Empirical Disadvantages for Color-Deficient People

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ABSTRACT

Trichromatic color vision in humans evolved most likely because it provides behavioral advantages in assisting attentional mechanisms, object recognition and, possibly, also detection of emotion states in other humans. Behavioral experiments, namely visual search and object recognition experiments, with normal-sighted observers have shown to support these hypotheses. We argue that the same types of experiments can be used to show that trichromacy does indeed give a behavioral, empirical measureable advantage before dichromacy or anomalous trichromacy by comparing behavioral responses of normal-sighted observers to color-deficient observers. More precisely, we suggest the use of visual search experiments to measure attentional responses, sample-to-match and object recognition tasks to measure objection recognition, and emotion detection to measure emotional responses. We furthermore implemented a visual search task to measure the performance of the attentional mechanism that showed that for the given experiment normal-sighted observers do indeed have an advantage over color-deficient observers.

1. INTRODUCTION

Trichromatic vision is based on the response of photosensitive receptors on the retina of the human eye, so-called *cones*, with sensibilities to light of different wavelengths. Color-deficient people typically have either reduced sensibility for one of the cones or lacking one of the cones altogether. Consequently, this will lead to a decreased ability of distinguishing certain colors. Color-deficient people truly encounter certain problems in daily life both in natural settings – for example when picking berries, determining whether a steak is raw or well-done etc–, and especially in social settings where color coding is heavily used in communication – for example when reading geographic and public transportation maps. More severely, they are excluded from certain professions that rely heavily on different colored signals, like pilots, train conductors etc. However, behavioral disadvantages of color-deficient people in natural and social settings is still only marginally researched. More specifically, two main questions remain: What is the behavioral advantage of trichromatic color vision in comparison to dichromatic color vision? And are there measurable behavioral differences between normal-sighted and color-deficient observers?

Studies suggest that color influences behavioral responses in the field of attention, object recognition, and interpretation of emotional states. Firstly, Treisman and Gelade (1980) proposed the feature-integration theory of attention stating that visual attention can be split up in a pre-attentive early state and a later stage. Color is used especially in the first stage to make elements "pop out" depending on their color contrast. Secondly, Bramão et al. (2012) suggested that colors helps to support object recognition at different states of visual processing. Thirdly, Changizi, Zhang, and Shimojo (2006) suggested that trichromatic color vision is used to better discriminate changes in skin spectra that arise to signal emotions, for example in socio-sexual contexts, and/or may indicate danger.

The previously mentioned research have in common that the hypotheses have been tested only on normal-sighted observers using both colored and black-and-white images showing that normal-sighted observers react faster and more accurate to colored than to black-and-white images. In this paper, we argue firstly that the same methodologies can be used to measure empirical differences between normal-sighted and color-deficient observers supporting the hypothesis that trichromatic color vision manifests an evolutionary advantage for attentional mechanism, object recognition and emotion detection over dichromatic or anomalous trichromatic vision. More precisely, we suggest the use of behavioral experiments involving visual search, object recognition, object identification, object class identification and emotion detection tasks for colored images to empirically measure disadvantages and advantages of color-deficient observers over normal-sighted observers. Secondly, we implemented a visual search experiment – the Visual Search Daltonization Evaluation Method (ViSDEM) – that is used to compare response times and accuracies for tasks involving the attentional mechanism of normal-sighted and color-deficient observers. We found out that color-deficient observers have indeed a slight behavioral disadvantage over normal-sighted observers.

2. BACKGROUND AND METHODOLOGY

Behavioral responses related to attention of trichromats, further called normal-sighted observers, and anomalous trichromats or dichromats, further called color-deficient observers, can be measured by visual search experiments as introduced by Treisman and Gelade (1980). In the basic implementations, the observer has to identify a target stimulus, like a symbol, object etc., among a number of distractors that differ in size, shape, color etc. In another experimentation design that we proposed (Simon-Liedtke, Farup and Laeng 2015), the observer is shown different natural images and a question/task related to the content of the image. The observer is then asked to answer as fast and as accurate as possible for each picture. For both experiments, response times (RTs) and accuracies (ACCs) of the answers are recorded, and analyzed by comparing RTs and ACCs of normal-sighted and color-deficient observers. We assume that according to our previously discussed hypothesis the normal-sighted observers will be able to respond faster and more accurately than the group of color-deficient observers.

Bramão et al. (2012) identified several object recognition experiments to access performance of color vision on object recognition. Images of different objects are shown to the observers, and the participant are asked to answer to certain questions. In the object verification task the observer has to state whether an object or a non-object is shown, in the category verification task the observer has to state whether the object is natural or artificial, and in the name verification task the observer has to state the correct name of the object. RTs of each observation were recorded and analyzed. We suggest implementing the same setup to compare performances of normal-sighted and color-deficient observers. Namely, we suggest the use of the object verification task, the category verification task, and the name verification tasks with colored objects, for which the RTs and ACCs are recorded. If our hypothesis about trichromatic vision is true, we assume that normal-sighted observers will be able to identify objects faster and more accurately than color-deficient observers.

The analysis of emotion detection through skin identification has to-date not yet been conducted. Thus, we propose an emotion detection experiment similar to the one that Adolphs *et al.* (2000) conducted based on the experiments to evaluate the universality of facial expressions proposed by Ekman (1999). Images of people imitating different facial expressions are shown to participants that are asked to name the emotional state that the expressions are meant to represent. Since the influence of emotion detection has to yet been analyzed to-date, the experimentation has to be conducted in two stages. In the first stage, normal-sighted and color-deficient observers are shown different images of facial expressions both colored and grayscale from males and females belonging to different emotion categories. In the second stage, only colored images are presented to both normal-sighted and color-deficient observers. For both stages we record the RTs and ACCs of the observations. If color vision in general and trichromatic color vision in particular facilitates emotion detection as expected, we expect, firstly, that observers in both groups will react faster and more accurate for the colored images than for the grayscale images, and, secondly, that for colored images normal-sighted observers will react faster and more accurate than color-deficient observers.

3. IMPLEMENTATION

To-date, we implemented a visual search experiment to analyze influence of color on attentional mechanism for normal-sighted and color-deficient observers: The method is originally designed to evaluate daltonization methods, and is called Visual Search Daltonization Evaluation Method (Simon-Liedtke, Farup and Laeng 2015). Fortunately, the results can also be interpreted in order to support for the previously discussed hypothesis that normal-sighted observers have a slight empirical measurable advantage to color-deficient observers. In our experiment, the observer looks at a range of images, for each of which we define certain tasks. The task consists of a statement, which the observer has to agree, respectively disagree to. The statement is connected to colors of objects, people etc. in the image like for example “The feather in the image has the same color hue as the background.” or “There is green powder in the image.” We conducted the experiment with 23 observers, of which 10 were normal-sighted and 13 deutan color-deficient, and we used 7 different sets of images. For more details on the implementation, please check our previous paper (Simon-Liedtke, Farup and Laeng 2015). We analyzed the confidence interval of the ACCs for both observer groups, and compared the medians of RTs for both groups according to a Mood’s median test.

4. RESULTS AND DISCUSSION

Figure 1 shows both RTs and ACCs of both normal-sighted and color-deficient observers. The median RT for the group of normal-sighted group is much lower than for the group of color-deficient observers. A Mood’s median test revealed a p-value of $4 \cdot 10^{-6}$ indicating that the medians of both populations are indeed significant different. The confidence interval (CI) of the ACCs for the group of normal-sighted observers is much higher than the CI of the ACCs for the group of color-deficient observers. Both observations agree with the assumptions we made prior to the experiment, namely that color-deficient people react less accurate and slower than normal-sighted observers. In other words, the results indicate that color-deficient people do indeed have behavioral disadvantages connected to their attentional system, and that these differences are indeed measureable with our proposed methodology based on visual search tasks.

5. CONCLUSIONS

We proposed a range of behavioral experiments through visual search, object identification and emotion detection tasks in order to test the hypothesis that trichromatic color vision provides evolutionary advantage for attention, object recognition and emotion detection. We suggest that color-deficient observers will respond slower, and less accurate to these tasks when compared to normal-sighted observers. Furthermore, we implemented a visual search experiment that shows that deutan color-deficient observers do indeed react slower and less accurate than color-deficient observers in a visual search experiment measuring attentional reactions.

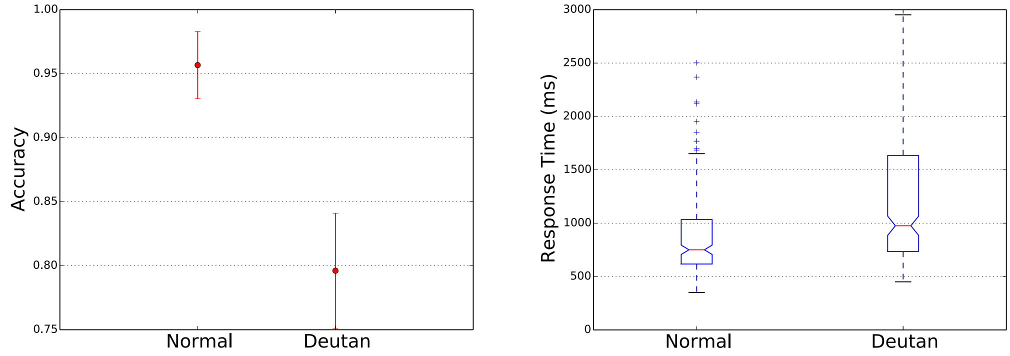

Figure 1: Accuracies (ACCs) and response times (RTs) of the visual search experiment for normal-sighted and deutan color-deficient observers indicating that color-deficient people do indeed react less fast and less accurate than normal-sighted observers. The median RTs of both groups are significant different according to the Mood median test.

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