–34

Rinner, O. Gegenfurtner, K. R. (2000). Time course of chromatic adaptation for color appearance and discrimination. *Vision Research*, 40, 1813–1826.

Shepard, R. N. (1992). The perceptual organization of colors: An adaptation to regularities of the

terrestrial world? In J. Barkow, L. Cosmides, & J. Tooby, (Eds.), The adapted mind (pp. 495–532). Oxford, UK: Oxford University Press.

Siple, P., Springer, R. M. (1983). Memory and preference for the colors of objects. *Perception & Psychophysics*, 34, 363–370.

Stokes, D. (2013) Cognitive penetrability of perception. *Philosophy Compass* 8,7, 646- 663.

Wakslak, C. J. & Kim, B. K. (2015). Controllable objects seem closer. *Journal of Experimental Psychology: General*, 144, 522–27.

Wallisch, P. (2017). Illumination assumptions account for individual differences in the perceptual interpretation of a profoundly ambiguous stimulus in the color domain: "The dress". *Journal of Vision*. 17,4,5, 1-14.

Werner, J.S., Schefrin, B.E. (1993). Loci of achromatic points throughout the life span *Journal of the Optical Society of America. A. Optics and Image Science*, 10,1509-1516.

Winkler, A. D., Spillmann, L., Werner, J. S., & Webster, M. A. (2015). Asymmetries in blue-yellow color perception and in the color of 'the dress'. *Current Biology*, 25 (13), R547–R548.

Witzel, C., Valkova, H., Hansen, T. & Gegenfurtner, K. R. (2011). Object knowledge modulates colour appearance. *i-Perception*, 2,1,13–49.

Witzel, C., (2016). Easy way to show memory color effect. *iPerception*, 7, 1–11.

Wyszecki, G., Stiles W. S. (2000). Color Science: Concepts and Methods, Quantitative Data and Formulae 2nd edition (New York, NY: John Wiley & Sons)

Yendrikhovskij., S. N., Blommaert, F. J. J., Ridder, H. D. (1999). Representation of memory prototype for an object color. *Color Research & Application*, 24, 393–410.