Color diagnosticity in object recognition

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Abstract

How does color influence object recognition? In this study a set of objects with three different color settings; appropriately colored, inappropriately colored or black and white, are used in an experiment to investigate the importance of color in object recognition. Objects are categorized as either man-made (e.g. furniture) or natural (e.g. fruit) and as high color diagnostic (HCD) or as low color diagnostic (LCD). An HCD object is an object that is highly associated with a particular color (e.g. banana), whereas for LCD objects, no specific color is highly associated with the object (e.g. car). The results from this study are consistent with the results from previous studies, where appropriately colored HCD objects are recognized faster than inappropriately colored HCD objects and where the difference is small for LCD objects. This study found no significant indicator that point toward color having a bigger influence on natural objects than on man-made objects. The black and white coloration show unexpected results, having the fastest recognition times for HCD objects and the slowest for LCD objects.
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1 Introduction

Color vision is a perceptual function that most of us takes for granted. For a person who can perceive colors, colors are constantly a part of our visual perception and we associate colors both with certain objects, emotions and special meanings [8]. Our color vision serves several purposes. Color brings a signaling function and helps us facilitate perceptual organization to distinguish different objects from a visual context. The ability to distinguish between different colors has been important to our survival from an evolutionary perspective and our visual system have developed special mechanisms to manage color vision. Through the evolution, our nervous system have constructed a complex strategy to transfer energy from light rays to conscious representations of different colors in the brain. Humans, along with other primates, have trichromatic color vision [7]. One theory is that the trichromatic color vision developed as an adaptive function for finding food such as fruits and leaves against a background where it otherwise would have been difficult to distinguish the edible. Color vision thus enhances the contrast of objects that otherwise would have been obscured by their surroundings. [8]. This notion indicates that our color vision are correlated to our ability to recognize objects in the environment.

This study aims to explore color perception and the importance of color for our recognition ability. This topic has been debated in science and various theories concerning the mechanisms of object recognition has been proposed. Some theories refute that color information influences object recognition, while other consider the surface color of an object as a contributing factor for recognition along with other factors such as texture and shape [2]. An important concept in many of the previous studies of object recognition is color diagnosticity. Color diagnosticity refers to the degree of which an object is associated with a specific color. Objects are divided into two different categories based on their level of color diagnosticity. High color diagnostic (HCD) objects are objects that are strongly associated with a particular color whereas for low color diagnostic (LCD) objects the color has little or no impact on our associations. The goal of this study is to test the hypothesis about the color diagnosticity, according to which, color should more strongly influence the recognition of HCD objects than the recognition of LCD objects [1]. By examine whether appropriately colored objects are recognized faster compared to other color versions it is possible to verify whether color information contributes to object recognition. Through an experiment the reaction time for recognizing both HCD and LCD objects was measured to provide an insight into whether the color diagnosticity hypothesis is valid. Another goal is to investigate whether there is an distinction in our recognition ability based on a categorization between man-made and natural objects. The results are presented by graphic visualization and analyzed by a subsequent discussion.
2 Background

Visual stimuli plays an important role in recognition of the surrounding world. Earlier studies have come to different conclusions in how color impacts our ability to recognize objects but more recent studies agree that it partly depends on the type of object [1][3][4][9]. Color demonstrates having a bigger impact in recognition of high color diagnostic (HCD) objects than of low color diagnostic (LCD) objects. Earlier studies have also demonstrated a difference in recognition between natural objects and man-made objects. Studies have shown that color plays a more significant role in recognition of natural objects than of man-made objects, but recent studies have had inconsistent results, showing that there is no difference between the two types [4].

2.1 Related work

Studies have been conducted that evaluates the color importance for object recognition. In 1999, Tanaka J.W and Presnell L. M, tested the hypothesis of color diagnosticy in object recognition [1]. The background for their experiment was that there had been studies about color perception that had conflicting results, some studies indicated that color played a big role in object recognition while other showed the opposite. They classified objects to be either high color diagnostic (HCD) or low color diagnostic (LCD) depending on how strongly the object was associated with a particular color. In their study, the participants were asked to classify the object, name the object and verify the accuracy of the objects surface color. They measured the time it took for the participants to recognize the object. Their results indicated that there was an significant distinction in reaction time for HCD objects depending on if they were appropriately colored or not. For LCD objects, the color did not affect the recognition. Their findings suggest that color can contribute to recognition independently of the shape of the object. Their results also confirmed the hypothesis of color diagnosticy and their conclusions suggest that color is important for recognition when dealing with isolated objects that have strong color associations.

A review that explored color perception by relating it to current scientific literature is ”The role of color in high-level vision” published in 2001 [2]. High-level vision refers to the interpretation and use of what is seen in an image and this includes our recognition ability. A motivation for their review was that the influence of color for our recognition ability was a research topic in the perception field with inconsistent results. Previous studies have had varied methods of choosing coloration and categorizing objects. There is also a division in the literature defining the processes of recognition. According to one approach, called ’edge-based’ theories, our recognition is solely dependent on the shape of the object [2]. Other scientists claimed that, in addition to the shape of the object, our perception is also influenced by the surface properties such as color.
and texture. This view is referred through ‘surface-plus-edge-based’ theories. Furthermore, the authors of the review describe the perceptual processes in the brain when we explore visual representations. One important discovery in this area is that the information about an object’s color activates many of the same visual brain areas that we know to be connected to object recognition. They also discuss the effects of top-down processing and the relationship between color knowledge and color perception. The conclusions suggest that the current view from the behavioral, neurophysiological and neuropsychological field indicate that color have an important role in both low-level and high-level vision.

Another study following in the footsteps of Tanaka & Presnell is “The role of color diagnosticity in object recognition and representation” published in 2009 [3]. They investigate the surface and edge-based theory where both shape and surface criteria (such as color and texture) plays a role in recognition of objects. The results strengthen the color diagnosticity hypothesis, i.e., that color plays a bigger role in recognition of HCD objects. They also conduct experiments where they use pictures within sentences to get a linguistic point of view of the problem.

“What regulates the surface color effect in object recognition: Color diagnosticity or category?” published in 2003 recreates some of the aspects of “Color diagnosticity in object recognition” [4]. They conduct the same experiments for investigating which objects to be considered LCD and HCD but uses an even lower threshold than Tanaka & Presnell (35% instead of 80%). Their results are consistent with those of Tanaka & Presnell [1] thus strengthening the hypothesis of color diagnosticity. The authors investigates another side of object recognition as well. Previous research have pointed toward a categorization of objects; that color is more beneficial for recognizing natural objects (e.g., fruits and vegetables) than man-made objects (e.g., tools and furniture). Their results indicate that there is no difference in reaction time between the two types of categories and they state that the interaction between category and color diagnosticity requires future examination. [4]
3 Method

Participants. The study was carried out in the KTH library with 21 participants. About 1/3 of the participants were Swedish students and the rest were exchange students. The age of the participants varied between 20 and 30 and all had normal color vision. Participants were instructed beforehand on what to do but were not given any knowledge of the purpose of the study.

Stimuli & design. The study was conducted through a computer program where the participants were shown different pictures on the screen. Each picture appeared in three different color settings: appropriate, inappropriate or black and white. There were a total of 20 different pictures of objects and because of the 3 different color settings, the total amount of pictures was 60. A between-group design was used where 3 maps of 20 pictures each rotated, i.e., participant 1 got map A, participant 2 got map B, participant 3 got map C, participant 4 got map A and so forth. Every object was only showed once for each participant. The order of the pictures was randomized to avoid biased results.

There were different categories of objects, half (10) were LCD and the other half were HCD. Of the 10 HCD objects, 5 was categorized as man-made objects (e.g., tools or furniture) and 5 was categorized as natural objects (e.g., fruit or vegetables). The same was done for the LCD objects. The labelling of the objects (whether they were LCD, HCD, man-made or natural) was derived from previous studies [1], [3], [4] and all pictures was taken from free images website services [5], [6]. The pictures were edited in GIMP to be on a white background of 250 x 250 pixels. See Appendix for a overview of all pictures used.

![Figure 1: Example of HCD objects](image1)

![Figure 2: Example of LCD objects](image2)
**Procedure.** The participants were shown pictures of objects on a laptop screen, one at a time. When the participant recognized the object they pressed “Enter” and the picture disappeared and they participants then had limited time (12 seconds) to type in the objects name. They could do so in Swedish, English or in their native language. There was a 5 second countdown between each new picture.

Because of the study being conducted in an open space, the sound level was measured for each participant using the Android app “Sound Meter Pro”. The average sound level was 71.7 dB. The average time taken to conduct the test was 3 minutes and 36 seconds.

Pilot testing was conducted on 3 KTH students before the actual study. They were shortly interviewed afterwards. Feedback from this resulted in an object (a screw) being removed because it was too hard to recognize. Other results of the pilot testing were that participants would be allowed to use any language as to not get stuck on the linguistic part of naming the objects. Positive response of the 5 second counter between pictures was received as well as being able to establish that 12 seconds were enough time to type the object in.

## 4 Results

Below are the data obtained in the study. In section 4.1 and 4.2, the measured data are presented through a set of diagrams to visualize the results. In section 4.1, the reaction time is visualized with respect to the separate objects and in terms of a distinction between the HCD and LCD objects. Section 4.2 presents the results with respect to the objects categorization. The relationship between the reaction time and the object’s category (natural or man-made) are visualized with respect to LCD and HCD. All data is derived from the average of all participants’ results. Reaction times over 4 seconds and wrong answers were removed from the results (9.3% removed).

### 4.1 Results by objects

#### 4.1.1 HCD objects

The results of the reaction time for different objects varied. Five items showed a clear increase in the time when the HCD object was inappropriately colored compared to the appropriately color version. For the first two HCD objects in the x-axis (banana and basketball) and the last object (teddy bear), there wasn’t any distinct difference in the results between the appropriate coloration and the inappropriate coloration. Black & white coloring had different results.
between HCD objects, for some of the objects the black and white coloring resulted in the fastest reaction time, while other objects had their slowest time with black and white coloring. In the case of the lime object, no participant got a correct answer when the lime was presented in an inappropriate color, thus all the participants answers in that section were removed from the results.

Figure 3: Results from the HCD objects.

4.1.2 LCD objects

The results between different coloration showed some other tendencies for the LCD objects. The time differences were small (<0.2 s) between the appropriate and inappropriate coloration for 5 of the objects. In the case of the monkey and the screwdriver the inappropriate coloration resulted in a distinct longer reaction time. On the contrary, the object of the lamp and elephant had distinct longer reaction time for the appropriate coloration compared to the inappropriate color version. Black and white coloring stood out in the case of the lamp and the screwdriver, where the reaction time was more than 0.5 seconds higher compared to the result of the fastest color variant.
4.1.3 All objects

The results from the mean reaction time for all objects show clear indications of the relationship between object recognition and coloration. For both HCD and LCD objects, the participants recognized the object fastest when it was presented in the appropriate color compared to the inappropriate color version. In the case of HCD objects, the longest time was in the case when the object was inappropriately colored and the black and white coloration got a minor lower reaction time than the appropriate coloration. For the LCD objects, the black and white coloration had the longest reaction time, although the variance between different coloration was small.

Figure 4: Results from the LCD objects.

Figure 5: Average results from all objects.
4.2 Results by category

When the objects are divided in their corresponding category, the result for HCD and LCD shows some differences. For the man-made objects, both HCD and LCD object have their fastest reaction time with appropriate coloration. In the natural object category, the black and white coloration had the fastest reaction time. The slowest reaction time for the natural objects was obtained when the objects were inappropriately colored. For both the man-made and natural objects, the inappropiate coloration had longer reaction time compared to the appropriate coloration.

![Figure 6: Average results from all objects.](image)

5 Discussion

The results are consistent with previous studies where appropriately colored HCD objects are recognized faster than inappropriately colored HCD objects [1][3][4]. No distinct difference between the two color settings are shown for the LCD objects and no significant indicator point toward color having a bigger influence when recognizing natural objects than man-made objects. What differs from previous results is the black and white colored objects. Previous studies have shown that HCD objects are recognized fastest when appropriately colored, second fastest is black & white and the slowest reaction times are noted for inappropriately colored objects.[1][3].

This report further support the color diagnosticity hypothesis, showing the same pattern between appropriate and inappropiate coloration regardless of the categorization between man-made and natural objects, but the black & white col-
oration differ. The results of this study indicate that LCD objects in black & white takes the longest time to recognize of the three color settings. Looking at the reaction times for the LCD objects (see Figure 4) we see that the screwdriver, the lamp and the shoe, colored in black and white, have very long reaction times. We also see that all man-made LCD objects, where the color setting shouldn’t play a role in the recognition times, have the slowest recognition times when in black & white. One explanation could be that the recognition time of LCD objects, where the specific color doesn’t matter, are still affected by it being colored or not. When colored, we might find it easier to recognize the form and shape and thus recognizing it quicker than when it’s in black & white. Whereas the black & white man-made objects have the slowest reaction times, the natural objects in black & white have the fastest. The inconsistency for black & white objects, when the other two color settings are consistent with previous results, is puzzling and requires further research.

5.1 Critical analysis

In order to draw definitive conclusions about the impact of color for object recognition, it is necessary to conduct comprehensive and complementary studies. Since the results from this study are similar with the results from previous studies, it is reasonable to assume that the hypothesis about the color diagnosticy holds. The measurement data obtained from this study were, however, collected from a relatively small amount of participants. In order to get more representative results, it may be necessary to increase the number of participants and perhaps examine different target groups.

A crucial factor in the experiment was the choice of the images. The participants only got to see 20 pictures of different objects, of which 50% were HCD objects, 50% were LCD objects, 50% were man-made objects and 50% were natural objects. A critical feature of the study was thus to select the images that represented each category. Within the division between HCD and LCD objects in color diagnosticy, there exists variations in each category. Some HCD objects are thus more strongly associated with a specific color than other HCD objects. Such variation may well have influenced the results. To obtain more objective results, it is necessary to choose items that are just as strongly (or weakly) associated with colors. To be able to perform such a selection, additional experiments are required. The previous studies that this study was based on did not list all LCD objects used and did not include an Appendix of what their pictures looked like. A picture of a car on a white background can differ vastly which could result in a difference of recognition times between same objects.
There also exists differences between categories relating to man-made and natural objects. Some items that are man-made objects can occur in a large variation where different shapes, colors and textures may represent the object (such as a lamp). Other items which are man-made might exist in relatively few different sets (such as a basketball). This may be one of the explanations for why some of the results, e.g., the lamp and screwdriver, were protruding. In addition to the selection of objects, the chosen picture of the object can affect the result. Although all images had consistent size and background, there was some variation in brightness, contrast and resolution. Furthermore, whether the picture was representative of the item was based on a subjective judgment. It can not be excluded that another picture of the same object would have influenced the outcome. Worth mentioning is also that the images were taken from free image websites where the range of images was limited. To minimize the risk that the image choices affects the results, it is necessary to either perform a more extensive selection method, or to use a much larger amount of objects to represent the various categories.

When we use our visual perception we always see objects in a context. To avoid that the background biases the reaction time, all objects were showed against a white background. Since we use our top-down knowledge to identify an object, the context of the object might be very important for our recognition. The lack of context in the experiment could therefore have affected the results. Furthermore, it is possible that in the case of natural objects, which often looks similar to other natural objects, the context is particularly crucial for our recognition ability. When such items are presented without context, it is possible that the color information becomes especially important. This could provide an explanation as to why none of the participants could recognize the lime object when it was inappropriately colored. Almost all participants answered that they either saw an orange or a lemon. If the lime had been shown in a context where they could have got some indication of its size, it is possible that participants might have been able to perceive the lime despite a faulty coloration.

In the analysis of the data, the reaction times that were over 4 seconds was removed. The motivation for this was that it might have been other factors that affected the participants response time in these cases. It may also be important to analyze the results based on the addition of a lower time limit. If participants happened to press 'Enter' too fast, without having identified the object, it is possible that the memory of the object may have helped the participants to answer correctly. Hence it can be useful to also add a lower bound in the analysis.

To further determine how our perception is influenced by colors, it is necessary to conduct further studies. A possible further development of the study is to examine how the results differ between internal categories of man-made and
natural objects. A more rigorous selection of images should be considered, as well as studies with a larger number of participants. One could also investigate how different combinations of color choice does influence perception. When coloring the inappropriately versions, it may be rewarding to use different types of contrast scales or color scales to create more consistent color versions of the images. Such a study could examine how our perception is affected by inappropriate coloring that is close, or far from, the appropriate color. To understand the complex relationship between perception and color vision, more extensive studies are required.

5.2 Reflection of the project

We think that the collaboration in the project has worked well and the work has proceeded smoothly. It was good to have several previous studies available on the topic of color perception that we could use in order to shape our experiment. We worked on schedule and got everything ready in time. Division of labor in the project worked as expected. We split up some of the main tasks between us. We presented the individual work to each other and discussed and improved until we both were satisfied. On the basis of the time frame of the project, we are very satisfied with our work. If we had had more time we might have used more objects and possibly a more rigorous selection of the images. We might also have conducted the experiment on more participants in order to obtain more generally applicable measurement data. If we would conduct the experiment again with more participants it would be useful to create a database to collect measurement data. In our experiment the program wrote the output to a file which we then had to manually compile. A strength in our method was that we based the selection of the objects from previous studies. We have learned a lot when it comes to planning an experiment. During the experiment, we found several minor things that could have been corrected if we had time to do the experiment again. Some weaknesses in the experiment was however corrected with the help of a preliminary pilot test. It has been interesting to implement and reconstruct an experiment in color perception and we have learned a lot about how the color provides information that can be critical for us in order to understand our visual environment.
References


## Appendix

### Natural HCD objects

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### Man-made HCD objects

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