Top-down knowledge affects perception when the input is ambiguous

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Abstract

Does what we see depend on what we know? Although many published findings have provided evidence that knowledge can affect perception, methodological and conceptual flaws render these findings inconclusive. The centerpiece of this debate is memory color, a phenomenon in which objects with a canonical color (e.g., a banana) appear colored even when depicted in greyscale. But prior reports of memory color are marred by methodological problems, small effect sizes, and replication failures. Here, we report a novel case of memory color that avoids these methodological problems and has a large effect size that is easy to replicate, putting this long-running debate to rest with a definitive demonstration that knowledge can indeed affect perception, when the stimulus is ambiguous.

Prior studies have reported many cases in which knowledge is claimed to affect perception: considering unethical and immoral acts supposedly makes the world appear darker (1), positive words appear brighter than negative words (2), and wearing a heavy backpack allegedly makes a hill look steeper (3, see 4 for a review). However, each of these examples, and many others like them, have been criticized for methodological problems, replication failures, and there being no clear instance of an example that can be perceived as a "subjectively appreciable demo" (5, pg. 66; 6-7). Thus, no undisputed examples exist of top-down effects on perception.

Here, we provide one such example. Specifically, we created a novel variant of the memory color effect where grey items look like their canonical color (e.g., a grey banana looks faintly yellow) (8,9). To achieve this affect, we presented grey items under a globally ambiguous viewing condition: very dim, mesopic light (sometimes referred to as twilight vision; Figure 1A and Supplement)[1]. We theorized that when visual input is sufficiently ambiguous, top-down knowledge will play a larger role in perception since the visual system will rely on that prior knowledge to disambiguate the sensory input. Thus, we predicted clear memory color effects under dim lighting conditions, but not under bright light where the sensory signal is unambiguous. A series of control conditions then tested other possible explanations of our effect, specifically experimental task demands, which have plagued previous studies of top-down effects on perception (5,6).

Results

In Experiment 1, we showed 15 participants 16 highly familiar items rendered in grey under both dim and bright light (Figure 1A; Supplement). After being shown each stimulus, participants were asked:

[1] A similar approach was taken by Elliott and Cao (15) who found instances of color perception under certain scotopic lighting conditions, which is generally thought to be impossible. However, the finding sin that study differ from this study in two key ways. First, they showed stimuli under scotopic light whereas we showed stimuli under mesopic light. In addition, and more importantly, many of the stimuli in that study were unfamiliar to participants (e.g., unknown textures and simple rings without any associated colors), thus, the memory color effect could not be driving those results.

Question 1: “Does it look like this image is in black and white or does it look like it is in color? It may be subtle or muted, and it doesn’t have to necessarily be as vivid as it normally appears, but is there any appearance of color?”

Question 2: “What color(s) do you see?”

Question 3: “On a scale of 1-5, how would you rate your experience? 1: I am not confident I see color. 5: It definitely appears colorful. It is not just black and white.”

Only trials where participants said “yes” to question 1 and claimed to see the correct color of an object (i.e., calling a Stop sign red) were counted as appearing colorful (although no participant ever stated the wrong color). Consistent with our predictions, participants reported strong memory color effects under dim light but not bright light (Figure 1B). Moreover, unlike prior studies that largely found memory color effects along the blue/yellow axis (8-11), we found the effect with numerous colors (e.g., purple, red, green, etc., Figure 2).

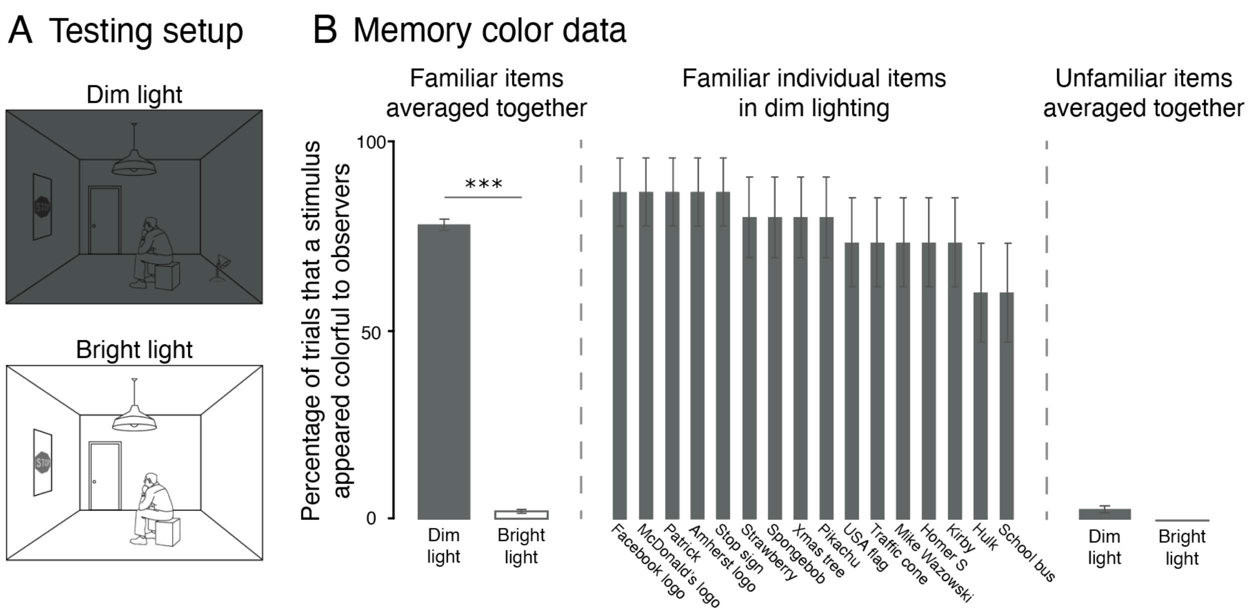

Figure 1. Experimental setup and behavioral results. A) Participants sat in a ~3x4 meter room isolated from outside light interference. In the dim light condition, one lamp with a white LED light bulb was placed behind the participant and was covered with a black cloth. In the bright light condition, the overhead light in the room was turned on. B) Memory color data. The vertical axis represents the percentage of trials in which a stimulus appeared colorful in each condition: (left panel) the familiar items after averaging across stimuli and participants, (center panel) the familiar items when examining each individual stimulus across participants, and (right panel) the unfamiliar items after averaging across stimuli and participants.

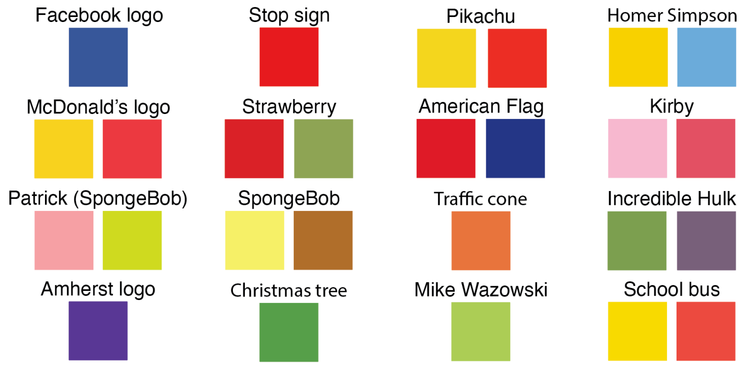

Figure 2. An approximation of the colors of the 16 objects. Every color for which at least one observer named that color is represented (e.g., the red strawberry and the green stem, Homer Simpson's yellow skin and blue pants, etc.). The items are ordered from strongest memory color effect to weakest (see Figure 1B center panel).

In Experiment 2, we replicated prior studies (12) finding no memory color effect in either lighting condition with *unfamiliar* stimuli using the same procedures as Experiment 1 (Figure 1C; Supplement). In Experiment 3, we partially occluded each familiar item such that only small portions were visible and participants could not identify them. However, before giving a response, participants were told the underlying identity of each item (e.g., "It's an occluded Stop sign"). Again, the same procedures as Experiments 1 and 2 were followed. Under an extreme view of top-down knowledge affecting perception, simply knowing an item's identity could lead to the memory color effect. Here, however, no participant ever reported perceiving color with occluded items under dim lighting (Supplement). This result suggests that although top-down knowledge can induce a memory color effect, it cannot do so in the abstract alone; there must be sufficient visual input that such knowledge can act upon.

Experiments 2 and 3 also rule out the possibility that the findings in Experiment 1 can be attributed to the experimental demand characteristics of the task (5,6,13). Under this view, participants may have reported seeing color because they guessed the true purpose of the experiment and wanted to comply with the experimenter's objectives. However, the demand characteristics between Experiments 1, 2, and 3 are seemingly identical. In every experiment, observers make subjective verbal reports, are aware that the experiment is about color, and so forth. Moreover, in both Experiments 1 and 3, observers also know the identity of the underlying object (seeing it in Experiment 1 and being told what it is in Experiment 3). If the results in Experiment 1 were simply due to experimental demand characteristics, they should also be found to some degree in both Experiments 2 and 3. The fact that no such effects were found in either experiment suggests that the memory color effect observed in Experiment 1 is unlikely due to experimental demand characteristics.

Discussion

Overall, we find a robust memory color effect when stimuli are shown in a sufficiently ambiguous situation. We argue these effects appear in ambiguous situations because those are the instances where prior knowledge can help disambiguate an underdetermined sensory signal. Previous studies may have found no effect (or a smaller effect) because the stimuli were presented without sufficient ambiguity (8-13). Interestingly, among studies that found memory color effects through achromatic adjustment on bright computer displays, the effects are largely restricted to canonically yellow objects (8-11). These results can be explained by an inherent ambiguity over blue and yellow — the daylight colors — and a tendency to attribute blueness to the lighting rather than the surface when judging near-grey surfaces, leading to the perception of surfaces being yellower than they actually are (10,14). Here, however, we demonstrate memory color effects for many objects off the blue/yellow axis, including purple, red, green, etc. (Figure 2). Therefore, printing the stimuli on poster paper and presenting them in dim lighting was critical, as it allowed us to generate globally ambiguous viewing conditions.

While we believe this is a clear example of top-down factors affecting perception, we do not believe that all other prior claims of knowledge affecting perception are accurate. Indeed, we agree with many of the critiques of these prior studies and are similarly skeptical of these findings (5-7). What differentiates this study from previous studies showing top-down factors affecting perception? One possibility is that filling-in the specific color of an object (e.g., the specific blue of the Facebook logo) is a relatively simple computational problem for the visual system to solve relative to, say, making the entire world look darker (1) or making a hill look steeper when a person is wearing a heavy backpack (3). In each of those cases, there is considerable variability in the sensory input (e.g., the overall lighting and shading conditions, how steep the hill initially looks, etc.), making it harder for the visual system to alter the percept. It should be noted, however, that the idea of knowledge affecting perception when the input is ambiguous may also extend to other perceptual domains beyond color. Going forward, future studies could examine the extent to which this principle generalizes in the search for more examples of top-down factors affection perception.

Acknowledgements

Thanks to Arash Afraz, Bevil Conway, Sarah Cormiea, Nancy Kanwisher, and N. Apurva Ratan Murty, for helpful discussions. This work was supported by the Templeton World Charity Foundation Grant TWCF-2022-30267 to M.A.C. and the Canadian Institute for Advanced Research to M.A.C.

References

1. Banerjee, P., Chatterjee, P., & Sinha, J. (2012) Is it light or dark? Recalling moral behavior changes perception of brightness. Psych. Sci. 23, 407-409.
2. Meier, B.P, Robinson, M.D., Crawford, L.E., & Ahlvers, W.J. (2007) When “light” and “dark” thoughts become light and dark responses: Affect biases brightness judgments. Emotion, 7, 366-376.
3. Bhalla, M., & Proffitt, D. R. (1999). Visual-motor recalibration in geographical slant perception. J. Exp. Psychol. Hum. Percept. Perform. 25, 1076–1096
4. Vetter, P., & Newen, A. (2014). Varieties of cognitive penetration in visual perception. Conscious. Cogn. 27, 62-75. 24, 930-944.
5. Firestone, C. & Scholl, B.J. (2016). Cognition does not affect perception: Evaluating the evidence for “top-down” effects. Behav. Brain. Sci. e229, 1-77.
6. Durgin, F. H., Baird, J. A., Greenburg, M., Russell, R., Shaughnessy, K., & Waymouth, S. (2009). Who is being deceived? The Experimental demands of wearing a backpack. Psychon. Bull. Rev. 16, 964–969.
7. Block, N. (2023) The border between seeing and thinking. Oxford University Press.
8. Hansen, T., Olkkonen, M., Walter, S., & Gegenfurtner, K.R. (2006) Memory modulates color appearance. Nat. Neurosci. 9, 1367-1368.
9. Olkkonen, M., Hansen, T., & Gegenfurtner, K. (2008). Color appearance of familiar objects: Effects of object shape, texture, and illumination changes. Journal of Vision, 8, 1– 16.
10. Witzel, C., Olkkonen, M., & Gegenfurtner, K.R. (2018) A Bayesian model of the memory color effect. iPerception. 9, 1-16.
11. Adeyefa-Olasupo, I-E. & Flombaum, J.I. (2018) Tutorial review: Evidence for memory color effect, 1923-2016. PsyArXiv. doi:10.17605/OSF.IO/5DW4G.
12. Kimura, A., Wada, Y., Masuda, T., Goto, S-I., Tsuzuki, D., Hibino, H., Cai., & Dan, I. (2013) Memory color effect induced by familiar of brand logos. PLoS One. 8, e68474
13. Valenti, J.J. & Firestone, C. (2019) Finding the “odd one out”: Memory color effects and the logic of appearance. Cognition. 191, 103934.
14. 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, R547-8.
15. Elliott, S.L. & Cao, D. (2009) Scotopic hue percepts in natural scenes. Journal of Vision. 13, 1-13

SUPPLEMENTARY MATERIALS

Top-down knowledge affects perception when the input is ambiguous

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Stimuli: Stimuli for Experiment 1 were chosen such that the color of each item was highly familiar to all participants. These images were chosen after extensive pilot testing on the Amherst College campus and deemed to be the most reliably familiar to this specific undergraduate population. After the items were chosen during pilot testing, the data reported in the main text was then obtained in all three Experiments in a new set of participants who were not involved in pilot testing. The familiar stimuli were:

1. Facebook logo
2. McDonald's logo
3. Patrick Star (from SpongeBob SquarePants)
4. Amherst College logo
5. Stop sign
6. Strawberry
7. SpongeBob SquarePants
8. Christmas Tree
9. Pikachu from Pokémon
10. American Flag
11. Traffic Cone
12. Mike Wazowski from Monsters, Inc.
13. Homer Simpson
14. Kirby the video game character
15. The Incredible Hulk
16. A school bus

The unfamiliar stimuli for Experiment 2 were comprised of 16 images that came entirely from American sports:

1. University of Alabama football helmet
2. University of Georgia football helmet
3. University of Michigan football helmet
4. University of North Carolina football helmet
5. Buffalo Bills football helmet
6. Cincinnati Bengals football helmet
7. Clemson University football helmet
8. Green Bay Packers football helmet
9. Kansas City Chiefs football helmet
10. Minnesota Vikings football helmet
11. New York Jets football helmet
12. New York Giants football helmet
13. San Francisco 49ers football helmet
14. Los Angeles Dodgers baseball hat
15. New York Mets baseball hat
16. Oakland A's baseball hat

These images were chosen because they are unfamiliar to participants who are not fans of American football and baseball.

All stimuli were printed out on large poster paper and hung on the wall. Each stimulus was presented one at a time ~1.5 meters from participants.

For Experiment 3, the same stimuli were used as in Experiment 1. However, in this case, several sheets of paper were placed on top of each individual print out such that only small portions of the item were visible. The only exception to this was the strawberry, which had to be removed from this Experiment since the majority of participants could identify it based solely on its texture.

For all Experiments the lighting conditions were measured using a spectroradiometer (SpectraScan PR-670) and the Macbeth white card. The white point for the dim light condition was *CIE XYZ* = [0.382 0.349 0.136]. The white point for the bright light condition was *CIE XYZ* = [105.9 102.0 50.54]. Luminance values of the stimuli varied from 0.048 cd/m^2 (darkest surface) to 0.24 cd/m^2 (brightest surface) under dim light, and 11.89 cd/m^2 to 130.3 cd/m^2 under bright light.

Participants: 15 participants completed Experiment 1 in the familiar items condition. 15 different participants completed Experiment 2 in the unfamiliar items condition. 15 different participants completed Experiment 3 in the occluded conditions. All participants were students from Amherst College who had normal or corrected-to-normal vision, no known neurological conditions, and passed the Ishihara color test (Birch, 1997). The Experimental procedure was approved by the Institutional Review Board at Amherst College and informed consent was obtained from each participant, who were compensated for their time.

Procedures: Note: Some of these procedures are also reported in the main text and are reproduced here for clarity of this supplement. Participants entered the room with none of the target stimuli visible in order to keep them ignorant of each item's true color (i.e., greyscale) and were given sufficient time for their eyes to adapt to the dim light. Each stimulus was shown one at a time and was presented in a randomized order between participants. After being shown each stimulus, participants were asked a scripted series of questions about the appearance of each image:

> **Question 1:** "Does it look like this image is in black and white or does it look like it is in color? It may be subtle or muted, and it doesn't have to necessarily be as vivid as it normally appears, but is there any appearance of color?"
>
> **Question 2:** "What color(s) do you see?"
>
> **Question 3:** "On a scale of 1-5, how would you rate your experience? 1: I am not confident I see color. 5: It definitely appears colorful. It is not just black and white."

For trials where participants said they had no sense of color in response to question 1, questions 2 and 3 were subsequently skipped. Only trials where participants claimed they did have a sense of color with the correct real-world color (i.e., a red and blue American flag) were considered as having produced the memory color effect.

The bright light condition always came last in order to prevent observers from knowing that the images were greyscale in reality.

Once the dim lighting condition was completed, each participant was asked to evaluate how familiar they were with the color of each item in everyday life. Specifically, they were asked:

> "Please rate on a scale from 1-5 how well you can imagine the specific color of each of these items."
>
> 1. "I am not familiar with the color(s) of this image."
>
> 3. "I can imagine the color(s) of this image, although I don't know the exact shade per se."
>
> 5. "I can imagine the specific shade(s) of color(s) for this image."

Memory color results:

<u>*Experiment 1*</u>*:* To binarize whether a participant saw a stimulus in color or not, we counted every instance when a participant answered Question 1 in the affirmative in response to being asked if they had seen color (i.e., as a 1) and every time they answered it in the negative as them having not seen color (i.e., as a 0). The results from this binarization are shown in the main text in Figure 1B. The results of these process are:

> *Dim light:* mean: 78%, standard error of the mean: 3%
> *Bright light:* mean: 2%, standard error of the mean: 1%

The results obtained based on the 1-5 rankings regarding the strength of the effect for trials in which a memory color effect was observed were:

> *Dim light:* 4.08, standard error of the mean: 0.08
> *Bright light:* 0.34, standard error of the mean: 0.19

The memory color effect was also quantified across participants for each individual item. For each item, the mean and standard error are reported below.

1. The Facebook logo — mean: 87%, standard error of the mean: 9%
2. The McDonald's logo — mean: 87%, standard error of the mean: 9%
3. Patrick Star from SpongeBob SquarePants — mean: 87%, standard error of the mean: 9%

4. The Amherst logo — mean: 87%, standard error of the mean: 9%
5. A Stop Sign — mean: 87%, standard error of the mean: 9%
6. Pikachu from Pokémon — mean: 80%, standard error of the mean: 11%
7. A strawberry — mean: 80%, standard error of the mean: 11%
8. SpongeBob SquarePants — mean: 80%, standard error of the mean: 11%
9. A Christmas tree — mean: 80%, standard error of the mean: 11%
10. The American flag — mean: 73%, standard error of the mean: 12%
11. A traffic cone — mean: 73%, standard error of the mean: 12%
12. Mike Wazowksi from Monsters, Inc. — mean: 73%, standard error of the mean: 12%
13. Homer Simpson — mean: 73%, standard error of the mean: 12%
14. Kirby the video-game character — mean: 73%, standard error of the mean: 12%
15. The Incredible Hulk — mean: 73%, standard error of the mean: 12%
16. A school bus — mean: 73%, standard error of the mean: 12%

Familiarity results: In Experiment 1, the mean familiarity score was 4.65 with a standard error of the mean of 0.06.

Experiment 2: The same analysis procedures for Experiment 2 were used as in Experiment 1. In this Experiment, 9 trials were excluded because participants were familiar with the color of the logos (three participants knew the colors for the New York Giants, two knew the Los Angeles Dodgers, two knew the New York Jets, one knew the Kansas City Chiefs, and one knew the University of North Carolina). The results from this binarization are shown in the main text in Figure 1B. The results of these process are:

Dim light: mean: 3%, standard error of the mean: 1%
White light: mean: 0%, standard error of the mean: 0%

The results obtained based on the 1-5 rankings regarding the strength of the effect for trials in which a memory color effect was observed were:

Dim light: 0.56, standard error of the mean: 0.23
Bright light: 0, standard error of the mean: 0

Familiarity results: For all trials that were not excluded (see above), participants rated their familiarity as a 1 (i.e., "I am not familiar with the color(s) of this image.").

Experiment 3: The same analysis procedures for Experiment 3 were used as in Experiments 1 and 2. In terms of the memory color effect:

Dim light: mean: 0%, standard error of the mean: 0%
Bright light: mean: 0%, standard error of the mean: 0%

Familiarity results: In Experiment 3, the mean familiarity score was 4.65 with a standard error of the mean of 0.06 (same as in Experiment 1).