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SHORT REPORT

The role of memory color in visual attention

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Abstract

The expected color of an object influences how it is perceived. For example, a banana in a greyscale photo may appear slightly yellow because bananas are expected to be yellow. This phenomenon is known as the memory color effect (MCE), and the objects with a memory color are called “color-diagnostic.” The MCE is theorized to be a top-down influence of color knowledge on visual perception. However, its validity has been questioned because most evidence for the MCE is based on subjective reports. Here a change detection task is used as an objective measure of the effect and the results show that change detection differs for color-diagnostic objects. Specifically, it was predicted and found that unnaturally colored color-diagnostic objects (e.g., a blue banana) would attract attention and thus be discovered more quickly and accurately. In the experiment, two arrays alternated with the target present in one array and absent in the other while all other objects remained unchanged. Participants had to find the target as quickly and accurately as possible. In the experimental condition, the targets were color-diagnostic objects (e.g., a banana) presented in either their natural (yellow) or an unnatural (blue) color. In the control condition, non-color-diagnostic objects (e.g., a mug) were presented with the same colors as the color-diagnostic objects. Unnaturally colored color-diagnostic objects were found more quickly, which suggests that the MCE is a top-down, preattentive process that can influence a nonsubjective visual perceptual task such as change detection.

Keywords Memory color effect (MCE) · Color perception · Visual attention · Change detection · Flicker paradigm · Diagnostic color · Canonical color

The memory color effect (MCE) is often cited as strong evidence for top-down influence of object knowledge on perception (e.g., Valenti & Firestone, 2019). However, its existence is controversial as much of the evidence in its favor is based on subjective reports, as is the case with many purported top-down effects (Firestone & Scholl, 2016). The present study evaluates the role of memory color in visual attention using a change detection task comparing objects that have a memory color (e.g., a yellow banana; here labelled color-diagnostic objects) to objects that can be any color (e.g., mugs or mittens; non-color-diagnostic objects).

In the MCE, the knowledge of an object’s expected color influences how it is seen: In colored pictures, a color-diagnostic object’s color appears to be more saturated than it is, and in greyscale pictures, it appears slightly tinted in its diagnostic color (e.g., Adams, 1923; Delk & Fillenbaum, 1965). A memory color is based on semantic knowledge gained through experience (Kimura et al., 2013) and most color-diagnostic objects are items found in nature where their coloration tends to be consistent, like fruits and vegetables. It is less common for manufactured objects to have a consistent, diagnostic color, as they are typically produced in a wide variety of colors. However, through repeated exposure, specific colors can be associated to novel objects (Adams, 1923) or manufactured objects such as stop signs and brand logos (Kimura et al., 2013; Witzel et al., 2011).

Experimental evidence for the MCE dates to the 1920s with a study by Adams (1923), in which participants viewed an image of a blue jar over the course of several weeks. They were then shown an identical image in greyscale and asked to remember its color, and many reported that it looked slightly blue or purple. Since then, other researchers have attempted to refine and expand on Adams’ methodology

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to account for confounds of memory, participant accommodation, and experimenter mediation (e.g., Delk & Fillenbaum, 1965; Hansen et al., 2006). While these studies present strong evidence for the MCE, questions remain about its validity. Many MCE studies (e.g., Hansen et al., 2006; Lupyan, 2015; Olkkonen et al., 2008; Witzel et al., 2011) relied on the participants' direct report of their color perception, leaving the results vulnerable to experimenter and participant expectations.

There is a continuing debate over whether semantic knowledge in the MCE interacts with sensory signals directly or with the later process of interpreting and responding to the stimuli (Valenti & Firestone, 2019). Many of these concerns were addressed in fMRI experiments by Bannert and Bartels (2013) and Vandenbroucke et al. (2016); both found that activity in the early visual cortex could predict the expected colors of greyscale or ambiguously colored versions of color-diagnostic objects. These studies strongly support a top-down MCE on early visual areas. Notably, Bannert and Bartels (2013) demonstrated that MCE occurs even when attention is consciously directed away from the objects' identities; this greatly reduces the likelihood of conflating perception with judgement (Firestone & Scholl, 2016).

The present study examines the interaction between memory color and visual attention using a change detection task. In this task, participants look for objects that appear or disappear so that they do not attend consciously to their identities or colors. It explores whether the MCE affects the serial search process typically required by this attentional task (Rensink, 2000). This allows an examination of the MCE without relying on participants' direct report of color, thus eliminating some of the potential confounds previously discussed.

In a typical change detection task (the flicker paradigm, see Rensink, 2000, 2001), two identical images alternate back and forth with one detail differing between them. Our study uses this flicker paradigm where only one object (the target) changes between the two alternating images: The target is present in one array and absent in the other. The participants must locate the target as quickly as possible. As in all change detection tasks, attention must land on the target before its change can be detected (Hughes et al., 2012; Rensink, 2000; Rensink et al., 1997; Schankin et al., 2017). Rensink (2000) demonstrated that response time increases linearly with the number of items present in the array, indicating that participants must serially attend to the objects in turn until they land upon the changing target. However, this serial search process can be altered if a target has features that draw attention to itself (a phenomenon called attentional capture; Theeuwes, 1994). Specifically, a unique color or an abrupt onset is very effective at guiding search to the target and significantly speeding the otherwise slow, serial process (Scholl, 2000). When attention is captured or drawn to a stimulus, it means that it has properties that are processed prior to the arrival of attention (preattentively), drawing attention to that location for further analysis. Importantly, objects in unexpected contexts, or with unexpected features, can also capture attention in change detection and change blindness tasks (Horstmann & Ansorge, 2016; Lapointe & Milliken, 2016; Mudrik et al., 2011; Underwood et al., 2008).

The experiments here address whether an unnaturally colored object (e.g., a blue banana) can draw attention in a change detection task. If so, it would provide evidence that an expected color (the MCE, a top-down semantic effect) can influence preattentional processing even when the task requires no processing of color or object identity. To examine this, change detection performance when the target object had its natural, expected color (e.g., a yellow banana) is compared with performance when it had an unnatural, unexpected color (e.g., a blue banana). The change detection task required only detecting which object appeared or disappeared without any processing of its color or identity. It is assumed that color-diagnostic objects presented in an unnatural color are unexpected, and therefore, will capture attention and be detected more quickly and more accurately. On the contrary, because color-diagnostic objects presented in their natural color are as expected, they will not capture attention and will only be detected via slower serial search.

Methods

Participants

Participants were 28 undergraduate students from Glendon College, York University, Toronto, Canada. There were 24 females and four males, 25 of whom were between 18 and 23 years of age, and three were 27 or older. All had normal or corrected-to-normal vision, including normal color vision. They were recruited via mass email and received one bonus mark in their course in return for their participation. They gave informed consent, and the study was approved by the Glendon Psychology, Delegated Ethics Research Review Committee, York University. As such, all methods of study were carried out in accordance with the declaration of Helsinki guidelines and regulations of 2003.

Materials

The experiment was conducted on TELLab (https://lab.tellab.org/), a web-based platform that hosts modifiable templates for psychology experiments. The "Change Detection" module was used to create a customized "flicker" paradigm task. The experiment was completed on the participants' personal computers and at their chosen time. Since each participant used a different computer, the screen size and viewing distance varied.

Twenty-eight objects were chosen (Fig. 1): half of them were color-diagnostic (clover, pencil, pinecone, basketball, avocado, strawberry, chocolate, banana, pumpkin, ladybug, toilet paper, road sign, rubber duck, and carrot) and half were non-color-diagnostic (baseball cap, mitten, bird, butterfly, snake, stapler, bottle, mug, comb, teapot, beetle, tulip, daisy, and fish). (Natural and man-made objects were included in both categories.) Each object was depicted by a realistic photograph as evidence suggests that the MCE is stronger and more reliable when using natural photos as opposed to drawings or outlines (Olkkonen et al., 2008).

Each color-diagnostic object was duplicated and given an unnatural "odd" color. This resulted in two color sets (Fig. 2): one set with a restricted color range as determined by the natural colors of color-diagnostic objects (e.g., a banana is yellow, chocolate is brown), and one set with a wider color range as required to make the unnatural colors sufficiently "odd" (noticeably different from the natural colors). Because the natural and unnatural color sets were different, control conditions were included to determine their effect on response time. The targets in the control conditions were non-color-diagnostic objects that can be found in many different colors (e.g., mugs, mittens). They were presented in colors matched to the natural and unnatural color sets of the color diagnostic objects. The objects' sizes and intensities were reasonably well matched across conditions and the details are available in the Supplemental Materials (https://osf.io/a3xm5/wiki/home/).

All objects were presented as targets except for the carrot, snake, pencil, stapler, pinecone, fish, pumpkin, and butterfly; these were always distractors. In total, 20 objects were used as targets. Each of the 20 targets was presented twice

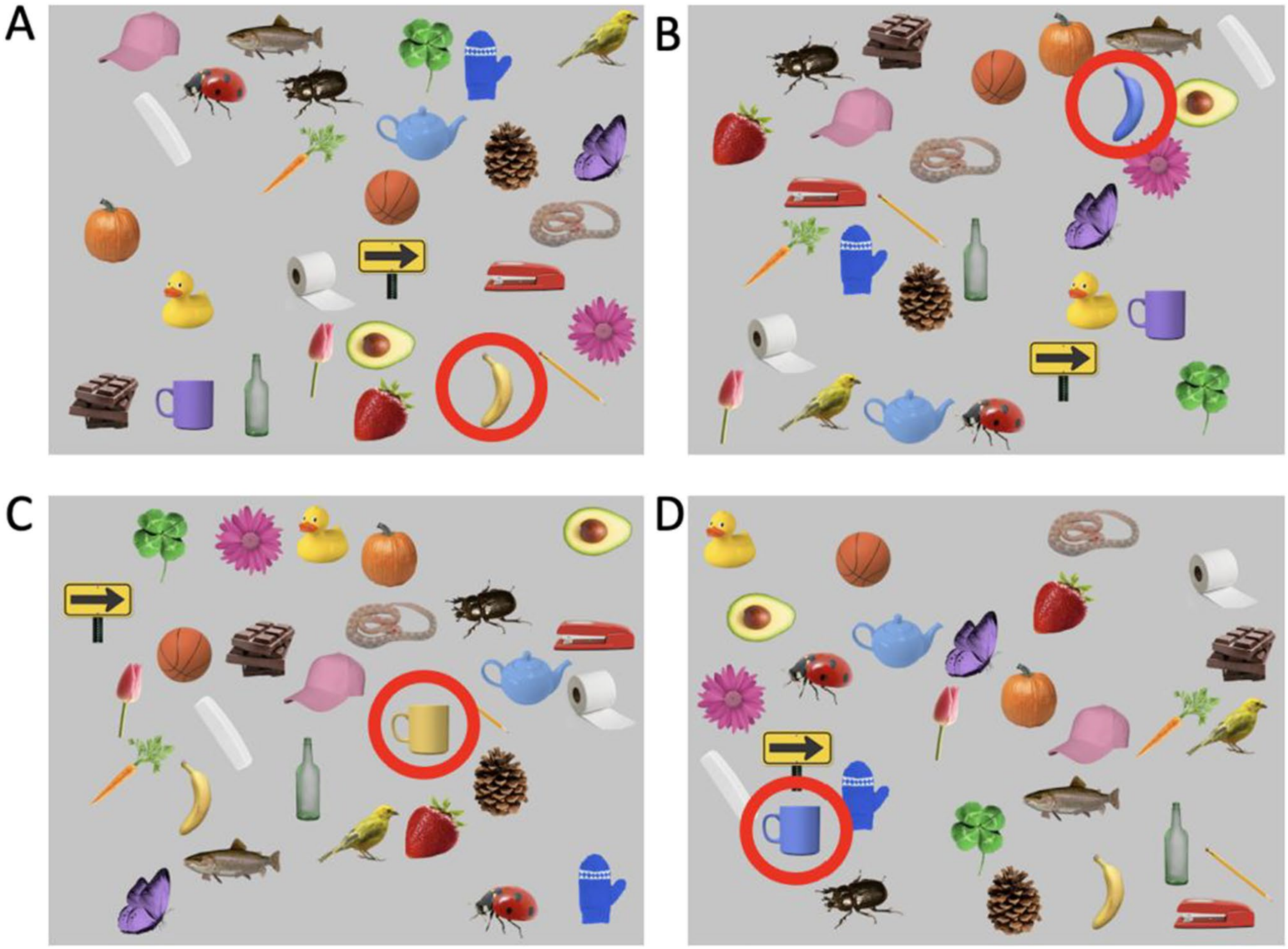
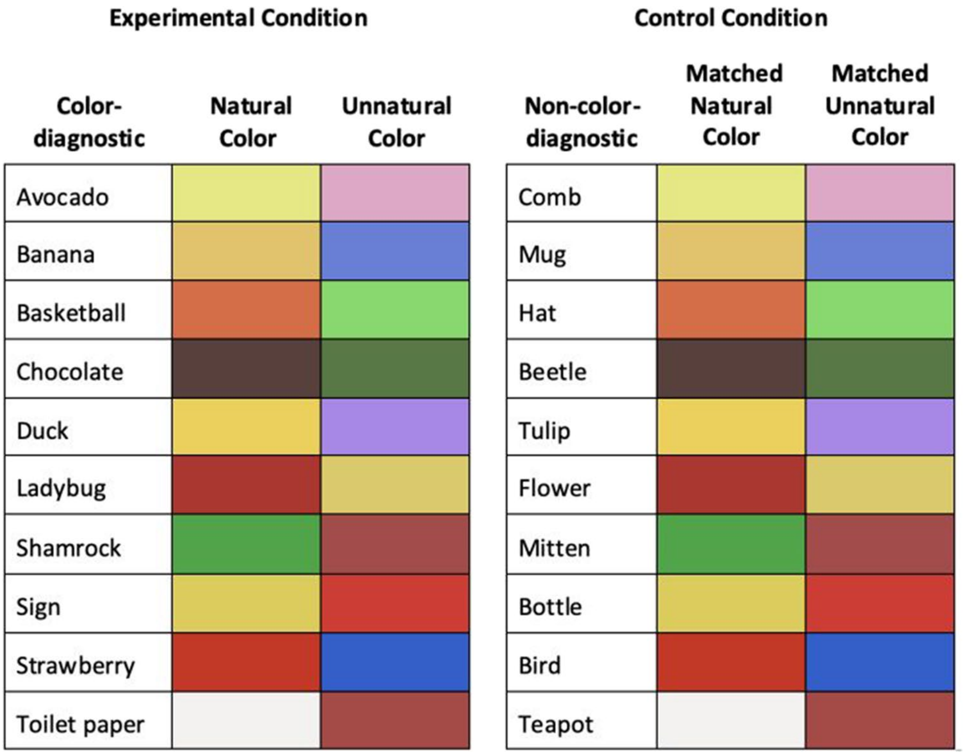


Fig. 1 Illustrations of all objects and examples of panels from each of the four conditions. In each panel, the red circle indicates the target for that condition. **A** A color diagnostic object with its natural color (here, a yellow banana). **B** A color diagnostic object with an unnatural color (here, a blue banana). **C** A non-color diagnostic object with its color matched to a natural color-diagnostic object (here, a yellow mug with the same yellow as the banana in Panel **A.** **D** A non-color diagnostic object with its color matched to the unnatural color-diagnostic object (here, a blue mug with the same blue as the unnaturally colored banana in Panel **B**. (Color figure online)



Experimental Condition			Control Condition		
Color-diagnostic	Natural Color	Unnatural Color	Non-color-diagnostic	Matched Natural Color	Matched Unnatural Color
Avocado	🟨	🟪	Comb	🟨	🟪
Banana	🟧	🟦	Mug	🟧	🟦
Basketball	🟧	🟩	Hat	🟧	🟩
Chocolate	🟫	🟩	Beetle	🟫	🟩
Duck	🟨	🟪	Tulip	🟨	🟪
Ladybug	🟥	🟨	Flower	🟥	🟨
Shamrock	🟩	🟥	Mitten	🟩	🟥
Sign	🟨	🟥	Bottle	🟨	🟥
Strawberry	🟥	🟦	Bird	🟥	🟦
Toilet paper	⬜	🟥	Teapot	⬜	🟥

Fig. 2 The natural and unnatural color sets. The two sets are different because the natural color set is too constrained to shuffle the colors among the color-diagnostic objects. Therefore, the same two sets are duplicated for the control object set to determine whether the color sets themselves affect response time. The control objects are all non-color-diagnostic. (Color figure online)

(once in each of its two colors; see Design section below) for a total of 40 experimental trials. Forty panels were constructed, each displaying all 28 objects (targets and distractors). The objects were located randomly on each panel (never touching or overlapping) with one designated to be the target.

Each panel was duplicated so that one panel included the target, and the other did not (Fig. 3). During a trial, those two matching panels were alternated rapidly back and forth separated by a blank screen. The timing was based on previous flicker paradigms (see Rensink, 2002): A panel was shown for 500 ms, followed by a blank screen for 200 ms to mask the illusion of movement, followed by its paired panel for 500 ms. This repeated so that the target object continually appeared and disappeared while all other objects remained present throughout.

Design

There were four separate conditions (Fig. 1) with ten trials in each condition. Color-diagnostic objects (e.g., bananas) were targets in two experimental conditions: they were presented in their natural color in one condition (e.g., yellow), and in an unnatural color in the other condition (e.g., blue). Non-color-diagnostic objects (e.g., mugs) were targets in two control conditions: They were presented in matched colors to the natural color, color-diagnostic objects in one condition (e.g., yellow), and in matched colors to the unnatural color, color-diagnostic objects in the other condition (e.g., blue). (See Fig. 1 for examples of panels from each of the four conditions, and Fig. 3 for the color sets in each condition. Details of experiment including stimuli, data, and analyses are available at https://osf.io/a3xm5/wiki/home/.)

Procedure

Participants were recruited via a mass email which included the following link to the experiment (https://lab.tellab.org/show/paradigm/changedetection/62349f7878ef22efd9700fab). On opening the experiment page, participants read through consent information and were then asked to provide their age, gender identity, and confirm that they have normal or corrected-to-normal vision including normal color vision. They then proceeded to the instructions and three practice trials before starting the real task. Participants had to spot the difference as quickly as possible between the alternating panels (i.e., find the appearing and disappearing object). Once they found it, they pressed the spacebar whereupon the reaction time was recorded and the panels stopped alternating. Then they clicked on the place where the target object was located.

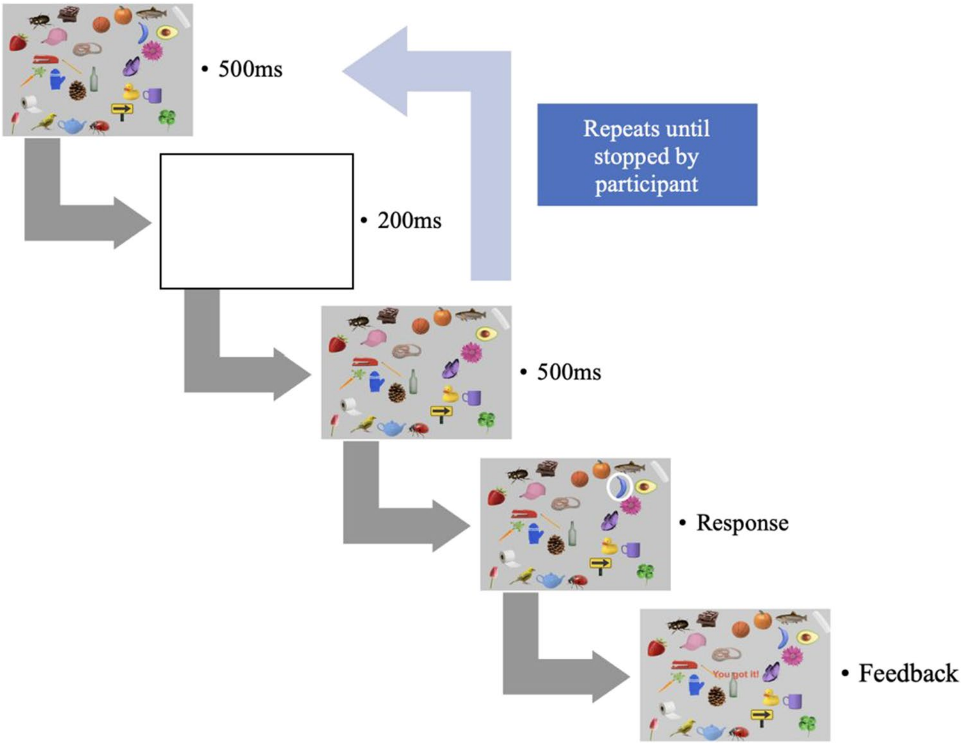


Fig. 3 Sample trial. Here, the target is a color-diagnostic object (banana) shown in an unnatural color (blue). The blue banana is near the top-right corner of the panel. The white circle around the blue banana in the response panel indicates the area in which the participant clicked (which in this case is the correct response, generating "You got it!" feedback). (Color figure online)

The participants were informed that target may or may not be present on the panel when the alternation stopped. Their location response was recorded for the accuracy measure and they received feedback on whether or not they were correct. The next trial then started automatically. (See Fig. 3 for an illustration of a trial.) The 40 trials were presented in blocks of 10, allowing the opportunity for a short break in between each block. Trials from each of the four conditions were evenly distributed among blocks. The order of trials within a block was randomized for each participant, but the order of the blocks was fixed. The accuracy (percent correct target location) and reaction time (the time it took to detect the changing target in milliseconds: RT) were recorded for each participant. A video demonstration of the experiment illustrating all four conditions can be found online (https://osf.io/a3xm5/wiki/home/).

Results

Accuracy

The mean and standard error of the accuracy scores (% correct responses) were calculated for each condition and are shown in Fig. 4. The average accuracy was above 93% in all conditions, indicating that target detection was easy. As planned, the mean detection accuracy obtained with color-diagnostic objects in unnatural colors (96.79%) was compared with the mean accuracy for the same objects presented in their natural colors (93.57%). As predicted, the mean accuracy was significantly higher for unnatural colors,

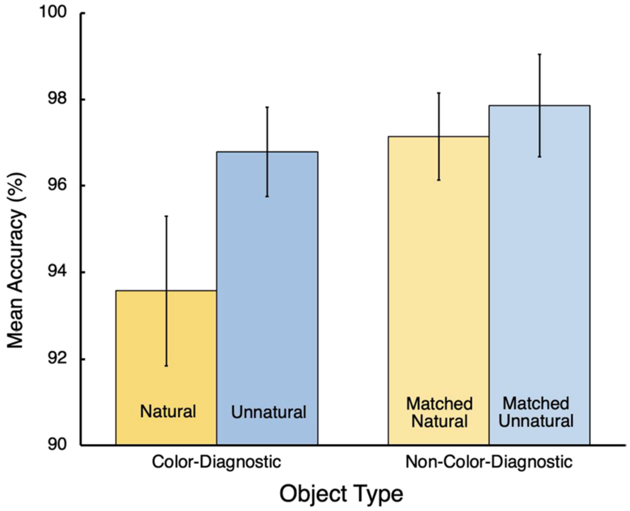


Fig. 4 Average % correct responses for the four conditions. One error bar shows ±1 standard error

one-tailed, paired *t* test: *t*(27) = 1.97, *p* = .03, power = .61, showing that color-diagnostic objects presented in unnatural colors were detected more accurately than those presented in their natural colors. Considering the high accuracy in all conditions, the RTs of correct trials can be taken as a valid measure of detection performance.

Reaction time

The log median RTs on correct trials were calculated in all four conditions. Medians were used since the RT distributions were skewed; the array alternation gave only one chance per cycle to notice the appearing and disappearing object, creating some very long reaction times (i.e., 20 s or more). The median distribution was also skewed (although less so) and the values were therefore log-transformed, a common treatment for RT data. A *t* test showed that, for color-diagnostic objects, the average log median RT was significantly faster when objects were presented in an unnatural color than when presented in their natural color, one-tailed paired *t* test: t(27) = −1.81, *p* = .04, power = .55. On average, the median RT for unnaturally colored color-diagnostic objects was 600 ms faster than that for naturally colored ones. These results suggest that the unnatural color of color-diagnostic objects sped up change detection. Figure 5 shows the averages of the median RT for all conditions.

In sum, the results show that change detection is more accurate and faster for color-diagnostic objects presented in unnatural, unexpected colors than in their natural, expected ones, in agreement with the prediction that the unnaturally colored objects would draw attention to themselves.

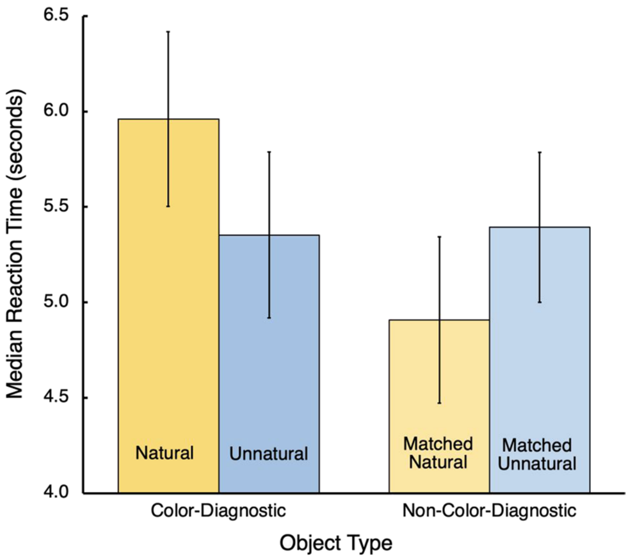


Fig. 5 Averages of median reaction times for the four conditions. One error bar shows ±1 standard error

Finally, to evaluate the potential influence of the specific color sets on the change detection performance, the results obtained with the non-color-diagnostic objects were analysed to compare the matched-natural color condition to the matched-unnatural one. For these objects, there was no difference in accuracy between the matched-natural and matched-unnatural color conditions, one-tailed paired *t* test: *t*(27) = −.420, *p* = .34, power = .13. However, the RT was significantly faster for the objects with matched-natural colors than those with matched-unnatural colors, 480 ms difference, one-tailed paired *t* test: *t*(27) = 1.995, *p* = .028, power = .62.[1] This 480 ms search advantage for the natural color set represents a baseline difference between the two color sets. Since the 600 ms advantage found with the color-diagnostic objects is in the opposite direction (i.e., in favor of the "unnatural" color set), it can be concluded that the unnatural colors of the color-diagnostic objects introduced a RT advantage of 1080 ms relative to the baseline of the control conditions. The semantic "oddness" of the unnatural color-diagnostic objects significantly decreased the RT, despite a bias to detect a naturally colored target faster.

Discussion

This study examined the impact of MCE on a change detection task—a perceptual task that does not require participants' direct report of perceived color, or deliberate processing of object color or identity. The detection speed and accuracy of changing color-diagnostic objects either presented in their natural or in unnatural colors were compared. The results show that on average, color-diagnostic objects shown in unnatural colors were detected 600 ms faster and with 3% fewer errors than those in their natural colors, suggesting that memory color affects preattentive processing and guides visual attention in a top-down manner. The results support the influence of the MCE on perception and suggest that the violation of a semantic assumption such as viewing objects in unexpected colors can influence top-down visual processing preattentively.

The current findings of preattentive capture are comparable to those shown by Scholl's (Scholl, 2000) change blindness experiment. In his study, an array of line drawings of objects were shown and the target was either a color singleton (a single-colored line drawing among all

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[1] A 2 × 2 within-subject ANOVA, with the independent variables color and object type, was conducted on the log median RTs. Its results show a significant interaction of color and object type, *F*(1, 27) = 12.25, p = .002; Eta^2 = .31; power = .92, confirming that the color choices had a reversed effect for color-diagnostic objects compared to non-color-diagnostic ones. No other effects were significant.

black line drawings) or a late-onset object (a black line drawing that appeared in the display after all others did). Both salient properties could trigger an "involuntary exogenous capture of visual attention" (Scholl, 2000, p. 377) to the target, shortening the search by 1.5 seconds (when the target was not a color singleton or a late onset object, the average search time was 5.1 seconds). Scholl's results showed that these salient properties draw attention; they are processed preattentively and guide attention to their location to shorten the otherwise slower serial search.

The same conclusion must be drawn from our study: the targets' salient properties (i.e., their unnatural colors) guided attention to their location, shortening the serial search. While Scholl's (Scholl, 2000) targets drew attention by virtue of a salient low-level feature, independently of the objects that had those features, our unnaturally colored targets had no special low-level feature that distinguished them from the other items in the display. Instead, the "oddness" of the unnaturally colored objects had a high level of semantic salience due to the MCE.

Nevertheless, our study also showed an effect of the colors on search times that was independent of the objects. In our control conditions, the response time for the matched-natural colors was 480 ms faster than for the matched-unnatural colors for the color-indifferent objects (e.g., mugs and mittens) suggesting that these natural colors drew attention more readily than the unnatural ones. Importantly, the opposite was true for the color-diagnostic objects. The unnatural colored objects drew attention even though the objects already faced a response time cost because their colors were less salient in the context of the non-target colors. Clearly, the high-level salience of their odd color overcame this low-level effect. The search was shortened by 0.6 seconds [or by 1.1 seconds taking the 480 ms difference with the control objects as the baseline (i.e., 600 ms plus 480 ms for a total of 1,080 ms)].

Like Scholl (2000), we argued that the shortened response times are evidence for preattentive processing, indicating that the salient targets drew attention more readily than the standard targets. At each step in the serial search through the array, a new fixation direction must be selected from the current location to the next. A target that happened to be highly salient would draw attention to itself, biasing the next fixation in its direction, saving additional search steps that would otherwise be necessary before a fixation fell randomly on the target. A detailed description of these possible response timelines and alternative search strategies is given in the Supplemental Materials (https://osf.io/a3xm5/wiki/home/). Necessarily, a stimulus can draw or capture attention only if some of its property has been processed prior to the arrival of attention. This "drawing attention" is shorthand for preattentive processing guiding attention's deployment.

Our findings suggest there is a reliable and robust preattentive effect of memory color even without reliance on direct report of perceived color and conscious awareness of object identity (as also reported by Firestone & Scholl, 2016). Even though participants were not required to attend to the color or identity of the objects and were, in fact, discouraged from doing so by the time sensitive nature of the task, they detected the unnaturally colored color-diagnostic objects faster. This is in line with the results of the fMRI study by Bannert and Bartels (2013), in which patterns of brain activity were comparable when participants viewed color-diagnostic objects and when they viewed the objects' respective colors, while no conscious attention to the identities of the objects was required. Our results provide additional evidence that color-diagnostic objects can be processed preattentively if presented in odd, unexpected colors violating the semantic expectation of their appearance (of the MCE). Similar semantic salience has been shown to draw fixations in visual search (LaPointe & Milliken, 2016; Underwood et al., 2008), although not over as large distances as a unique low-level feature can.

While the MCE has been linked to scene processing (Gegenfurtner & Rieger, 2000; Oliva & Schyns, 2000), and natural scenes (Witzel et al., 2011), our results suggest that the MCE can influence perception even when objects are not presented in natural scenes (i.e., as image cutouts on a grey background). A potential direction for future research is to examine strength of the MCE with change detection or change blindness in natural and unnatural scenes.

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Authors' contributions Authors contributed to the paper as follows: A.C.: study conception, experiment design and execution, interpretation of results, writing. P.C.: supervision, review and editing. J.R.: supervision, review and editing. All authors: data analysis.

Data availability All data generated or analyzed during this study are included in this published article and its supplementary information files (https://osf.io/a3xm5/wiki/home/).

Code availability N/A.

Declarations

Ethics approval Approval was obtained from the Glendon Psychology Department Delegated Research Ethics Review Committee. The procedures used in this study adhere to the tenets of the Declaration of Helsinki.

Consent to participate Informed consent was obtained from all individual participants included in the study.

Consent for publication The authors affirm that human research participants provided informed consent for publication of the data in this study.

Conflicts of interest None.

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