VISUAL®

VISUAL REALITY * COLLECTION OF STUDIES

UNDERSTANDING VISUAL PERCEPTION AS A COGNITIVE ACTIVITY

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ABOUT

Title ↘ Author ↘
Thesis supervisor ↘
Date↘ Place ↘

Visual reality * A collection of studies. Understanding visual perception as a cognitive activity, decoding the objective functionality in design. Writen by Myra Bizimi. Supervised by Katerina Antonkaki. Published on the 9th of March 2022. At the University Of West Attica Department of Graphic Design & Visual Communication.

INDEX

LET'S SEE [redacted] [redacted] [redacted] [redacted] [redacted] [redacted]


REALITY
VISUAL

*The understanding, like the eye, whilst it makes us see and perceive all other things, takes no notice of itself : and it requires art and pains to set it at a distance and make it its own object....

* John Locke {1632 – 1704} was an English philosopher and physician Locke's theory of mind is often cited as the origin of modern conceptions of identity and the self, figuring prominently in the work of later philosophers such as Jean-Jacques Rousseau, David Hume, and Immanuel Kant.

ABSTRACT

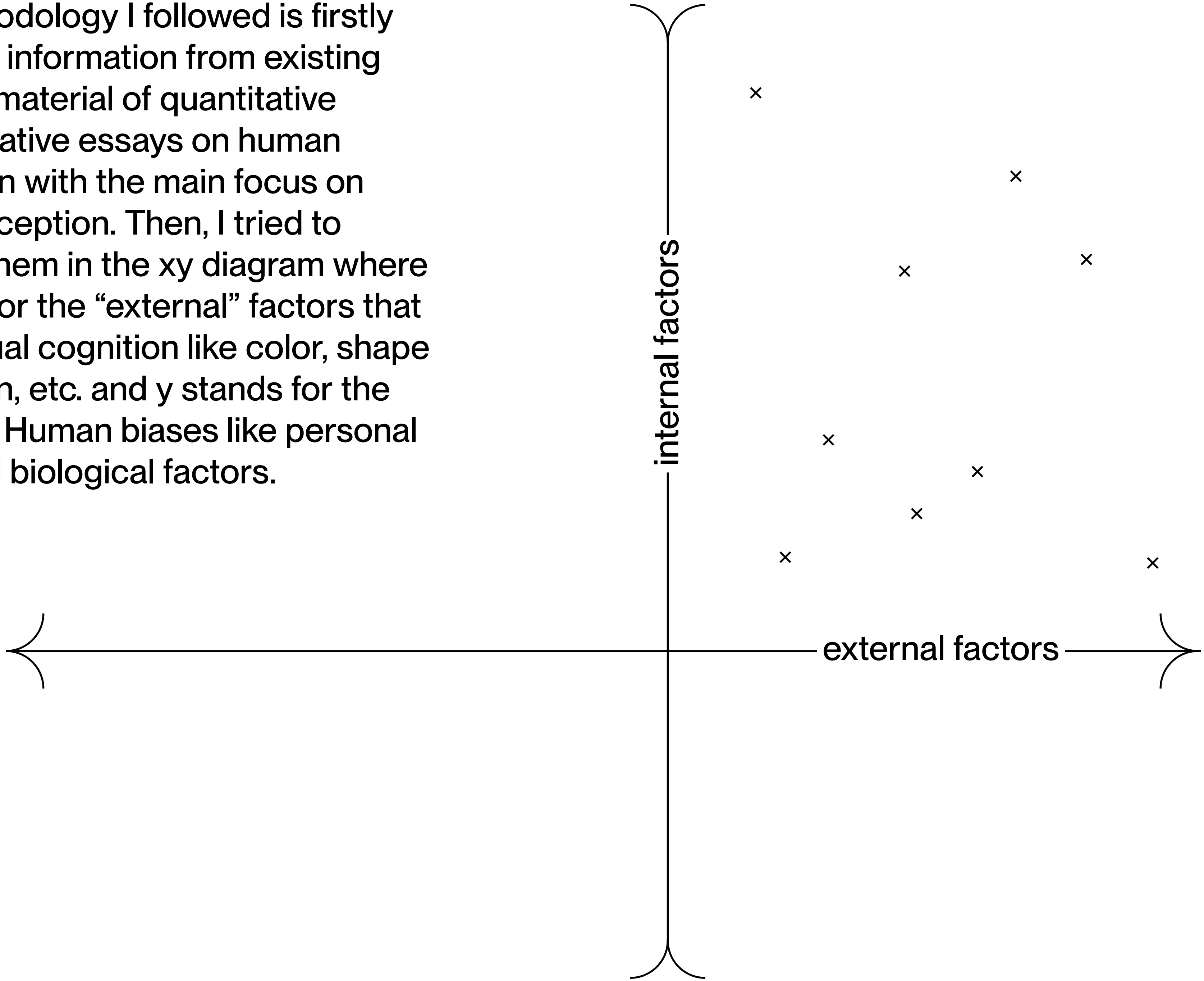
How does new design emerge, where do new design ideas come from, and what is the purpose of design?

The majority of individuals, even designers, will respond with a reflexive: New design is founded on good ideas, is motivated by what people require, and ultimately serves the people. This sounds like the well-known human-centered design approach (HCD).(Arnold, 1959a).

But what does putting the human in the ‘center’ actually means, in everyday design practice.

In order to put humans in the center, we have first to understand how we perceive our environment. This realization ignited my curiosity, so I started searching.

The methodology I followed is firstly collecting information from existing research material of quantitative and qualitative essays on human perception with the main focus on visual perception. Then, I tried to pinpoint them in the xy diagram where x stands for the “external” factors that affect visual cognition like color, shape orientation, etc. and y stands for the “internal”. Human biases like personal views and biological factors.



The purpose of this collection is to better understand how visual stimuli work, how perception is created through the visual organization of consciousness. So, therefore, grasp how to design & organize visual information.

During the conduction of my thesis, I came across very interesting data. Gaining a better understanding of how design cognition can inspire new discussions about the future. Finally, all this information sparked my interest in matching the design with the needs of a user. Thus, achieving as successful communication as possible.

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INTRODUCTION

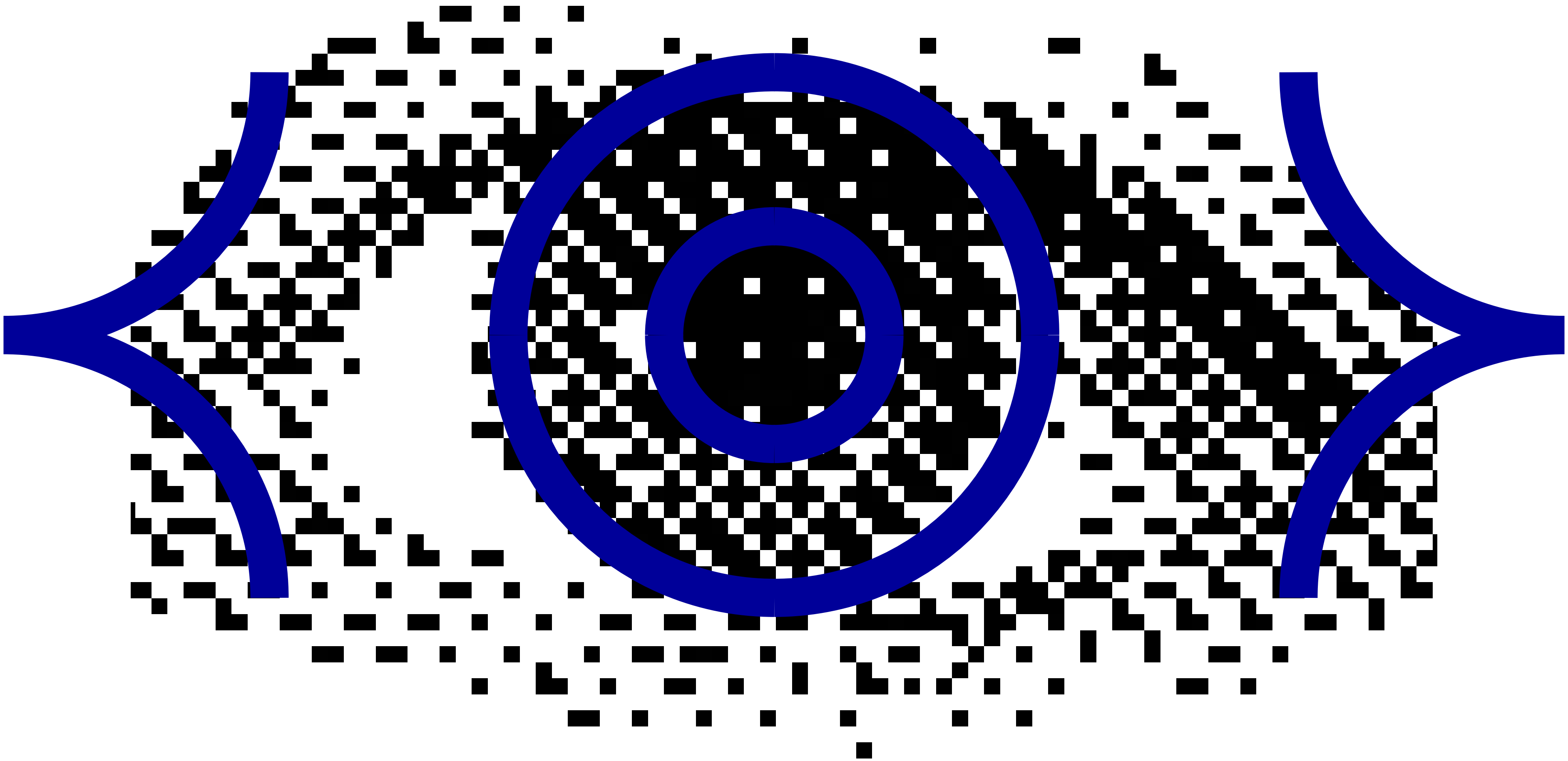
In order to use a human-centered design approach we have first to involve and decode the human perspective.

For each individual, perceived reality, which is based on preceding complex and mostly unconscious neural processing, is the essential and only graspable reality (Carbon, 2016b).

Perception creates its own reality that guides us fast and effectively through the surrounding world that provides fuzzy and highly ambiguous information (Carbon, 2014).

Humans use multisensory channel processing & integrate all available signals to generate a coherent representation of entities.

Since we cannot change reality,



let us change → the eyes which see it

– Nikos Kazantzakis

By learning the core we can move towards a multisensory view and as a result, get a better understanding of how to design and organize information.

Integrating the other senses and thinking of the sum of these sensory inputs is an ideal way to assist the aesthetic experience and the natural way of handling the design. In order to understand this system, we start by decoding the vision as our lives get denser and denser in visual stimuli.

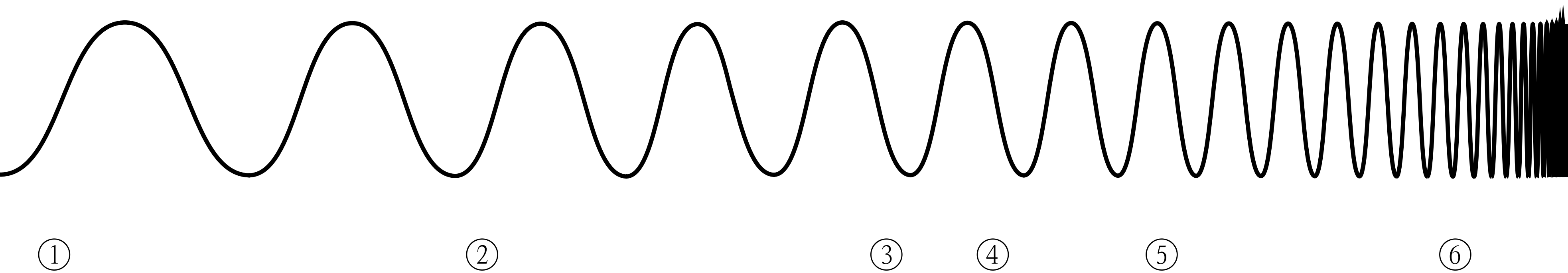
In order to start decoding how perception creates the reality and vise versa we start with the “Visual Empire” of stimuli.

First, we start with the base of the visual stimulus the light, and then by how a stimulus gets to our attention. Also, we see how culturalcircumstances affect our visual perception and lastly, that vision is unique to the eye of the beholder. Understanding visual perception as a cognitive activity can help us design and organize our visual information.

Does our perseption overlaps with our reality?

IT ALL STARTS WITH LIGHT

Visible light is a small part within the electromagnetic spectrum



① RADIO WAVES ② INFRARED RAYS

③ VISIBLE LIGHT ④ ULTRAVIOLET RAYS ⑤ X-RAYS ⑥ GAMMA RAYS

We see these waves as the colors of the rainbow. Each color has a different wavelength. White light is actually made of all of the colors of the rainbow because it contains all wavelengths, and it is described as polychromatic light.

A white object reflects all colors (wavelengths), and a black object absorbs all colors. If we change from white light to pure blue light, the objects that under normal white light conditions look red no longer look red. It absorbs the blue light and appears to be black.

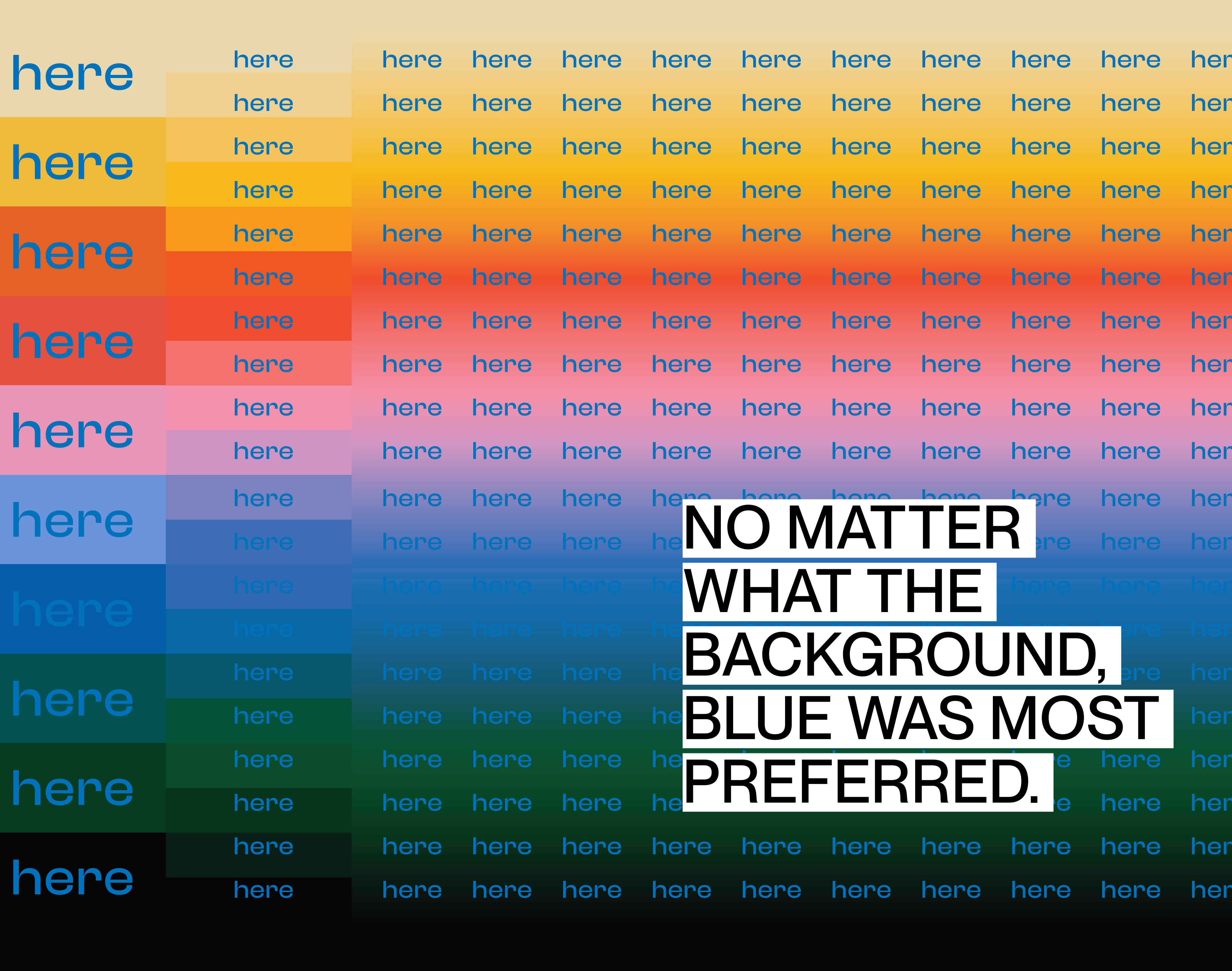
Color serves many important functions in visual communication.

WHAT IS YOUR FAVORITE COLOR?

If you answered blue, congrats you chose the world's favorite color!

There seems to be a global inclination toward preferring blue regardless of its presented medium. Although, color has always been considered to be linked with subjectivity, especially where preferences are concerned. Blue seems to be a different case no matter gender, culture, & ethnicity it is the most popular color.

In many cases, blue was also stated as the most likeable color when people were asked their favorite color without any visual stimuli.


NO MATTER WHAT THE BACKGROUND, BLUE WAS MOST PREFERRED.

FIND A GREEN LETTER

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Easy right?

Even in cluttered environments, certain colors contributed to the decrease in search time. The color and positioning of the targets in the distractor fields had interaction effects as well.

Demonstrating that during the visual search process, one will have a direct impact on the other. Positioning was determined to be insignificant on its own.

The green colour produced overall faster search times, an average of 1.92 s compared with the slowest search times of beige (2.43 s) and peach (2.63 s). This difference in search time was highly statistically significant ($p < 0.000$).

The act of 'seeing' an object is the result of light from any luminous source. Depth, dimension, perspective, realism, and visual intrigue may all be added to design due to light.

VISUAL ATTENTION

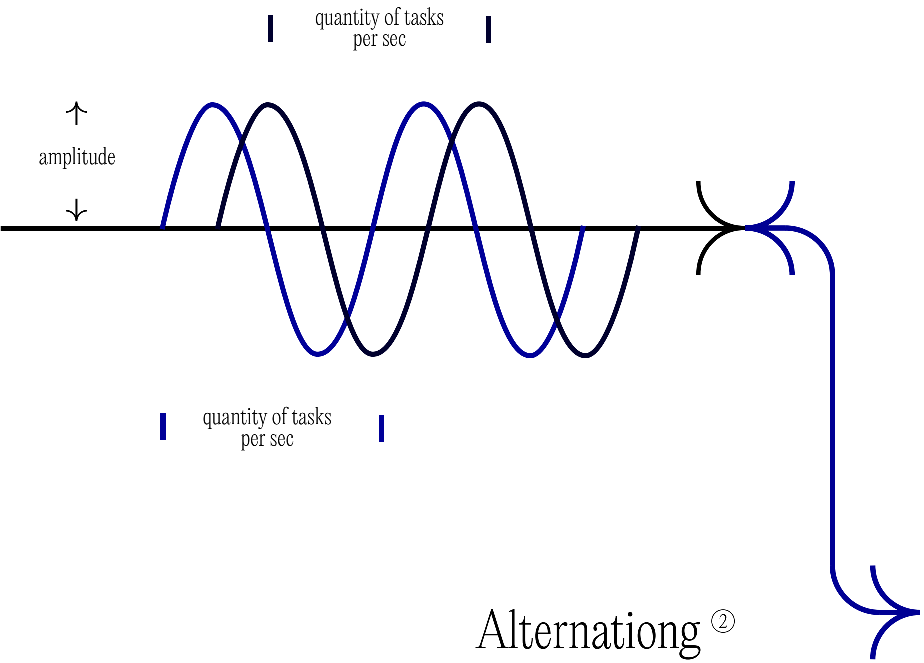
How many times have we heard the word "attention"? We are always asked to be alert and focused; from our school days to our daily commute to work.

But what does attention actually mean?

The term attention refers to the degree of activity of the mental functions: perception, thought and motivation, but also the degree of activity of the sensory organs regarding the information we receive from the environment. Based on the above we can consider concentration as the ability to direct and focus attention on specific stimuli.

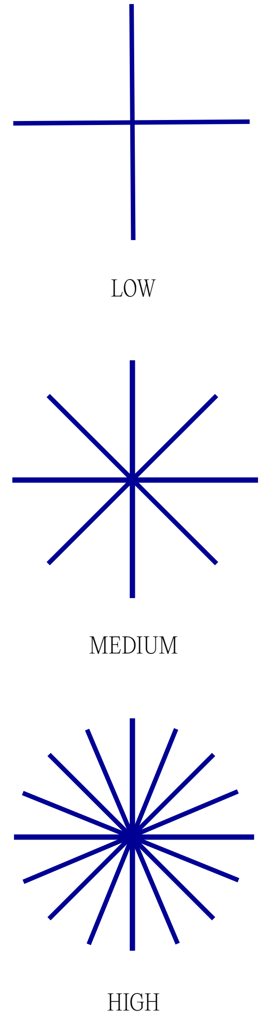
Attention can be described by several "relative" characteristics

Amplitude ①



Alternationg ②

Intensity ③

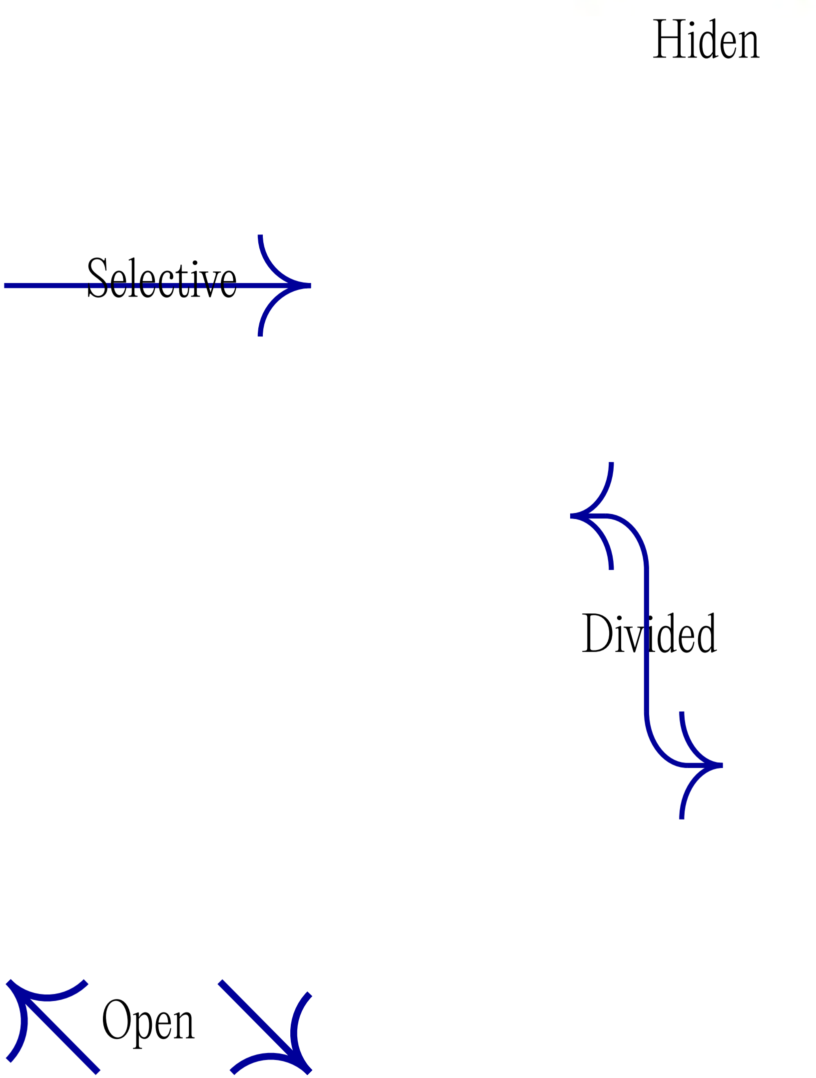


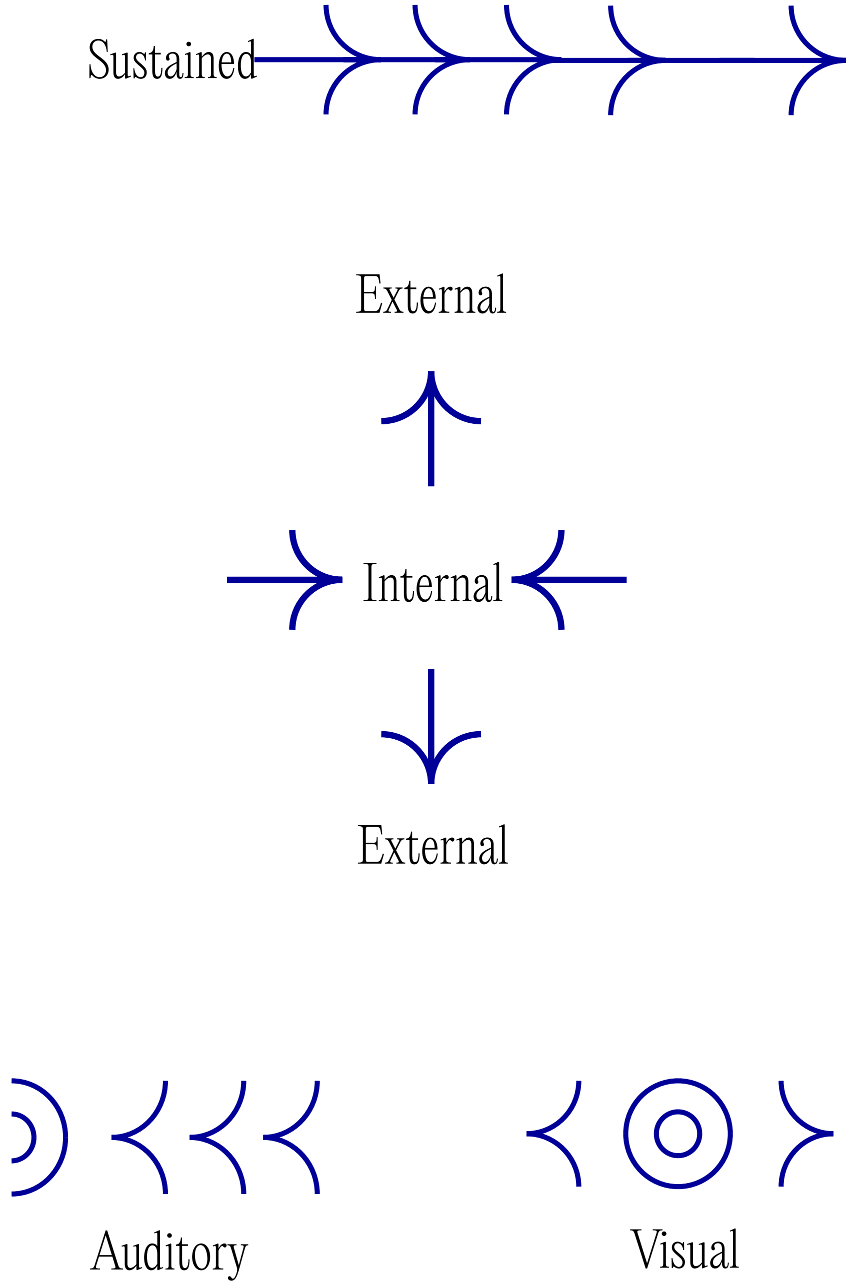
① The quantity of information that we can pay attention to at the same time and the quantity of tasks that we can do simultaneously.

② The ability to be able to change the focusof attention.

③ The amount of attention resources which are paying attention to a given stimulus.

Attention is a general concept, but variations exist in its name when referring to more concrete and detailed aspects; these are usually understood as different types of attention.





Our visual attention, at any given moment, is focused on some parts of the scene, while many portions of the scene go relatively unattended

How many times we were searching for our keys even though they

Even though we have the impression that we see everything in front of our eyes, most of the time we see visual textures rather than objects of our visual field.

Search is guided to a often very small subset of all possible objects by several sources of information. There are several factrors guiding the visual search some of them are listed below.

were right infront of us?

② Top-down, user-driven guidance in which attention is directed to objects with known features of desired targets.

③ Guidance based on the perceived value of some items or features.

① Bottom-up, stimulus-driven guidance in which the visual properties of some aspects of the scene attract more attention than others.

④ Guidance based on the history of prior search.

1

You probably did the same visual journey as the heat map shows.

Qualities including color, orientation and closure are referred to as basic (or guiding) features because they can lead to the deployment of attention.This reveals the principles that the artist used to create the hierarchy of the points of the painting thus, revealing the message.

Other features may be noticeable while paying close attention to an item and may be useful for object recognition, but they do not guide attention.

It's not merely subjective phenomenology that causes this "pop-out”. The term "pop-out" refers to extremely effective guidance

There are two fundamental rules of bottom-up salience. The salience of a target increases with a difference from the distractors (target-distractor heterogeneity) & with the homogeneity of the distractors (distractor-distractor homogeneity) along basic feature dimensions. Bottom-up salience is the most extensively modeled aspect of visual guidance. (Duncan, J. & Humphreys, 1989)

2

NAME THE INK COLOR

red

yellow

green

blue

red

yellow

green

blue

red

NAME THE INK COLOR

red

yellow

green

blue

red

yellow

green

blue

red

Top-down processing involves the brain 'sending down' stored information to the sensory system as it receives information from the stimulus, enabling a plausible hypothesis to be made without the need to analyze every feature of the stimulus.

Although naming the ink color seems like an easy task at first, it gets difficult to identify the color of the presented word if it did not match its semantic meaning.

When the color did not match it required participants to pay more attention to the task at hand.

3

FIND THE FISH

Top-down processing involves the brain 'sending down' stored information to the sensory system as it receives information from the stimulus, enabling a plausible hypothesis to be made without the need to analyze every feature of the stimulus.

Although this seems like an easy task at first, Stroop discovered that participants could easily identify the color of the presented word if it matched its semantic meaning.

When the color did not match the semantic meaning of the word it required participants to pay more attention to the task at hand.

4

FIND THE METAL CAN


ΜΕΡΟΔΟΥΛΙ

FIND THE 

Evidence indicating the observer's prior history, particularly his or her search history, influences attention steering.

The preview benefit has been demonstrated in several studies: when half of the search array is presented a few hundred milliseconds before the rest of the array, the effective set size is reduced, either because attention is directed away from the old marked items (visual marking) and/or towards the new items (visual marking) (onset prioritization). Even for overlearned targets, viewing the qualities of the target searches faster than reading a word cue describing the target. This target feature priming takes roughly 200 milliseconds to generate.

What is interesting is that priming by the characteristics of a previous stimulus can be completely unintentional; simply repeating the target from trial to trial is enough.

The contextual cueing effect is commonly viewed as an abstract type of scene guidance: just as you learn that the toaster is on the counter next to the coffee maker in your friend's kitchen, you learn that the T is in the bottom left corner of a configuration of rotated Ls. In circumstances where guidance is already virtually flawless, such as pop-out search and attentionally-cued search, contextual cueing effects can be detected.

Contextual cueing shows reaction facilitation rather than guidance.

Visual search is largely effortless. Unless we're seeking for clues to find Atlantis in aerial images or looking for Waldo, we usually find what we're looking for in seconds or less. Attentional guiding mechanisms are responsible for this remarkable ability. Design utilize guiding attention to ensure direct and effortless communication

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WHICH LINE
IS LONGER?

PERSONAL
VIEW

We perceive the world around us based on our personal stimuli, our influences, our behaviors & our beliefs.

The two words are equal in length.

Not so obvious when you see then in the context of the picture.

For African natives, this might not be the case. Studies have shown Europeans/ Americans are more susceptible to falling into this kind of optical illusion, as we are familiarized with 2D representations of the 3D world. Different exposure to environmental cues affect to a large sum the susceptibility to this illusion have been noted.

Although our perception is very accurate, it is not perfect, especially in our visual perception, illusions occur. Our visual perception is an intricate jigsaw puzzle with pieces that fit together in many ways, so trying to decode the role of personal bias behind it can help us figure out the whole visual cognition.

When you see the lines out of the picture's context , you can come to a different conclusion.

Now clearly the two words are equal.

WHICH ONE OF THE PAINTINGS IS ASIAN AND WHICH EUROPEAN?

見立 士農工商
豊国画
豊国画
豊国画
①
②
③


2
1
3

An easy task right?

There are a lot of factors that helped you make a decision. In these paintings, we see illustrated how different cultures see the world.

① In Japanese painting we can see that in most cases there is no main focus point, in contrast to European engraving, where there is a clear focal point. Interestingly enough, if you ask Japanese participants to describe the scene they're more likely to start with a recap of the context, whereas European participants tended to start with prominent elements in the display.

② Spatial details are meticulously depicted in Japanese paintings compared to European ones, as the facial characteristics of people are treated with care in each feature. This supports the hypothesis that Asians, unlike Europeans and Americans, pay more attention to the "whole" of a stimulus.

③ We can also see differences in the way they choose to frame their topic. In the former, they tend to depict individuals as part of a larger context and generally include more content. Whereas in European art, they choose to place the human at the center.

Usually emotion & visual perception are considered separate domains of study although it seems to be a connection between them.

Fear, for example, can influence visual processes, whereas sad moods can increase sensitivity to visual illusions and goal-directed desires can modify the apparent size of goal-relevant objects.

Emotional moods can also impact the layout of the physical environment, such as the seeming steepness of a slope and the distance from a balcony to the ground. We propose that emotions give embodied information about the costs and rewards of predicted acts, information that may be used automatically and promptly, obviating the need to consider future actions' implications.

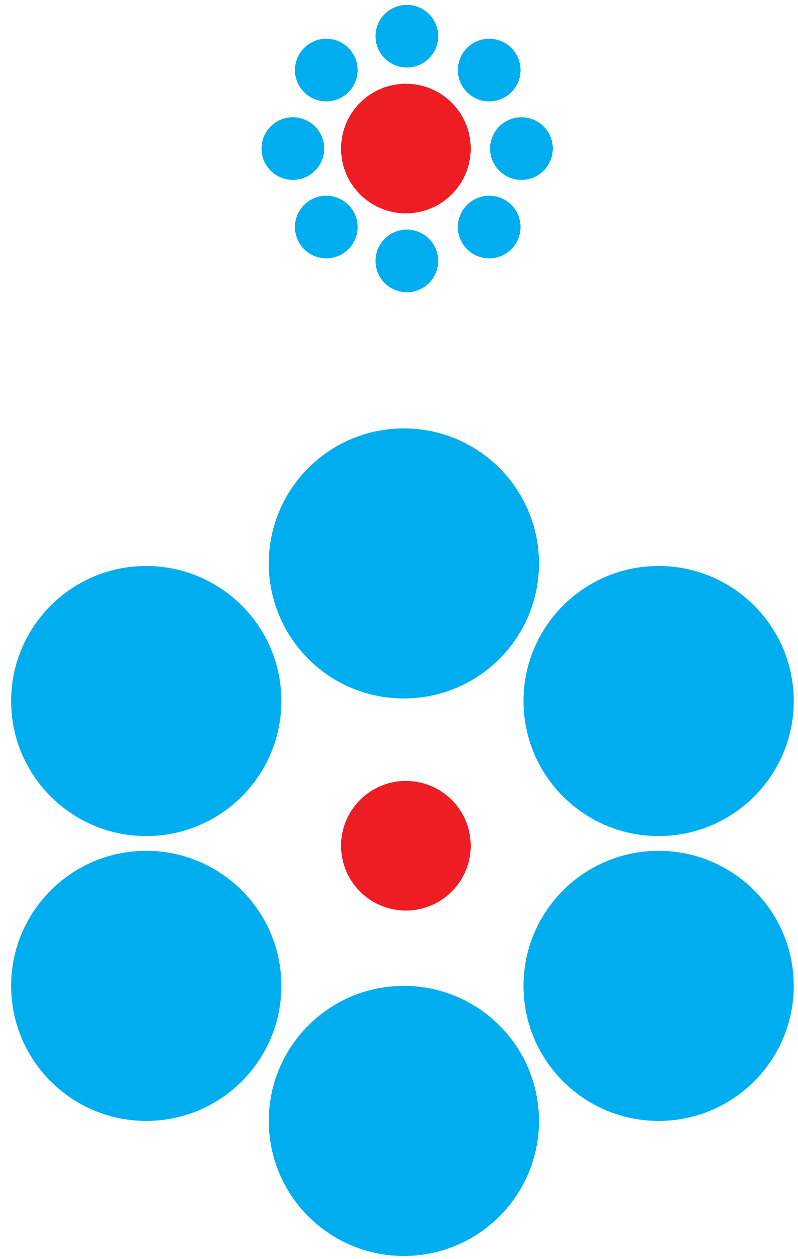
As a result, emotions have a powerful motivating influence on how our reality and environment are perceived.

Emotional influences on perception evolve to minimize negative and maximize positive outcomes, in communication.

It's important to remember that emotion is partly based on perception.

Many emotions occur spontaneously in response to emotionally evocative events, some requiring more interpretation (increasing gas prices), and others requiring less (snakes, spiders)

COMPARE THE RED CIRCLES?

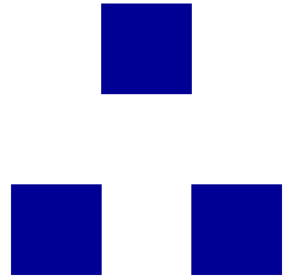


Sad moods were observed to reduce context effects and improve judgment accuracy.

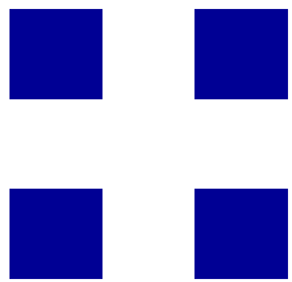
This illusion we see is a visual contrast effect in which the same target circle seems smaller when it is surrounded by large circles and bigger when it is surrounded by small circles. The illusion is extremely compelling, but new research suggests that melancholy moods lessen the illusion's effectiveness.

In the current context, this phenomenon is intriguing since it implies that emotional factors may have equal impacts on perceptual and intellectual processes. Sad moods interfere with normal relational processing (processing incoming information with respect to present mental context), leading to item-specific or referential processing, according to explanations.

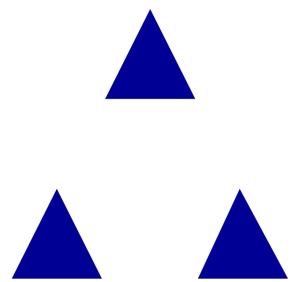
MATCH THE TARGET
FIGURE WITH
THE COMPARISON
FEAGURE AT THE
BOTTOM THAT
IS MOST SIMILAR



target
figure



comparison
figure 1



comparison
figure 2

if you choose

comparison figure 1 → sad :(

comparison figure 2 → happy :)

The objective is three little squares organized in the shape of a triangle, as depicted. Then we asked to choose which of the two comparison figures is the most similar.

A triangle made up of small triangles is one comparison figure, while a square made up of small squares is the other. Because the goal figure was made out of squares, a local response would be to choose the figure with squares. Because the general shape of the objective figure was a triangle, a global response would be to choose the figure with triangles.

When researchers induce happy or sad moods (for example, by having participants write about a happy or sad event in their lives for a few minutes), participants in happy moods are more likely to adopt a global perceptual style, whereas those in sad moods are more likely to adopt a local perceptual style.

Thus, one's current emotional state influences whether one concentrates on the global forest or the local trees.

These findings suggest that, rather than reflecting a direct link to perception, positive affect can empower (and negative affect can inhibit) either a big or small view, depending on which is dominant in a given situation.

For example, acrophobia is one of the most common phobias, and recent findings suggest that acrophobics perceive the world differently than the rest of us. People with acrophobia may have this sensation as a result of seeing heights to be greater than those of us who do not have the phobia.

Perception, cognition, emotion are all intertwined. Each of us creates a unique system. Cultural variations (both physical and social) play a role in perceptual differences between populations. Emotion affects the way we see. Perception can be systematically altered in ways that may aid communication. Maybe by learning how it works we can overcome barriers.

έ

IN WHICH FLOOR
ARE YOU?

DIFFERENT
WAY OF SEEING

1ST FLOOR
2ND FLOOR
3RD FLOOR
4TH FLOOR
5TH FLOOR

NOW?

1ST FLOOR

2ND FLOOR

3RD FLOOR

4TH FLOOR

5TH FLOOR

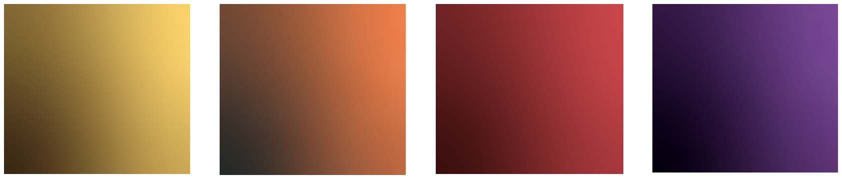
Much easier right the second time?

By using a simulation method, we examined how people with color blindness perceive hues. Color-vision deficiency can have a significant impact on daily activities like cooking, driving, reading, orientation, and shopping (Color Blindness, n.d.; Skupien, 2013).

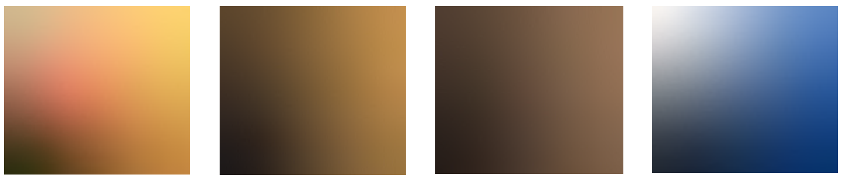
Color is an important means of conveying information. In communication systems, including signage, books, maps, websites, and electronic devices color plays an important role. However, as most of these systems are designed for people who can distinguish colors, people with color blindness often find it difficult to read or understand information.

Color blindness, or color vision deficiency, is the inability to perceive differences between certain colors. Globally, about 1 in 12 men (8%) and 1 in 200 (0.5%) women sees color differently from most of the population (National Eye Institute [NEI], 2015)

Normal vision



Color-blind vision*



① ② ③ ④

① Yellows appear yellowred for the color blind

Saturation levels are similar for both kinds of vision

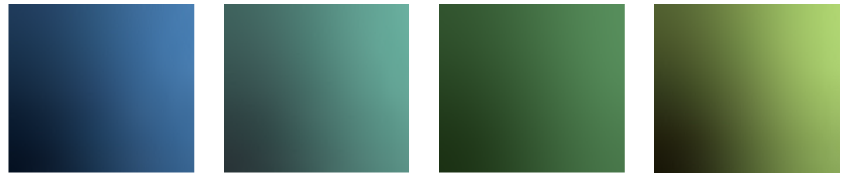
② Oranges look dull with less saturation for the color blind

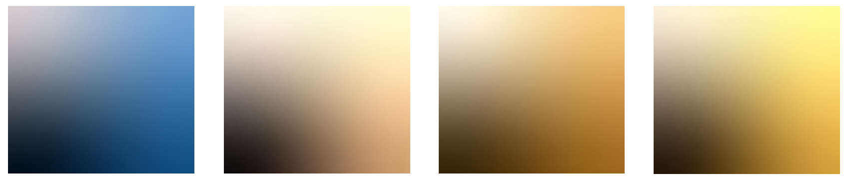
③ Reds look neutral with almost no red (very low saturation) for the color blind

④ Purples look blue with no red at all for the color blind

Similar saturation level for both kinds of vision

* DEUTERANOPIA COLOR BLINDNESS.





⑤ ⑥ ⑦ ⑧

⑤ Blues look grayish blue for the color-blind

⑥ Blue-greens look like less saturated yellow-reds with no green at all for the color blind

⑦ Greens look very similar to yellows (Y on NCS) for the color blind

⑧ Yellow-greens look yellow-red with no green at all for the color blind

Similar saturation

Due to the lack of contrast between the backgrounds of signs and the lighting, road and traffic signs are difficult to read for those who are color blind, according to Cole and Lian (2006). To make maps, GPS systems, graphic presentations, or cautionary cautions understandable to the color blind, it is helpful to incorporate supplemental forms of information such as color names, graphic symbols, or patterns.

Color becomes a more significant tool for communicating information. As a result, colorblind persons have even greater challenges, as many color apps are still developed with people with normal vision in mind.

Given that color-blind people frequently use public places, designers should pay more attention to avoiding problematic color combinations and instead of using color-blind-friendly color schemes when creating public and commercial places..

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T h e p r o b l e m i s i n t h e w a y t h e m i n d i n t e r p r e t s w h a t t h e e y e s s e e - - l i k e a n o p t i c
e x c e p t t h i s m i s m a t c h b e t w e e n w h a t i l l u s i o n a n d r e a l i t y h a p p e n s w i t h o r d i n a r y p r i n
T h e p r o b l e m i s i n t h e w a y t h e m i n d i n t e r p r e t s w h a t t h e e y e s s e e - - l i k e a n o p t i c
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The problem is in the way the mind interprets what the eyes see -- like an optical illusion, except this mismatch between what illusion and reality happens with ordinary print on a page. The problem is in the way the mind interprets what the eyes see -- like an optical illusion, except this mismatch between what illusion and reality happen
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Trying to read the previous page seems impossible.

Every day we read hundreds of words from text messages from our loved ones to road signs, to the nutrition labels of our favorite chocolate bar, to our favorite book. Reading is clearly a visual process that we do effortlessly every day is not always so easy always. Developmental dyslexia, a learning disability specific to reading, affects an estimated 5% of children in school.

Reading requires the processing of both the visual information from the page and the linguistic information that the print represents.

We found a similar consistency of curve profiles between dyslexic and non-dyslexic readers when we measured reading rates by luminance contrast of text and background (O'Brien, Mansfield & Legge, 2000).

Thus, print size and print contrast are visual variables for which dyslexic reading speed exhibits the same qualitative dependence a skilled reading.

Significant spatial frequency bandwidth is usually required for letter recognition and reading.

For word identification & reading, letter recognition alone is insufficient; inter-letter effects must also be considered.

The argument that dyslexic readers require larger print to compensate for a higher or broader spatial frequency bandwidth for reading does not account for the data because if this were the case, reading performance would improve as the print size was increased. Similarly, the theory that dyslexic readers have a unique print size where their reading performance peaks due to differential sensitivity to specific spatial frequencies was disproved. There were no points above crucial text size where dyslexic readers might read more efficiently.

QGpq B81Iil

O0sa B81Iil

QGpq B81Iil

O0sa B81Iil

Here we see the design in practice.

Even when using the textured paper we could clearly define the character.

For low vision readers, certain letters and numbers can be hard to distinguish from one another but by designing letterforms that increase character recognition such limitation can be overpassed.

The good attributes this font displace are:

/ Recognizable Footprints

/ Differentiated letterforms

/ Unambiguous Characters

/ Exaggerated forms

/ Opened Counterspace

/ Angled spurs and differentiated tails

/ Circular Details

Accessibility in design has a lot of advantages for all users. This is because accessibility elements that benefit people with disabilities also benefit everyone else. Demanding environments will present barriers to many users, regardless of their abilities. Abilities, you can create products and services that everyone can find useful and enjoy.

CONCLUSION

By now we have seen that communication happens in a diversity of environments, each with its own language, culture, and semantics.
vre in between art and science.

In the research community, design as a recognized discipline is a relative newcomer.

Design exists somewhere in between art & science.

When approaching the design process with only the scientific method the outcome could not be anything but single-sided if not sterile; likewise, the design could not exist if the artistic values were the only matter, a blend of the two is necessary.

The only guide of design is the ever-evolving human visual perception.

In trying to make prognoses about the future, the cognitive process usually starts with the past, touches on the present situation, and adapts to the future to predict. As we live in a very fluid world, new technologies emerge quicker than ever and affect every aspect of our lives, I cannot be very well equipped to forecast developments in design.

But, I look forward to a more inclusive and transdisciplinary approach to the design processes.

RESEARCH

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Effects of Hue, Saturation, & Brightness on Preference

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Abstract: A study was done to investigate preference responses for foreground– background color relationships.

To do this, 123 university undergraduates in Ankara, Turkey, were asked to view eight background colors selected from HSB color space on which color squares of differing hues, saturations, and brightnesses were presented. Subjects were asked to show the color square they preferred on the presented background color. Findings showed that colors having maximum saturation and brightness were most preferred. Blue was the most preferred hue regardless of background. The findings for preferences for foreground–background color relationships are also included in this article

Introduction

To prefer is to like better or best. In this study the term preference was considered synonymous with "pleasantness" and "appeal," in the sense the study participants were asked to select the color squares that "suited most to" or "looked good on" the background. Preference, pleasantness, and appeal all suggest subjectiveness. Although preference is to some extent specific to individuals, there are many questions surrounding the complexity of the issue. The extent to which preferences on color combinations reflect personal "taste," reflect culture, are universal or biological, and are influenced by fashion trends at the time are all unanswered issues at hand. Despite these variables, many, including Birren,[1] Chevreul,[2] Munsell,[3] and Itten,[4] have studied color, developing theories by their experiences. In this article these studies are designated as expert views. Note that the expert views did not use controlled-environment setups. Guilford,[5] Smets,[6] and Eysenck[7] did experiments within a controlled environment on color preference, in which color was treated in isolation.

Although a single color in isolation may incite preference responses, in actuality colors are rarely viewed in isolation. Color combinations involve more than one color stimulus being perceived simultaneously. This occurrence may evoke visual sensations that differ from those that result from a single color stimulus. Color combinations have not been studied as widely and intensively as colors in isolation. Studies on preferences for color combinations include those by Helson and Lansford8 and by Camgo z.9.

The intention of this study was to explore the effects of hue, saturation, and brightness on preference for colors presented on colored backgrounds.

Research Hypotheses

The following hypotheses were investigated to reveal foreground– background color relationships:

1. Hue has an effect on preferences for a specific background color.
2. Varying brightness–saturation levels of color samples have an effect on preferences for a specific background color.
3. The hue of a background has an effect on preferences for color samples.
4. The location of a color sample on the computer screen has an effect on preferences.
5. Gender has an effect on color preferences.

The experiment

Experimental Setup

The experimental setup consisted of a computer monitor in a windowless room illuminated with cove lighting (Fig.1). Cove lighting was preferred as it excluded the possibility of glare on the monitor and created a perfectly diffuse environment without any highlights that might have distracted the subjects. Standard Philips TL 54 fluorescent with a 6200 color temperature (CT) and a 72 color rendering index (CRI) was used in the coves for lighting the room.

The computer monitor was set to 1024 768 HiColor (16 bit), all desktop patterns were turned off, and the background color on the monitor was set to a light gray (hue 0, saturation 0, luminance 200; red 212, green 212, blue 212). The calibration was set as: contrast 240; brightness 230; B 140. The Photoshop monitor setup was: gamma 2.0; white point 6500 K; phosphors Trinitron; ambient light medium; gamma (calibrate) 12; white point: all RGB 255; balance: all RGB 0; black point: all RGB 0. The display was spatially uniform and channel independent, which was tested with chromameter measurements.

TABLE I. Brightness–saturation levels that are most preferred on specified backgrounds.

Background Color	Preferred Brightness – Saturation
Red	BS100 (21%)
Yellow	BS100 (23%), B75 (17%), B50 (17%)
Yellow-Green*	BS100 (26%)
Green	BS100 (29%)
Cyan	S25 (24%), BS100 (17%), S50 (14%)
Blue	BS100 (33%)
Purple	BS100 (28%), S50 (26%)
Magenta*	BS100 (22%)

* The mean for BS100 was not singled out in the statistics, thus the response distributions were used.

TABLE II. Hues that are most preferred on specified backgrounds.

Background Color	Preferred Color
Red	Blue (35%)
Yellow	Blue (23%), Red (17%)
YellowGreen*	Blue (19%)
Green*	Blue (21%)
Cyan	Blue (44%)
Blue	Purple (21%), Red (22%), Magenta (20%)
Purple	Magenta (36%)
Magenta	Blue (43%)

* No statistically significant hues were differentiated for these backgrounds, thus inclinations from response distributions have been included.

Experimental Procedure

One hundred twenty-three undergraduate students studying in art/design-related departments were presented image sets displayed on a computer monitor. Each image set consisted of a background color selected from HSB (hue, saturation, brightness) color space and 63 color squares of differing hues, saturations, and brightnesses. Every subject viewed and answered the experimental question for the eight background colors.

The experimenter verbally asked each participant: "Which color square would you prefer on the background color on the screen?" No time limits were set for making the decisions. Participants were tested individually over a period of 5–15 min, depending on their response speed.

Despite the quantity of color squares from which to choose (63 color squares for each background), the participants had no difficulty in choosing one over the others. Making a single choice took about 10–15 sec for one participant, although it varied from approximately 5 sec to 50 sec because of variation in individual response speed. No matter how long it took to choose a single color square, none of the participants showed any difficulty or hesitation in making a selection of a single color square.

In addition to the main image set, three more image sets were shown to the participants, who answered the same question for those as well. These supplementary sets were used to investigate the effect of location of the color squares on the choices.

All the participants were students in the Faculty of Art, Design, and Architecture at Bilkent University in Ankara, Turkey. The majority were 20- to 24-year-old (78%) female (59%) second-year students (55%) in the Department of Interior Architecture and Environmental Design (81%). All were from urban areas, with the majority being inhabitants of Ankara (76%); thus, no participants were from diverse cultural backgrounds in small towns or rural areas. Participants with vision deficiencies were asked to take the test wearing the corrective equipment—contact lenses or eyeglasses—hat they wore regularly. There were no participants with severe eye or vision problems, which would have required their exclusion from the test. Participants were also given Ishihara's Tests for Colour-Blindness (Ishihara).[10] Anyone unable to read any of the plates shown could not participate.

Experimental Procedure

Adobe Photoshop 4.011 was used to create the entire image set. The screen area was adjusted to 1024x768 pixels for every image produced. All images were created in JPEG format and RGB mode. The Photoshop color picker function was used to create displayed colors. Foreground and background colors were selected from a color spectrum based on the HSB color model. HSB lets the user choose a color with a hue from 0 to 360 , with saturation and brightness values from 0% to 100%.

The main image set consisted of eight images, each with a different background color. All the background colors were fully saturated (100% saturation) and fully bright (100% brightness). The angle for hue was defined as an angle relative to pure red on the color circle. Hues were selected from the standard color circle beginning with red (0), continuing at 45 intervals, and ending at magenta (315). The background colors used are (Fig. 2):

0 Red, 100% saturation, 100% brightness
45 Yellow, 100% saturation, 100% brightness
90 Yellow-Green, 100% saturation, 100% brightness
135 Green, 100% saturation, 100% brightness
180 Cyan, 100% saturation, 100% brightness
225 Blue, 100% saturation, 100% brightness
270 Purple, 100% saturation, 100% brightness
315 Magenta, 100% saturation, 100% brightness

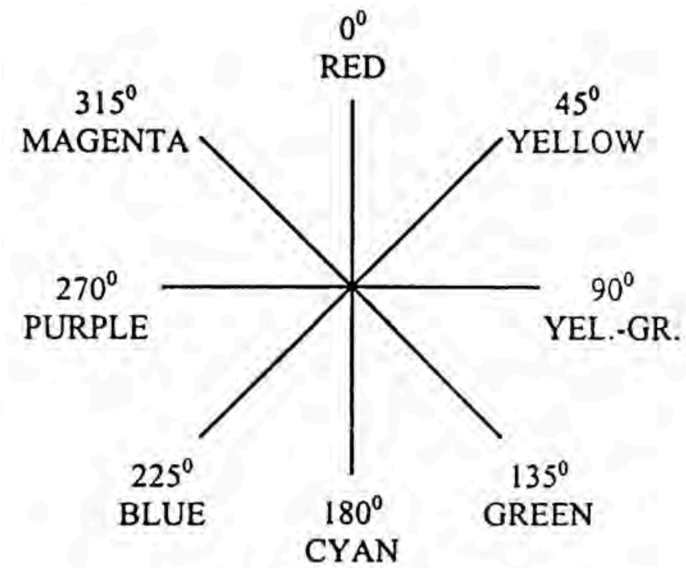


FIG. 2. Color circle used.

On every background color all the remaining hues (excluding the background hue) were represented in seven rows. Each hue row was then divided into nine columns, in each of which the hue was represented with varying brightness and saturation levels. Explanations and examples of the images are included in Appendix A.

Three different supplementary image sets were prepared to test the location effect. The researcher investigated whether any particular brightness–saturation range (column) or hue range (row) was preferred independent of its place in an image. The first two image sets were scrolling sets. In one set, the rows (hues) scrolled downward and in another the columns (brightness–saturation) scrolled to the right. The last supplementary set was a rotating set, in which the whole image was rotated clockwise at 90 intervals (0, 90, 180, 270). All the supplementary sets were applied on four background colors, which were paired as angular opposites of each other on the HSB color circle. The backgrounds used for the supplementary sets were: red 0 – cyan 180 and yellow 45 – blue 225 . Examples of the images for the supplementary sets are included in Appendix A.

Data Analysis

Analysis of variance (ANOVA) was used to calculate the statistics for the collected data. The randomized complete block design was used in data analysis. The data were arranged into homogeneous groups and were compared for a number of treatments. For the main image set the homogeneous groups (blocks) were different amounts of brightness–saturation levels, as presented in columns to the observer, while the treatments were differing hues, as presented in rows to the observer. A research hypothesis is considered statistically significant if the p value of the test is smaller than 0.05.

SAS (Statistical Analysis System) software12 was used in the analysis of the collected data. Each background color was analyzed for column–row effect using the ANOVA procedure, with the columns representing the brightness– saturation and the rows representing hue. The results of the statistical analysis show that hue had an effect on preferences on specified background colors (with p values between 0.0001 and 0.0209), except for yellow-green and green (p 0.9248 and 0.1618, respectively). Brightness– saturation also had an effect on preferences on specific background colors (with p values between 0.0001 and 0.0200). Duncan's multiple-range test was also applied. Pairwise comparison for each possible pair was done using this test, which provided information on the differences between the means of each individual class, brightness–saturation and hue, for the individual background colors. The results from the ANOVA procedure and Duncan's multiple-range test are included in Appendix B, Table I.

Background effect was also investigated by making a data structure. The statistics show a brightness–saturation effect (p 0.0001) and a hue effect (p 0.0001) on any background color viewed. Thus, despite the changing hues of the background, certain brightness–saturation levels and certain hues were preferred over others (100% brightness–saturation and blue; see Appendix B, Tables II and III).

The effect of location was investigated by analyzing the responses for the viewed individual background colors. In these images the positions of the color squares were changed while the background color remained the same.Responses were analyzed statistically for each brightness–saturation and hue range for every image shown. The results indicate a hue effect (with p values between 0.0001 and 0.0014) and a brightness–saturation effect (with p values between 0.0001 and 0.0011), despite the changing locations of the hues and brightness–saturation levels on the computer screen (Appendix B, Tables IV–VII).

An ANOVA analysis was done to investigate gender effect for the main image set. The results revealed no gender effect on preference choices (with p values between 0.0604 and 0.2215; see Appendix B, Table VIII).

Discussion

Analyzing the data required an interpretation of all the p values obtained from the main and supplementary sets (Appendix B). Sometimes the data from the main image set did not significantly differentiate among any color attributes (hue, saturation, brightness), but statistically significant groupings were found for supplementary sets. As the colors shown for every image and the subject group were the same, all statistics were interpreted as a whole. The tables and figures indicating the most preferred color attributes contain statistically significant attributes obtained from Duncan's analysis. If there were no differentiated attribute from Duncan's analysis, but the attribute was still statistically significant,the attributes of the highest percentage from the data for that image were included. All the percentages given were obtained from the main image set.

The BS100 range was significantly preferred by the participants (with p values between 0.0001 and 0.0200; Appendix B, Table I). Therefore, it was found that the brightest and most saturated color squares were preferred on the brightest and most saturated background colors. This finding supports the results of experiments with isolated colors. Guilford,5 Smets,6 Guilford and Smith,[13] and Sivik[14] all stated

that isolated colors that were brighter and more saturated were more preferred. Only Eysenck7 stated a contradicting result, that brighter colors were less preferred. Studies on color combinations, especially the ones with foreground–background color relationships, suggest brightness contrast. Washburn and Grose[15] and Reddy and Bennett[16] demonstrated that in the judgment of experiment participants, the more brightness contrast was increased, the more preferred was a color combination. This argument cannot be evaluated within the scope of this study because in participant preferences there was no brightness contrast between the background and foreground colors and the background colors were presented as a predetermined condition. However, in much of the literature on color combinations how various attributes of background colors enhance the pleasantness of foreground colors with varying background presentations has been investigated. One exception to the preferred BS100 range in the current study was seen with the yellow background, where brightness levels of B50 and B75 were also preferred along with BS100 (p 0.0001, Appendix B, Table VI). On the purple background saturation levels of S50 and S75 were preferred along with BS100 (p 0.0002, Appendix B, Table I). Another exception was observed for the cyan background, for which saturation levels of S25 and S50 also were preferred along with BS100 (p 0.0001, Appendix B, Table V). In the third supplementary image set, a saturation of S25 was preferred over the other brightness–saturation levels for the cyan background (p 0.0001, Appendix B, Table VI).

Regardless of the background colors viewed, the subjects preferred blue the most [Fig. 3 (p 0.0001, Appendix B, Table III)]. This corresponds with the findings of previous experimental research. Wijk et al.,17 Guilford,5 Eysenck,7 Granger,18 and Guilford and Smith13 all found that blue was preferred the most when isolated colors were presented. Sivik14 stated blue was the color preferred in more instances despite its change in brightness and saturation. Saito19 stated that blue was named most when people were asked the color they liked best. Washburn and Grose15 found that blue was the most preferred color regardless of its background.

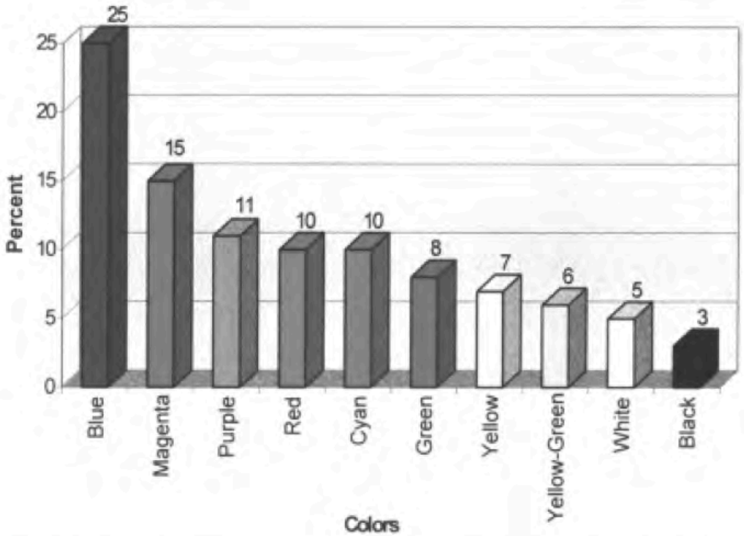


FIG. 3. Percentage scale of preference for hues on any background color.

Data gathered in this inquiry demonstrated that green (8%), yellow (7%), yellow-green (6%), and the noncolors white (5%) and black (3%) were the hues preferred the least (Fig. 3). The studies by Guilford,5 Eysenck,7 Granger,18 Guilford and Smith,13 and Washburn and Grose15 also stated yellow was the least preferred hue.

Blue was preferred on background colors of red, cyan, and magenta. Magenta was preferred the most on the purple background (Appendix B, Table I). For the yellow and blue background colors it was hard to determine if there was any agreement on preference. The results from the main image set for the yellow background showed a scattered distribution of preferences. The first supplementary set (scrolling down) statistically showed a preference for blue, while the last supplementary set (rotating) favored red as the preferred hue on a yellow background. The same participants viewed all the image sets. Thus, it can be concluded that yellow is a difficult background on which to make a hue preference, although there is a considerably significant inclination towardpreferring blue and/or red. A similar difficulty in deciding on

preferences was found for the blue background. No preference was statistically significant for any color set on the blue background in the main image. The results of the first supplementary image set statistically singled out purple as the most preferred hue on a blue background. The results for the last supplementary set (rotating) showed red, magenta and purple as the preferred hues on blue (Appendix B, Tables IV and VII). The yellow-green and green backgrounds had scattered response distributions. Although the participants had no statistically significant hue preference on the yellow-green and green backgrounds, there was an inclination towards blue on these backgrounds.

The findings on foreground–background color relationships presented above do not support the views of Granger,18 Chevreul,2 and Itten4 concerning hue combinations. There does not seem to have been a harmony of either analogous or contrasting colors in making preference judgments. It may be interesting to research the issue further by excluding the dominant blue from the image sets. The exclusion of blue may direct subjects to suggest different color combinations, or it may simply promote another dominant hue. The results of the statistical analysis show that in this experiment neither the gender of the participant nor the location of color squares on the computer screen had a significant effect on color preference (Appendix B, Tables IV–VIII).

Findings on the Research Hypotheses

1. Hue has an effect on preferences on a specific background color.
2. Varying brightness–saturation levels of color samples have an effect on preferences on a specific background color.
3. Despite the changing hues of the background, some brightness–saturation levels and some hues are preferred over others.
4. Despite the changing locations of color samples on the computer screen, some brightness–saturation levels and some hues are preferred over others.
5. Gender does not have an effect on color preference.

Conclusion

Analyses of data demonstrated that all three attributes of color (hue, saturation, and brightness) were important in preferences. Colors having maximum brightness and maximum saturation levels were ranked higher than any other brightness–saturation combination. Previous experimental studies on isolated colors also have suggested an increase in rated pleasantness with an increase in brightness and saturation.

Blue was the most preferred hue regardless of background shown. This confirms the findings of previous studies (Wijk et al.,17 Guilford,5 Eysenck,7 Granger,18 Guilford and Smith13), which found that blue appeared to be the preferred color in isolation. In the present study analyses of individual backgrounds were tabulated according to most preferred hues on specified background colors (Table II).

The results of the statistical tests showed that location and gender had no significant effect on preference in this experiment. The findings showed that the preferred color choices, although statistically significant, encompassed a low percentage of the subjects. The choices did not encompass 45% of the respondents and were usually around 20%. This may suggest a variety in preference choices.

Color has always been considered to be linked with subjectivity, especially where preferences are concerned. Culture also is always believed to have an influence, as is gender. The general preference found for blue in this study supports the findings of previous studies having subject groups of varied cultures. No matter what the background,blue was most preferred. There seems to be a global inclination toward preferring blue regardless of its presented medium. In many cases, blue was also stated as the most likeable color when people were asked their favorite color without any visual stimuli. This finding contradicts the views on color combinations of the experts, who had formulated numerous color pairs based on the premise that pleasurable combinations result from the hue component of color.

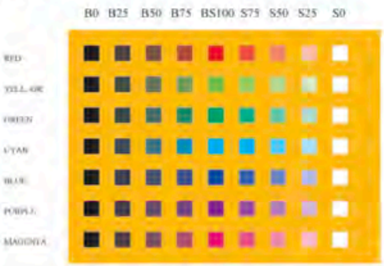
The attributes of brightness and saturation seem to play a great role in creating pleasurable color combinations in abstract representations. The results of this study demonstrated that foreground colors were preferred when their saturation and brightness levels were increased. The participants picked the maximum levels available. The literature review suggests brightness and saturation contrasts to be effective for preference in foreground–background color relationships. It may be interesting to reverse this experiment and present backgrounds of the same hue with varying brightness and saturation levels to find out on which background a specific color square is preferred more. In this way, additional knowledge about the contrast relations between background and foreground may be gained.

Next it is intended to conduct a similar experiment with CIELAB color space and compare the obtained results with those for HSB color space.

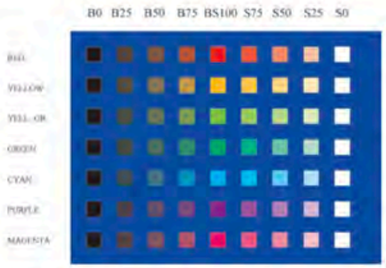
The conclusions of this study should be used with caution, taking into account the limitations and delimitations of the experimental setup, and the characteristics of the subject group involved. The results of the study may be used in computer applications such as computer graphics and Web page design and in luminous signage applications. Moreover, we believe the study has contributed to the available data on this subject by broadening the understanding of color preferences.

APPENDIX A
Two Examples from each Image Set

The Main Image Set: Places of Brightness-Saturation levels and Hues remained the same while background colors were changing.



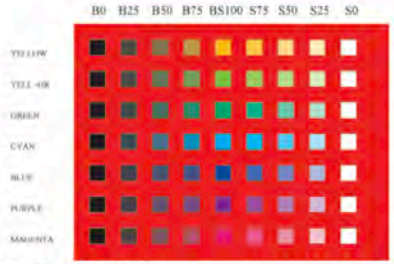
Yellow Background



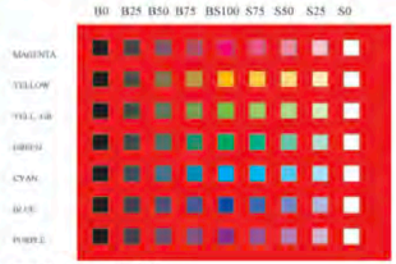
Blue Background

The First Supplementary Image Set (scrolling down): Places of Hues were changing in each image, moving towards one row below. For example, yellow in the first row in the first image would move to the second row in the second image, etc.

APPENDIX A (CONTINUED)

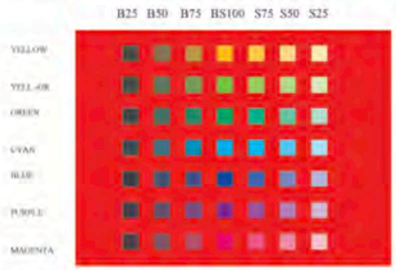


Red Background/ 1st Image

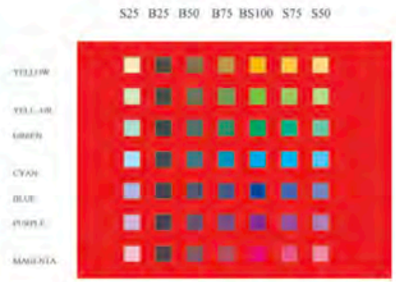


Red Background/ 2nd Image

The Second Supplementary Image Set (Scrolling to the right): Places of Brightness-Saturation levels were changing in each image, moving towards one column to the right. B25 in the first column in the first image would move to the second column in the second image, etc.

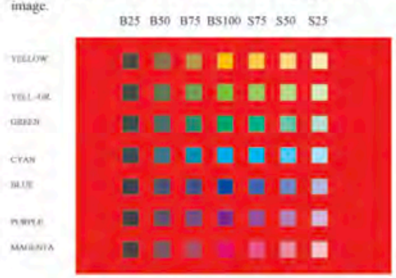


Red Background/ 1st Image



Red Background/ 2nd Image

The Third Supplementary Image Set (Rotating): Images were rotated 90° clock-wise, where places of both Brightness-Saturation levels and Hues were changing with each image.



Red Background/ 1st Image

Red Background/ 2nd Image

APPENDIX B
p-Values and Duncan Groupings

TABLE I. Brightness–saturation and hue effect.

Background colors	*p* values for brightness–saturation	Duncan grouping for brightness–saturation	*p* values for hue	Duncan grouping for hue
Red	0.0128	Overlapping	0.0002	H225-Blue
Yellow	0.0003	Overlapping	0.0209	Overlapping
Yellow-green	0.0033	Overlapping	0.9248	None different
Green	0.0001	BS100	0.1618	Overlapping
Cyan	0.0084	Overlapping	0.0001	H225-Blue
Blue	0.0001	BS100	0.0064	Overlapping
Purple	0.0002	BS100, S50, S75	0.0004	H315-Magenta
Magenta	0.0200	Overlapping	0.0001	H225-Blue

TABLE II. Brightness–saturation and background effect.

	p values for brightness–saturation	Duncan grouping for brightness–saturation
On any background color	0.0001	BS100

TABLE III. Hue and background effect.

	p values for hue	Duncan grouping for hue
On any background color	0.0001	H225—blue

TABLE IV. Hue effect for the first supplementary image set (scrolling down).

Background colors	*p* values for hue	Duncan grouping for hue
Red	0.0001	H225—blue
Yellow	0.0001	H225—blue
Cyan	0.0001	H225—blue
Blue	0.0001	H270—purple

TABLE V. Brightness–saturation effect for the second supplementary image set (scrolling to the right).

Background colors	*p* values for brightness–saturation	Duncan grouping for brightness–saturation
Red	0.0001	BS100
Yellow	0.0011	Overlapping
Cyan	0.0001	S50, S25, BS100
Blue	0.0001	BS100

TABLE VI. Brightness–saturation effect for the third supplementary image set (rotating).

Background colors	*p* values for brightness–saturation	Duncan grouping for brightness–saturation
Red	0.0005	BS100
Yellow	0.0001	BS100, B50, B75
Cyan	0.0001	S25
Blue	0.0001	BS100

TABLE VII. Hue effect for the third supplementary image set (rotating).

Background colors	*p* values for hue	Duncan grouping for hue
Red	0.0014	H225—blue
Yellow	0.0001	H0—red
Cyan	0.0001	H225—blue
Blue	0.0001	H0—red, H315—Magenta, H270—Purple

TABLE VIII. Gender effect on the main image set.

Background colors	*p* values for gender	Duncan grouping for gender
Red	0.0667	None different
Yellow	0.0604	None different
Yellow-green	0.1465	None different
Green	0.0635	None different
Cyan	0.1106	None different
Blue	0.0686	None different
Purple	0.2215	None different
Magenta	0.1482	None different

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The influence of colour on visual search times in cluttered environments

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Fifty subjects participated in a series of visual search tasks where the aim was to explore the influence of colour on visual search times for targets situated in a series of cluttered distractor fields. The results supported previous findings regarding the effect of colour and showed that, even in cluttered environments, certain hues helped in the reduction of search times. The findings also indicated that there were interaction effects between the colour and positioning of the targets in the distractor fields.

Introduction

Point-of-purchase displays

Consumers usually only look at a small percentage of all the stimuli presented to them in a retail environment (Park et al., 1989; Inman and Winer, 1998). Hence, it is important to establish how design elements in that environment can be manipulated in order to maximize their impact. Point-of-purchase displays have been shown to possess the capacity for captivating consumers' attention and can at times increase sales by as much as 50% (Inman et al., 1990; Bemmaor and Mouchoux, 1991). It is such evidence that has encouraged companies to invest increasingly larger portions of their marketing budgets on point-of-purchase displays (Kahn and McAlister, 1997).

An important factor contributing to the success of point-of-purchase displays (Park et al., 1989) is the fact that between one-half and two-thirds of all purchase decisions are made at the point of purchase (Frontiers, 1996; Inman and Winer, 1998). However, it is not known how point-of-purchase displays manage to capture consumers' attention and why they are preferred over other stimuli present in retail environments.

Because of the high number of stimuli presented simultaneously within the shopping environment, consumers' perceptual and behavioural responses are generally automatic and at a subconscious level. Bearing this in mind it should come as no surprise that much of consumer behaviour happens with minimal or no awareness (Kirsch and Lynn, 1999). Specific brain regions that respond to environmental novelty in the absence of awareness have even been identified (Berns et al., 1997).

Since it is known that consumers respond to in-store stimuli with little awareness it is useful to establish how various design elements can reduce the search time in the visual search process. A point-of-purchase stand that attracts attention eliminates the possibility that another stimulus will distract customers' attention (i.e. a competitor's brand).

Clutter in the consumer environment

Paradoxically, the high number of fancy displays and products within the retail environment functions as an obstacle when trying to communicate effectively with consumers. All the different stimuli form a barrier of clutter that consumers neither have the time nor the desire to attend to. The clutter bombards our senses and demands an intense simultaneous processing of information.Our selective perception filters out information that is not compatible with our existing values (Lewin, 1951). The only stimuli that may 'break through' such protection are novel elements that need further processing.

Visual search targets

Visual information is the most common way for individuals to acquire information about brands in consumer choice environments. Humans tend to search visually for a target in most settings and research has shown that, when doing so, they tend to start at the upper left corner of the visual field and work their way down, in a similar fashion to the process of reading (Megaw and Richardson, 1979). However, it is worth bearing in mind that, since this is a learnt behaviour, such visual search patterns are likely to be culture specific.

It has been suggested elsewhere that colour is one design element that can assist in attracting consumers' attention and can also help captivate it (Danger, 1987). This may be why colour can help reduce the visual search time.

A consistent finding is that search times and errors increase with the number of distractors in a search display (Eriksen and Spencer, 1969). It has been established that search times also increase when the targets and the non-targets are of similar colour (Farmer and Taylor, 1980;D'Zmura, 1991) and that the speed of the visual search depends on how easily the target item enters the visual short-term memory (Duncan and Humphreys, 1989, 1992). It is also known that, when a specific stimulus is similar in colour to the background it is presented against, it tends to reduce the attentional value of the colour (Farmer and Taylor, 1980). However, simply knowing that search times increase linearly with the amount of distractors in a display is not very helpful information when trying to create new displays for cluttered commercial environments. Instead there is a need for establishing whether certain design elements such as colour can help reduce search times in such cluttered and often chaotic settings.

The importance of colour

In a commercial context the design elements in the physical environment are of great importance, particularly colour, since it can attract consumers to a product (Bloch, 1995). However, there are very few studies that have documented the effects of colour on behaviour (Davidoff, 1991; Gorn et al., 1997) and generally the previously reported effects of colour in producing changes in mood states are artefacts of poor experimental design and the demand characteristics of the research context (Davidoff, 1991). Although there is little systematic empirical research on the effects of colour it is widely accepted within marketing circles that there are three independent properties of colour: hue, saturation and value (Thompson et al., 1992). Hue is the pigment of the colour, saturation is the proportion of pigment within the colour and the value is the degree of darkness or lightness of the colour.

However, there are more robust findings in colour research that have shown that hue is an effective tool for reducing visual search times when trying to locate a specific target in a scene (Williams, 1966; Carter, 1982). These results can be usefully translated into a retail context in the sense that, if the consumer finds what they are searching for quickly, then there is less opportunity to be distracted by other stimuli (e.g. the displays of competitors' products).

Previous research that has investigated the relationship between colour and visual search times has mainly focused on 'colour-singleton' search (i.e. the search for a single, odd-coloured item among homogeneously coloured distractors) and as a result has failed to address the question of which colours have maximum impact in cluttered, multicoloured environments.

Eleven basic colours have been identified, which are consistently recognized with minimal response times (Boynton, 1988; Davies and Corbett, 1995). These are white, grey, black, red, green, yellow, blue, orange, pink, purple and brown. Generally, any colour attracts more attention other than black and white (Evans et al., 1997).

The aim of this study was to establish whether a particular colour can function as an aid for reducing search times for a given target in a multicoloured and cluttered environment, similar to that found in many retail contexts.

The following two hypotheses were tested
.

H1: The speed of target detection in a cluttered scene will be influenced by the target colour.

H2: Basic colours will be detected more rapidly than non-basic colours.

Methodology

Participants

Fifty participants from a large UK university participated in the individual laboratory sessions. Twenty-three of the participants were male and 27 were female. The age range was 18–54 years (mean = 29.74 years). The participants were volunteers recruited by the experimenter from a number of different undergraduate courses and could be considered motivated by an outline of the study. The sample was a convenience one.

Stimuli

A 6x2x4 within-subjects design was created for measuring whether colour has the capacity for influencing the time it would take to identify the accurate target in a cluttered setting and whether the basic colours would be detected more rapidly. For this purpose a restricted palette of colours was used in the experiment. The decision to use the hues red, blue, green, turquoise, beige and peach was based upon the fact that red, blue and green are a part of the 11 basic colours, which are recognized with minimal response times. Turquoise, beige and peach were chosen since they are not part of the basic 11 colours and should therefore theoretically take longer to find in a visual scene.

After selecting the hues, a fixed value and saturation was used for each (value = 129 and saturation = 255). A variety of different shapes were used for producing the background, including the target shapes of a circle and a square. These shapes were coloured and distributed in a random array as the background for the target search, simulating the 'cluttered' retail environment that is typically encountered by the consumer. The targets presented for the participants to identify were either a coloured circle or square. The target was always present in the background and, thus, available for a 'positive' identification.

All colour search experiments reported were set up using a Dell computer and the stimuli were presented on a Panasonic Panasync four-colour computer monitor that was 28.5 cm wide and 21.5 cm high. The 'cluttered' background containing a specific target was presented using a modified Microsoft PowerPoint programme that allowed the experimenter to time (in seconds) how long it took for a subject to detect the target stimulus.

Each target screen had a high number of distractors with a similarity between targets and nontargets. Previous studies have shown that search times increase with the number of distractors (Eriksen and Spencer, 1969) and with the hue similarity of targets and non-targets (Farmer and Taylor, 1980; D'Zmura, 1991). Based on these previous studies where, for example, it took D'Zmura's (1991) participants a minimum of 700 ms and a maximum of 2000 ms to find an orange target amongst 32 yellow and red distractor targets, it was expected that the response time in this experiment would be between 1 and 3 s.

Each experimental run consisted of 96 slides, of which 48 slides showed the target stimulus and 48 slides were search screens. All of the target colours (red, green, blue, turquoise, beige and peach) used in the experiment had the same saturation (255) and were presented in the shape of either a circle or square. Using two different shapes controlled for the possibility that the participants were responding to the shape of the stimuli rather than the colour. The search screens all consisted of 225 different-shaped and coloured distractor targets (with the saturation and value controlled), ten of which were the same shape as the actual search target and five of which were of the same hue but completely different in saturation and value. The order of the distractor targets was altered in each one of the search screens so that the subjects would not become too familiar with a particular sequence.

Based upon previous findings that humans tend to search visually for a target starting from the top left and work their way down from left to right (Megaw and Richardson, 1979), the screen was hypothetically divided into four equal segments, forming a 2x2 matrix. The target was positioned in one of the four segments on each search screen and this was repeated so that each target stimuli appeared in all four positions. Position 1 was in the top left 'square', position 2 was the top right 'square', position 3 was the bottom left 'square' and position 4 was the bottom right 'square' of the screen.Four different positions were used for each colour target in order to control for the influence that 'position' might have on the response times. As the participants conducted the visual searches, the experimenter recorded whether or not the participant identified the search target accurately. When the participant identified the target on the screen with the mouse pointer and clicked on the search screen a new target for the next search exercise was presented automatically.

Procedure

The participants were seated in front of the computer, with the screen approximately 70 cm away from them. The aim of the particular task was explained together with their rights in line with the British Psychological Society ethical guidelines.

Each experiment started with a screen consisting of only one stimulus, which was a square or a circle, coloured either red, green, blue, turquoise, beige or peach. The subjects could look at the target for as long as they wanted and when they were ready they were instructed to click on the screen to make the corresponding search screen appear.

The subjects then had to search for the stimulus they had seen on the previous screen with the cursor. Once they found the target they had to point on it with the mouse and click. This timed the search process from leaving the target screen to identifying the target on the distractor screen. The next target screen would then appear automatically, again consisting of a single stimulus. This procedure was repeated until all of the 48 target stimuli had been presented to the subject. Four different screen arrangements, which were randomly assigned to the different participants, were used in order to control for possible order effects.

TABLE 1. Fastest and slowest mean search times

Target	Mean search time (s)	Accuracy (%)	Target	Mean search time (s)	Accuracy (%)
Ten fastest			Ten slowest		
Square green 4	1.78	98	Square red 3	3.76	90
Circle blue 4	1.82	98	Circle blue 3	3.88	88
Square beige 2	2.12	90	Square peach 3	3.88	76
Circle green 3	2.16	92	Circle peach 3	3.92	93
Circle red 2	2.20	88	Square peach 1	4.14	88
Circle green 4	2.28	92	Square beige 4	4.34	90
Circle peach 1	2.30	86	Square green 1	4.38	92
Square red 2	2.46	98	Square peach 2	4.50	82
Square green 3	2.46	94	Square peach 4	5.18	76
Square blue 3	2.50	96	Circle beige 2	6.62	88

Results

The influence of colour on the subjects' visual search time was analysed using a repeated measures ANOVA in a 6x2x4 (hues shapes position) design.

Table 1 shows the ten quickest and the ten slowest search times. Stimuli with less than a 75% accuracy level were not included in the table. Examining the ten quickest search times in Table 1 it can be seen that there was an even distribution in the positioning of the targets between matrix segments 2, 3 and 4: however, a target in position 1 only appeared once. The most salient colour appeared to be green (four hits from ten), followed by red and blue (each with two hits from ten) and then beige and peach (each with one hit from ten).

The ten slowest search times indicated that position had an effect on influencing search times. Position 3 appeared most frequently (four hits from ten), followed by an equal distribution of positions 1, 2 and 4 (each with two hits from ten). Peach was the most salient colour for a slow response time (five hits from ten), followed by beige (two hits from ten) and then red, blue and green (each with one hit from ten). The test for sphericity indicated that the variance was unequal and, therefore, the more conservative Greenhouse–Geisser was used for significance decisions. The analysis of variance for within-subjects effects showed that both colour ($F_{5,240}$ = 15.108 and p = 0.000) and colour/ position ($F_{6.8,330}$ = 6.144 and p = 0.000) and their interactions were significant.

It can be seen from Table 2 that overall the colour green had the fastest response time with a mean value of 1.92 s and this was closely followed by blue with a mean of 1.93 s and then red with a mean value of 2.08 s. All of the secondary colours had the slower response values, with the peach colour being the slowest.

TABLE 2. Estimated marginal means for the colour response times

Colour	Response times (s)
Green	1.92
Blue	1.93
Red	2.08
Turquoise	2.12
Beige	2.43
Peach	2.63

TABLE 3. Estimated marginal means for the position response times

Position	Response times (s)
1	2.12
2	2.31
3	2.15
4	2.16

Table 3 shows that there is a difference in the mean values according to the position of the target. Positions 1, 3 and 4 had similar response times on average, ranging from 2.12 to 2.16 s, while position 4 had the largest mean response time of 2.31 s (p = 0.075).

Figure 1 indicates that targets placed in position 1 (top left-hand side of the screen) had similar search times regardless of the colour of the search target. It also shows that the search times for positions 2, 3 and 4 were more dependent on the colour of the target. Blue and green targets had the quickest search times when placed in position 4 and red targets when placed in position 2 (p = 0.000)

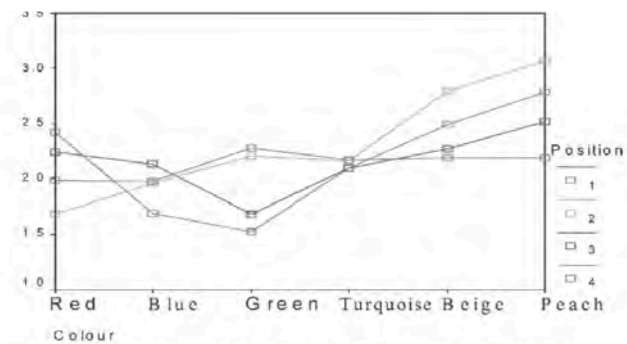

FIGURE 1. Mean search times for interaction effects: position × colour.

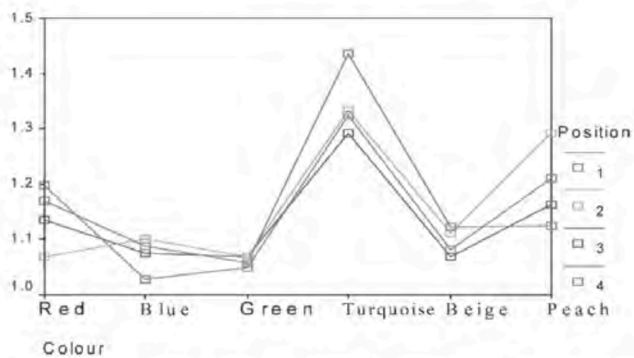

FIGURE 2. Interaction effects: accuracy × colour × position (1 = 100% accurate and 2 = 100% inaccurate).

TABLE 4. ***Post hoc* test for colour**

Collated colours	*t*-value	d.f.	Significance
Blue and peach	–5.764	49	0.000
Blue and beige	–3.788	49	0.000
Green and beige	–3.989	49	0.000
Peach and green	5.455	49	0.000
Peach and turquoise	6.225	49	0.000
Red and peach	–5.371	49	0.000
Red and beige	–3.490	49	0.001
Turquoise and beige	–3.305	49	0.002
Red and blue	1.607	49	0.115
Red and green	1.575	49	0.122
Peach and beige	1.288	49	0.204
Red and turquoise	0.924	49	0.360
Green and turquoise	–0.587	49	0.560
Blue and turquoise	–0.531	49	0.598
Blue and green	0.210	49	0.835

The mean times for each one of the colours were as follows: Green = 1.92, Blue = 1.93, Red = 2.08, Turquoise = 2.12, Beige = 2.43 and Peach = 2.63.

When examining the accuracy level for position taking the colour of the target into account, it can be seen that the accuracy level (correct identification of target) was highly dependent on the colour. The poorest identification was when the target was turquoise in colour (p = 0.001).

In order to confirm which colours had the ultimate impact on visual search times, a series of post hoc tests were conducted. It can be seen from Table 4 that a general pattern emerged. The targets of the primary colours red, green and blue were identified significantly quicker than the targets coloured in the non-primary colours.

The difference between the colours red and peach was significant ($t = -5.37$, d.f. = 49 and $p < 0.05$) and this was also found to be the case when comparing peach with blue ($t = -5.76$, d.f. = 49 and $p < 0.05$), peach with turquoise ($t = 6.225$, d.f. = 49 and $p < 0.05$) and peach with green ($t = 5.45$, d.f. = 49 and $p < 0.05$).

In addition, beige targets were identified at a significantly slower rate than red targets ($t = 3.49$, d.f. = 49 and $p < 0.05$), blue targets ($t = -3.78$, d.f. = 49 and $p < 0.05$) and green targets ($t = -3.98$, d.f. = 49 and $p < 0.05$) and also turquoise targets ($t = -3.30$, d.f. = 49 and $p < 0.05$). The one contrast that was not significant was the comparison between the green and turquoise targets.

Discussion and Conclusion

The aim of this study was to determine whether different hues could affect the search times for targets in cluttered settings. In order to control for the possible confounding variables of saturation, value, position and shape each of the search screens contained five distractor targets with the same hue, but with completely different saturations and values: in addition, two different shaped targets were employed and four different positions.

The key findings of this study showed that hypothesis 1 could be supported: certain hues are detected more rapidly than others even when the targets are in a cluttered environment. The green colour produced overall faster search times, an average of 1.92 s compared with the slowest search times of beige (2.43 s) and peach (2.63 s). This difference in search time was highly statistically significant ($p < 0.000$). The relative means for each colour can be seen in Table 2.Hypothesis 2 could also be supported, since it was found that the means for the search times of the basic colours were quicker than those for the non-basic colours. This was also supported in detail by the post hoc tests. The search times for the peach and beige targets were significantly slower than those for the basic colours. However, the turquoise colour was not significantly slower than the basic colours, but it did also have a statistically low accuracy level. This means the turquoise targets were consistently misidentified (false positives) and would indicate the unreliability of this hue as an 'attention getter' if used as a design element in a point-of-purchase display. The accuracy level for the turquoise targets was only 66% compared to the green targets, which were the most accurately identified ones, with an accuracy level of 94%.

The results also demonstrated that the positioning of the target affected the target identification. However, there was a strong interaction effect, thereby indicating that the colour of the target had a powerful influence on any target position effects. The basic colours were consistently identified more readily than the non-basic colours, regardless of position in the array.An analysis of Fig. 1, where the interaction effects of accuracy, colour and position are shown, showed that the difference in accuracy in identifying the correct colour target was colour specific rather than position specific. In terms of performance the green and blue targets were the colours most frequently identified accurately, irrespective of positioning. It should be noted that positioning on its own was not found to be significant ($p = 0.075$): instead it was found to be highly significant when interacting with colour ($p = 0.000$), thus demonstrating that one will directly affect the other during the visual search process.

One possible explanation as to why colour causes these differences in visual search times to occur is related to the fact that human colour perception is affected by experience, socialization and knowledge (Taft and Sivik, 1991, 1992). Therefore, it is unlikely that the findings of this study will be universal, even though it is likely that Westernized societies will have similar results. This may also offer an explanation for the misidentification of the turquoise colour targets, as it is possible that the participants may not have had a lot of previous experience with the colour and may therefore have identified it as being blue or green instead.

Future research should examine the differences in the influence of colour on search times between subgroups in society. The influence of colour is likely to be similar to the extent that we have all experienced the same culture, but there will be significant differences to the extent that we each belong to unique small groups and have individual experiences. This may make it even more difficult for designers to create point-of-purchase displays that can attract every consumer's attention, particularly across national boundaries and cultures. One of the main limitations of this study was that, by using simple objects such as circles and squares, it is not possible to be certain that it is applicable to a real life setting. Therefore it would be useful to conduct future studies using 'real-life settings', where different coloured point-of-purchase displays are presented in cluttered surroundings, in order to determine whether these findings are ecologically valid. The results supported the findings of previous studies, mainly that target search times are influenced by hue and positioning. However, this study was undertaken in order to confirm that these variables also affect search times in cluttered environments, such as those found in retail settings. Overall, this study demonstrated that different colours do indeed affect search times in cluttered visual environments and that basic colours are more effective than non-basic colours. This needs to be taken into consideration when trying to design point-of-purchase materials that can be identified by consumers with as little time and effort as possible.

Many other colours could have been included in this study. However, it was not the intention to find out which particular colour would have the ultimate impact on visual search. Which colours and what sort of difference is something to be explored more fully in future studies.

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Five factors that guide attention in visual search

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How do we find what we are looking for?

Even when the desired target is in the current field of view, we need to search because fundamental limits on visual processing make it impossible to recognize everything at once. Searching involves directing attention to objects that might be the target. This deployment of attention is not random. It is guided to the most promising items and locations by five factors discussed here: bottom-up salience, top-down feature guidance, scene structure and meaning, the previous history of search over timescales ranging from milliseconds to years, and the relative value of the targets and distractors. Modern theories of visual search need to incorporate all five factors and specify how these factors combine to shape search behaviour. An understanding of the rules of guidance can be used to improve the accuracy and efficiency of socially important search tasks, from security screening to medical image perception.

How can a texting pedestrian walk right into a pole, even though it is clearly visible1? At any given moment, our attention and eyes are focused on some aspects of the scene in front of us, while other portions of the visible world go relatively unattended. We deploy this selective visual attention because we are unable to fully process everything in the scene at the same time. We have the impression of seeing everything in front of our eyes, but over most of the visual field, we are probably seeing something like visual textures, rather than objects[2,3]. Identifying specific objects and apprehending their relationships to each other typically requires attention, as our unfor- tunate texting pedestrian can attest.

> **Figure 1** illustrates this point. It is obvious that this image is filled with the letters M and W in various combinations of red, blue, and yellow, but it takes attentional scrutiny to determine whether or not there is a red and yellow M.

The need to attend to objects in order to recognize them raises a problem. At any given moment, the visual field contains a very large, possibly uncountable number of objects. We can count the M and W characters of Fig. 1, but imagine looking at your reflection in the mirror. Are you an object? What about your eyes or nose or that small spot on your chin? If object recognition requires attention, and if the number of objects is uncountable, how do we manage to get our attention to a target object in a reasonable amount of time? Attention can process items at a rate of, perhaps, 20–50 items per second. If you were looking for a street sign in an urban setting containing a mere 1,000 possible objects (every window, tyre, door handle, piece of trash, and so on), it would take 20–50 seconds just to find that sign.

It is introspectively obvious that you routinely find what you are looking for in the real world in a fraction of that time. To be sure, there are searches of the needle- in-a-haystack, Where's Waldo? variety that take significant time, but routine searches for the salt shaker, the light switch, your pen, and so forth, obviously proceed much more quickly. Search is not overwhelmed by the welter of objects in the world because search is guided to a (often very small) subset of all possible objects by several sources of information. The purpose of this article is to briefly review the growing body of knowledge about the nature of that guidance.

We will discuss five forms of guidance:

- Bottom-up, stimulus-driven guidance in which the visual properties of some aspects of the scene attract more attention than others.
- Top-down, user-driven guidance in which attention is directed to objects with known features of desired targets.
- Scene guidance in which attributes of the scene guide attention to areas likely to contain targets.
- Guidance based on the perceived value of some items or features.
- Guidance based on the history of prior search.

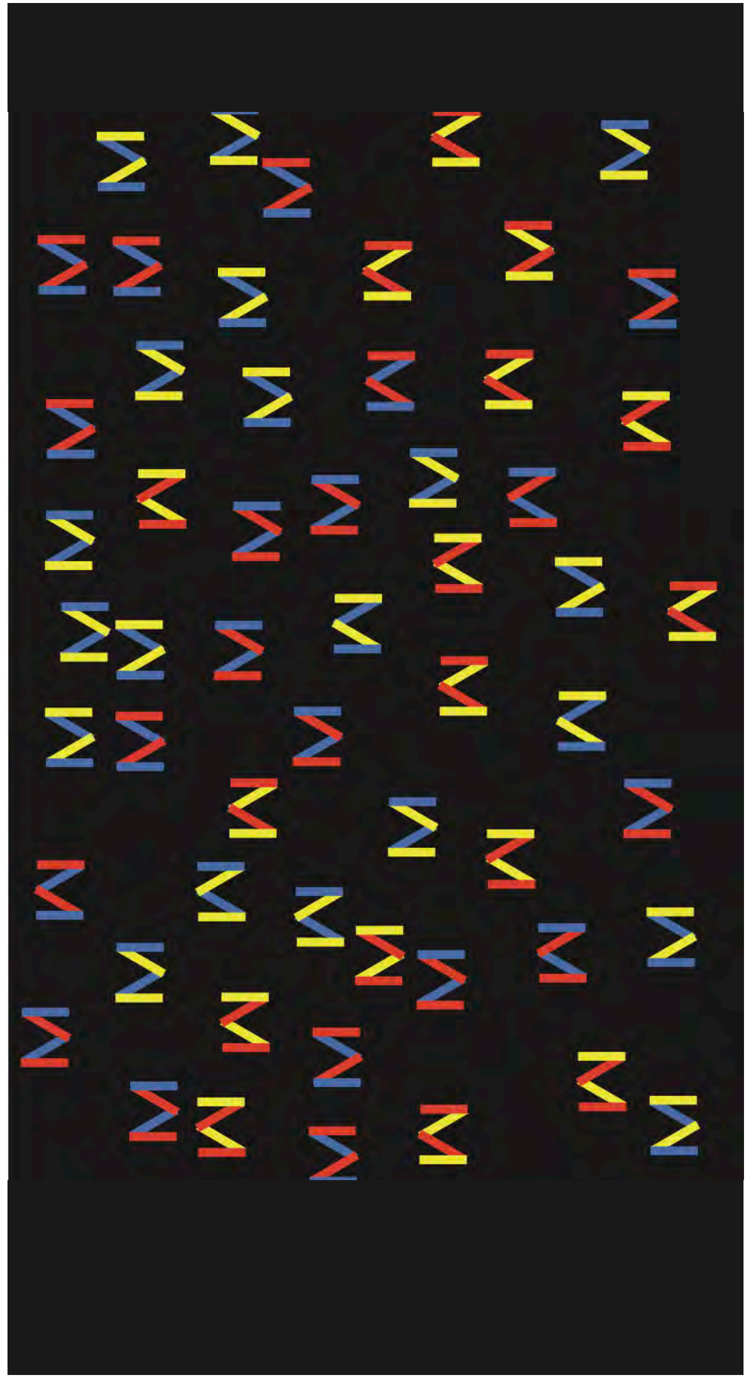

Figure 1 | A surprisingly difficult search task. On first glimpse, you know something about the distribution of colours and shapes but not how those colours and shapes are bound to each other. Find instances of the letter M that are red and yellow.

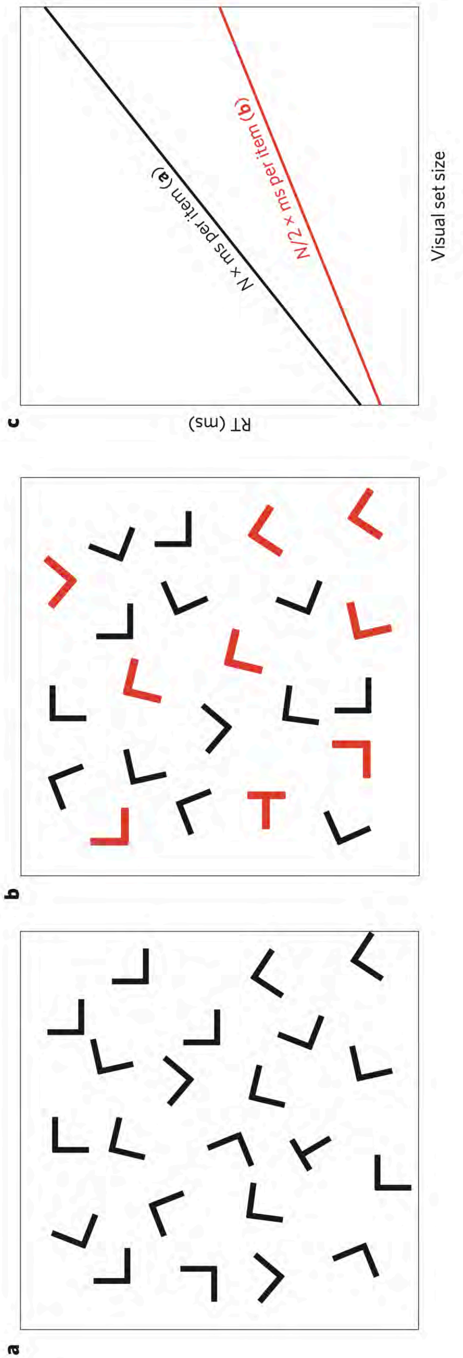

Figure 2 | The basic visual search paradigm. a–c, A target (here the letter T) is presented amidst a variable number of distractors (a,b). Search 'efficiency' can be indexed by the slope of the function relating reaction time (RT) to the visual set size (N) (c). If the target in panel b is a red T, the slope for b (red line) will be half of that for panel a (black line) because attention can be limited to just half of the items in b.

Measuring guidance

We can operationalize the degree of guidance in a search for a target by asking what fraction of all items can be eliminated from consideration. One of the more straightforward methods to do this is to present observers with visual search displays like those in Fig. 2 and measure the reaction time (RT) required for them to report whether or not there is a target (here a T) as a function of the number of items (set size). The slope of the RT × set size function is a measure of the efficiency of search. For a search for a T among Ls (Fig. 2a), the slope would be in the vicinity of 20–50 ms per item[4]. We believe that this reflects serial deployment of attention from item to item5, although this need not be the case6.

In Fig. 2b, the target is a red T. This search would be faster and more efficient7 because attention can be guided to the red items. If half the items are red (and if guidance is perfect), the slope will be reduced by about half, suggesting that, at least in this straightfor- ward case, slopes index the amount of guidance.

The relationship of slopes to guidance is not entirely simple, even for arrays of items like those in Fig. 2 (ref. 8), but see ref. 9. Matters become far more complex with real-world scenes where the visual set size is not easily defined[10,11]. However, if the slope is cut in half when half the items acquire some property, like the colour red in Fig. 2b, it is reasonable to assert that search has been guided by that property[9].

The problem of distractor rejection. As shown in Fig. 2, a stimulus attribute can make search slopes shallower by limiting the number of items in a display that need to be examined. However, guidance of attention is not the only factor that can modulate search slopes.

If observers are attending to each item in the display (in series or in parallel), the slope of the RT × set size function can also be altered by changing how long it takes to reject each distractor. Thus, if we markedly reduced the contrast of Fig. 2a, the RT × set size func- tion would become steeper, not because of a change in guidance but because it would now take longer to decide if any given item was a T or an L.

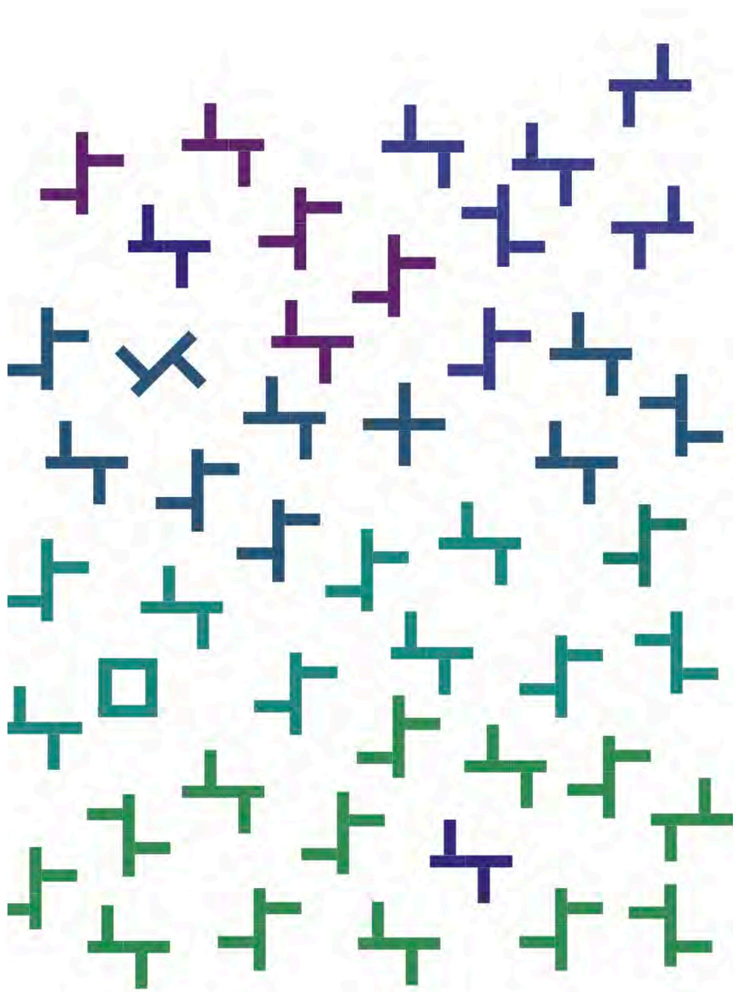

Figure 3 | Which items pop out of this display, and why?

Bottom-up guidance by stimulus salience

Attention is attracted to items that differ from their surroundings, if those differences are large enough and if those differences occur in one of a limited set of attributes that guide attention. The basic principles are illustrated in Fig. 3.

Three items pop out of this display. The purple item on the left differs from its neighbours in colour. It is identical to the purple item just inside the upper right corner of the image. That second, purple item on the right is not particularly salient even though it is the only other item in that shade of purple; its neighbours are close enough in colour that the differences in colour do not attract attention. The bluish item to its immediate left is salient by virtue of an orientation difference. The square item a bit further to the left is salient because of the presence of a 'closure' feature12 or the absence of a collection of line terminations13. We call properties like colour, orientation, or closure basic (or guiding) features, because they can guide the deployment of attention. Other properties may be striking when one is directly attending to an item, and may be important for object recognition, but they do not guide attention. For example, the one plus symbol in the display is not salient, even though it pos- sesses the only X-intersection in the display, because intersection type is not a basic feature14. The 'pop-out' we see in Fig. 3 is not just subjective phenomenology. Pop-out refers to extremely effec- tive guidance, and is diagnosed by a near-zero slope of the RT × set size function; although there may be systematic variability even in these 'flat' slopes15.

There are two fundamental rules of bottom-up salience16. Salience of a target increases with difference from the distractors (target–dis- tractor heterogeneity) and with the homogeneity of the distractors (distractor–distractor homogeneity) along basic feature dimensions. Bottom-up salience is the most extensively modelled aspect of visual guidance (reviewed in ref. 17). The seminal modern work on bottom-up salience is Koch and Ullman's[18] description of a winner-take-all network for deploying attention. Subsequent decades have seen the development of several influential bottom-up models, for examples, see refs 19,20–22.

However, bottom-up salience is just one of the factors guiding attention. By itself, it does only modestly well in predicting the deployment of attention (usually indexed by eye fixations). Models do quite well at predicting search for salience, but not as well at predicting search for other sorts of targets[17]. This is quite reasonable. If you are looking for your cat in the bedroom, it would be counterproductive to have your attention visit all the shiny, colourful objects first. Thus, a bottom-up saliency model will not do well if the observer has a clear top-down goal[23.]

One might think that bottom-up salience would dominate if observers 'free- viewed' a scene in the absence of such a goal, but bottom-up models can be poor at predicting fixations even when observers free view scenes without specific instructions[24.]

It seems that observers generate their own, idiosyncratic tasks, allowing other guiding forces to come into play. It is worth noting that salience models work better if they are not based purely on local features but acknowledge the structure of objects in the field of view[25.] For instance, while the most salient spot in an image might be the edge between the cat's tail and the white sheet on the bed, fixations are more likely to be directed to middle of the cat[26,27].

Top-down feature guidance

Returning to Fig. 1, if you search for Ws with yellow elements, you can guide your attention to yellow items and subsequently deter- mine if they are Ws or Ms[7]. This is feature guidance, sometimes referred to as feature-based attention[28]. Importantly, it is possible to guide attention to more than one feature at a time. Thus, search- ing for a big, red, vertical item can benefit from our knowledge of its colour, size, and orientation[29]. Following the target–distractor heterogeneity rule, search efficiency is dependent on the number of features shared by targets and distractors[29], and observers appear to be able to guide attention to multiple target features simultaneously[30.] This finding raises the attractive possibility that searching for an arbitrary object among other arbitrary objects would be quite efficient because objects would be represented sparsely in a high-dimensional space. Such sparse coding has been invoked to explain object recognition[31,32]. However, searching for arbitrary objects turns out not to be particularly efficient[11,33]. By itself, guidance to multiple features does not appear to be an adequate account of how we search for objects in the real world (see 'Guidance by scene prop- erties' section).

What are the guiding attributes?

Feature guidance bears some metaphorical similarity to your favour- ite computer search engine. You enter some terms into the search box and an ordered list of places to attend is returned. A major difference between internet search engines and the human visual search engine is that human search uses only a very small vocabu- lary of search terms (that is, features). The idea that there might be a limited set of features that could be appreciated 'preattentively'34 was at the heart of Treisman's feature-integration theory35. She proposed that targets defined by unique features would pop out of displays. Subsequently, others modified the role of features to propose that they could guide the deployment of attention7,36.

There are probably only two dozen attributes that can guide attention. The visual system can detect and identify a vast number of stimuli, but it cannot use arbitrary properties to guide attention in the way that Google or Bing can use arbitrary search terms. A list of guiding attributes is found in Box 1. This article does not list all of the citations that support each entry. Many of these can be found in older versions of the list37,38. Recent changes to the list are marked in italic in Box 1 and citations are given for those.

Attributes like colour are deemed to be 'undoubted' because multiple experiments from multiple labs attest to their ability to guide attention. 'Probable' feature dimensions may be merely probable because we are not sure how to define the feature. Shape is the most notable entry here. It seems quite clear that something about shape guides attention[39]. It is less clear exactly what that might be, although the success of deep learning algorithms in enabling com- puters to classify objects may open up new vistas in the understand- ing of human search for shape40.

The attributes described as possible await more research. Often these attributes only have a single paper supporting their entry on the list, as in the case of numerosity: can you direct attention to the pile with more elements in it, once you eliminate size, density, and other confounding visual factors? Perhaps41, but it would be good to have converging evidence. Search for the magnitude of a digit (for example, 'find the highest number') is not guided by the semantic meaning of the digits but by their visual properties42.

The list of attributes that do not guide attention is, of course, potentially infinite. Box 1 lists a few plausible candidates that have been tested and found wanting. For example, there has been consid- erable interest recently in what could be called evolutionarily moti- vated candidates for guidance. What would enhance our survival if we could find it efficiently? Looking at a set of moving dots on a computer screen, we can perceive that one is chasing another43. However, this aspect of animacy does not appear to be a guiding attribute44. Nor does threat (defined by association with electric shock) seem to guide search[45]. Some caution is needed here because a failure to guide attention is a negative finding and it is always possible that, were the experi- ment done correctly, the attribute might guide after all. Thus, early research[46] found that binocular rivalry and eye-of-origin informa- tion did not guide attention, but more recent work[47,48] suggests that it may be possible to guide attention to interocular conflict, and our own newer data49 indicates that rivalry may guide attention if care is taken to suppress other signals that interfere with that guidance. Thus, binocular rivalry was listed under 'doubtful cases and prob- able non-features' in ref. 37, but is now listed under 'possible guiding attributes' in Box 1.

Faces remain a problematic candidate for feature status, with a substantial literature yielding conflicting results and conclusions. Faces are quite easy to find among other objects[50,51] but there is dis- pute about whether the guiding feature is 'face-ness' or some sim- pler stimulus attribute[52,53]. A useful review by Frischen et al.[54] argues that "preattentive search processes are sensitive to and influenced by facial expressions of emotion", but this is one of the cases where it is hard to reject the hypothesis that the proposed feature is mod- ulating the processing of attended items, rather than guiding the selection of which items to attend. Suppose that, once attended, it takes 10 ms longer to disengage attention from an angry face than from a neutral face. The result would be that search would go faster (10 ms per item faster) when the distractors were neutral than when they were angry. Consequently, an angry target among neutral dis- tractors would be found more efficiently than a neutral face among angry. Evidence for guidance by emotion would be stronger if the more efficient emotion searches were closer to pop-out than to clas- sic inefficient, unguided searches, for example, for a T among L characters[55]. Typically, this is not the case. For example, Gerritsen et al.[56] report that "visual search is not blind to emotion" but, in a representative finding, search for hostile faces produced an inef- ficient slope of 64 ms per item even if it is somewhat more efficient than the 82 ms per item for peaceful target faces.

BOX 1 I THE GUIDING ATTRIBUTES FOR FEATURE SEARCH. CHANGES TO PREVIOUS VERSIONS OF THE LIST[37,38] ARE MARKED IN ITALICS.

UNDOUBTED GUIDING ATTRIBUTES
Colour
Motion
Orientation
Size (including length, spatial frequency, and apparent size[120])

PROBABLE GUIDING ATTRIBUTES
Luminance onset (flicker) but see ref. 121
Luminance polarity
Vernier offset
Stereoscopic depth and tilt
Pictorial depth cues but see ref.62
Shape
Line termination
Closure
Curvature
Topological status

POSSIBLE GUIDING ATTRIBUTES
Lighting direction (shading)
Expansion/looming
Number
Glossiness (lustre)
Aspect ratio
Eye of origin/binocular rivalry

DOUBTFUL CASES
Novelty
Letter identity
alphanumeric category
Familiarity over-learned sets, in general[111]

PROBABLY NOT GUIDING ATTRIBUTES
Intersection
Optic flow
Colour change
3D volumes (for example, geons)
Luminosity
Material type
Scene category
Duration
Stare-in-crowd122,123
Biological motion
Your name
Threat
Semantic category (animal, artefact, and so on)
Blur[124]
Visual rhythm[125]
Animacy/chasing[44]

Threat[45]

FACES ARE A COMPLICATED ISSUE
Faces among other objects
Familiar faces
Emotional faces
Schematic faces

FACTORS THAT MODULATE SEARCH
Cast shadows
Amodal completion
Apparent depth

There are stimulus properties that, while they may not be guidıing attributes in their own right, do modulate the effectiveness of other attributes. For example, apparent depth modulates apparent size, and search is guided by that apparent size[57]. Finally, there are properties of the display that influence the deployment of attention. These could be considered aspects of 'scene guidance' (see 'Guidance by scene properties' section). For example, attention tends to be attracted to the centre of gravity in a display58. Elements like arrows direct attention even if they themselves do not pop out[59]. As dis- cussed by Rensink[60], these and related factors can inform graphic design and other situations where the creator of an image wants to control how the observer consumes that image.

There have been some general challenges to the enterprise of defining specific features, notably the hypothesis that many of the effects attributed to the presence or absence of basic features are actually produced by crowding in the periphery[3]. For example, is efficient search for cubes lit from one side among cubes lit from another side evidence for preattentive processing of 3D shape and lighting61, or merely a by-product of the way these stimuli are repre- sented in peripheral vision[62]? Resolution of this issue requires a set of visual search experiments with stimuli that are uncrowded. This probably means using low set sizes as in, for example, the evidence that material type is not a guiding attribute[63].

A different challenge to the preattentive feature enterprise is the possibility that too many discrete features are proposed. Perhaps many specific features form a continuum of guidance by a single, more broadly defined attribute. For instance, the cues to the 3D lay- out of the scene include stereopsis, shading, linear perspective and more. These might be part of a single attribute describing the 3D disposition of an object. Motion, onsets, and flicker might be part of a general dynamic change property[64]. Most significantly, we might combine the spatial features of line termination, closure, topologi- cal status, orientation, and so on into a single shape attribute with properties defined by the appropriate layer of the right convolutional neural net (CNN). Such nets have shown themselves capable of categorizing objects, so one could imagine a preattentive CNN guiding attention to objects as well[65].

So far, such an idea remains a promissory note. Regardless of how powerful CNNs may become, humans cannot guide attention to entirely arbitrary/specific proper- ties in order to find particular types of object[66] and it is unknown if some intermediate representation in a CNN

could capture the prop- erties of the human search engine. If it did, we might well find that such a layer represented a space with dimensions corresponding to attributes like size, orientation, line termination, vernier offset, and so on, but this remains to be seen.

Guidance by scene properties

While the field of visual search has largely been built on search for targets in arbitrary 2D arrays of items, most real-world search takes place in structured scenes, and this structure provides a source of guidance. To illustrate, try searching for any humans in Fig. 4. Depending on the resolution of the image as you are viewing it, you may or may not be able to see legs poking out from behind the roses by the gate. Regardless, what should be clear is that the places you looked were strongly constrained. Biederman, Mezzanotte, and Rabinowitz[67] suggested a distinction between semantic and syntactic guidance.

Syntactic guidance has to do with physical constraints. You don't look for people on the front surface of the wall or in the sky because people typically need to be supported against gravity. Semantic guidance refers to the meaning of the scene. You don't look for people on the top of the wall, not because they could not be there but because they are unlikely to be there given your understanding of the scene, whereas you might scrutinize the bench. Scene guidance would be quite different (and less constrained) if the target were a bird. The use of semantic and syntactic language should not be seen as tying scene processing too closely to linguistic processing nor should the two categories be seen as neatly non-overlapping[68,69]. Nevertheless, the distinction between syntactic and semantic factors, as roughly defined here, can be observed in electrophysiological recordings: scenes showing semantic violations (for example, a bar of soap sitting next to the computer on the desk) produce different neural signatures than scenes showing syntactic violations (for example, a computer mouse on top of the laptop screen)70. While salience may have some influence in this task[71], it does not appear to be the major force guiding attention here[24,72]. But note that feature guidance and scene guidance work together. People certainly could be on the lawn, but you do not scrutinize the empty lawn in Fig. 4 because it lacks the correct target features. Extending the study of guidance from controlled arrays of distinct items to structured scenes poses some methodological challenges. For example, how do we define the set size of a scene? Is the rose bush an item in Fig. 4, or does each bloom count as an item? In bridging between the world of artificial arrays of items and scenes, perhaps the best we can do is to talk about the 'effective set size'[10,73], the number of items/locations that are treated as candidate targets in a scene given a specific task. If you are looking for the biggest flower, each rose bloom is part of the effective set. If you are looking for a human, those blooms are not part of the set. While any estimate of effective set size is imperfect, it is a very useful idea and it is clear that, for most tasks, the effective set size will be much smaller than the set of all possible items[11].

Preview methods have been very useful in examining the mecha- nisms of scene search[74]. A scene is flashed for a fraction of a second and then the observer searches for a target. The primary data are often eye-tracking records. It is common for these experiments to involve searching while the observer's view of the scene is restricted to a small region around the point of fixation ('gaze-contingent' dis- plays). Very brief exposures (50–75 ms) can guide deployment of the eyes once search begins75. A preview of the specific scene is much more useful than a preview of another scene of the same category, although the preview scene does not need to be the same size as the search stimulus74. Importantly, the preview need not contain the target in order to be effective76. Search appears to be more strongly guided by a relatively specific scene 'gist'[73,77], an initial understand- ing of the scene that does not rely on recognizing specific objects[78].

The gist includes both syntactic (for example, spatial layout) and semantic information, and this combination can provide powerful search guidance. Knowledge about the target provides an independ- ent source of guidance[79,80]. These sources of information provide useful 'priors' on where targets might be ("if there is a vase present, it's more likely to be on a table than in the sink"), which are more powerful than memory for where a target might have been seen[81,82,83] in terms of guiding search.

Preview effects may be fairly limited in search of real scenes. If the observer searches a fully visible scene rather than being limited to a gaze-contingent window, guidance by the preview is limited to the first couple of fixations[84]. Once search begins, guidance is pre- sumably updated based on the real scene, rendering the preview obsolete. In gaze-contingent search, the effects last longer because this updating cannot occur. This updating can be seen in the work of Hwang et al.[85], where, in the course of normal search, the semantic content of the current fixation in a scene influences the target of the next fixation.

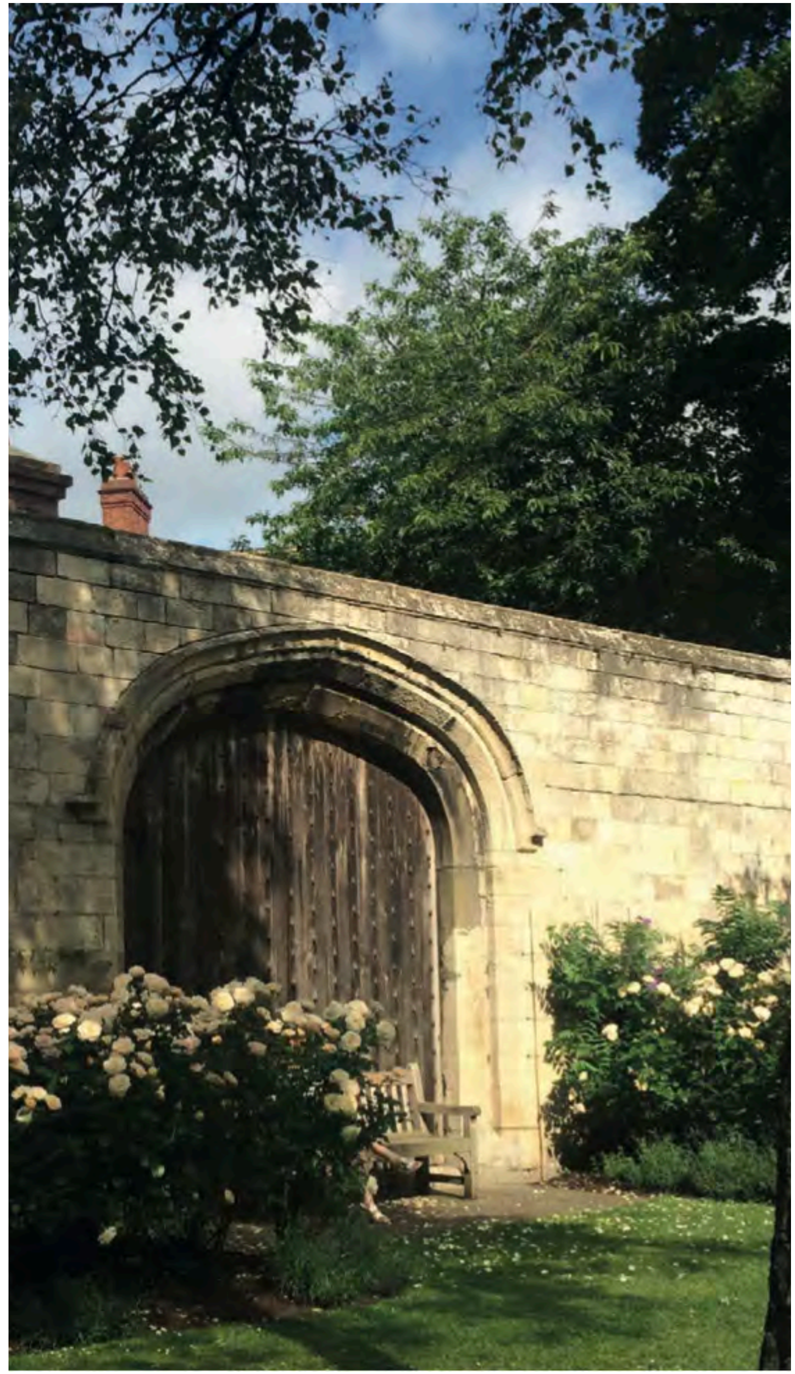

Figure 4 | Scene guidance. Where is attention guided if you are looking for humans? What if the target was a bird?

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Modulation of search by prior history

In this section, we summarize evidence showing that the prior his- tory of the observer, especially the prior history of search, modulates the guidance of attention. We can organize these effects by their timescale, from within a trial (on the order of 100 s to ms) to lifetime learning (on the order of years). A number of studies have demonstrated the preview benefit: when half of the search array is presented a few hundred milliseconds before the rest of the array, the effective set size is reduced, either because attention is guided away from the old 'marked' items (visual marking86) and/or toward the new items (onset prioritization[87]).

On a slightly longer timescale, priming phenomena are observed from trial to trial within an experiment, and can be observed over seconds to weeks. The basic example is 'priming of pop-out'[88], in which an observer might be asked to report the shape of the one item of unique colour in a display. If that item is the one red shape among green on one trial, responses will be faster if the next trial repeats red among green as compared with a switch to green among red; although the search in both cases will be a highly efficient, col- our pop-out search. More priming of pop-out is found if the task is harder89. Note that it is not the response, or the reporting feature, that is repeated in priming of pop-out, but the target-defining or selection feature.

More generally, seeing the features of the target makes search faster than reading a word cue describing the target, even for over-learned targets. This priming by target features takes about 200 ms to develop[90]. Priming by the features of a prior stimulus can be entirely incidental; simply repeating the target from trial to trial is sufficient[91]. More than one feature can be primed at the same time[91,92]and both target and distractor features can be primed[91,93]. Moreover, it is not just that observers are more ready to report tar- gets with the primed feature; priming actually boosts sensitivity (that is, d')[94]. Such priming can last for at least a week[95].Observers can also incidentally learn information over the course of an experiment that can guide search. In contextual cueing96, a subset of the displays are repeated across several blocks of trials. While observers do not notice this repetition, RTs are faster for repeated displays than for novel, unrepeated displays[97].

The contextual cueing effect is typically interpreted as an abstract form of scene guidance: just as you learn that, in your friend's kitchen, the toaster is on the counter next to the coffee maker, you learn that, in a con- figuration of rotated Ls, the T is in the bottom left corner. However, evidence for this interpretation is mixed. RT × set size slopes are reduced for repeated displays[96] in some experiments, but not in others[98]. Contextual cueing effects can also be observed in cases where guidance is already nearly perfect, such as pop-out search[99] and attentionally-cued search[100]. Kunar et al.[98] suggested that contextual cueing reflects response facilitation, rather than guidance. Again, the evidence is mixed. There is a shift towards a more liberal response criterion for repeated displays[101], but this is not correlated with the size of the contextual cueing RT effect.

In pop-out search, sensitivity to the target improves for repeated displays with an effect on decision criterion[99]. It seems likely that observed contextual cueing effects reflect a combination of guidance effects and response facilitation, with the mix depending on the specifics of the task. Oculomotor studies show that the context is often not retrieved and available to guide attention until a search has been underway for several fixations[102,103].

Thus, the more efficient the search, the greater the likelihood that the target will be found before the context can be retrieved. Indeed, in simple letter displays, search does not become more efficient even when the same display is repeated several hun- dred times[104], presumably because searching de novo is always faster than waiting for context to become available. Once the task becomes more complex (for example, searching for that toaster)[105], it becomes worthwhile to let memory guide search[82,106].

Over years and decades, we become intimately familiar with, for example, the characters of our own written language. There is a long-running debate about whether familiarity (or, conversely, novelty) might be a basic guiding attribute. Much of this work has been conducted with overlearned categories like letters. While the topic is not settled, semantic categories like 'letter' probably do not guide attention[107,108], although mirror-reversed letters may stand out against standard letters[109,110]. Instead, items made familiar in long- term memory can modulate search[111,112], although there are limits on the effects of familiarity in search[113,114].

Modulation of search by the value of items

In the past few years, there has been increasing interest in the effects of reward or value on search. Value proves to be a strong modula- tor of guidance. For instance, if observers are rewarded more highly for red items than for green, they will subsequently guide attention toward red, even if this is irrelevant to the task[115]. Note, colour is the guiding feature; value modulates its effectiveness. The learned associations of value do not need to be task-relevant or salient in order to have their effects116 and learning can be very persistent with value-driven effects being seen half a year after acquisition[117]. Indeed, the effects of value may be driving some effects of long-term familiarity described in the previous paragraph[111].

Unless we are scrutinizing aerial photographs for hints to North Korea's missile programme, or hunting for signs of cancer in a chest radiograph, we typically find what we are looking for in seconds or less. This remarkable ability is the result of attentional guidance mechanisms. While thirty-five years or so of research has given us a good grasp of the mechanisms of bottom-up salience, top-down feature-driven guidance and how those factors combine to guide attention[118,119], we are just beginning to understand how attention is guided by the structure of scenes and the sum of our past experiences.

Future challenges for the field will include understanding how discrete features might fit together in a continuum of guidance and extending our theoretical frameworks from two-dimensional scenes to immersive, dynamic, three dimensional environments.

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Cross-Cultural Differences in Visual Perception of Color, Illusions, Depth, and Pictures

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At the end of a particularly long and tiring period of trekking through the forest from one hunting group to another, I found myself on the eastern edge, on a high hill which had been cleared of trees by a missionary station. There was a distant view over the last few miles of forest to the Ruwenzori Mountains: in the middle of the Ituri Forest such views are seldom if ever encountered. With me was a Pygmy youth, named Kenge, who always accompanied me and served, amongst other capacities, as a valid introduction to BaMbuti groups where I was not known. Kenge was then about 22 yr. old, and had never before seen a view such as this … As we turned to get back in the car, Kenge looked over the plains and down to where a herd of about a hundred buffalo were grazing some miles away. He asked me what kind of insects they were, and I told him they were buffalo, twice as big as the forest buffalo known to him. He laughed loudly and told me not to tell such stupid stories… (Turnbull, 1961, pp. 304–305)

Anecdotes like the one above from missionaries and anthropologists dating to the nineteenth century sparked curiosity as to whether visual perception is innate (we are biologically predisposed to see the world as it is, with no need for cues) or visual perception is learned (we construct our perceptions from experience). You should recognize this as the nature–nurture debate espoused by the early philosophers Plato and Aristotle, and later by Descartes and Locke. When looking at this issue from a cross-cultural perspective, the question becomes, “Do group differences in perception result from heritability (genetic variation) or from differences in culture (how these groups live)?” The aim of this chapter is to illustrate some examples of differences in visual perception that exist among different cultural groups, so that we may develop a deeper understanding of people from other cultures.

The origins of methodological cross-cultural perception can be traced to the work of W. H. R. Rivers (1864–1922), a neurologist and anthropologist who was the first scientist to systematically study cross-cultural perception while on an expedition to Torres Straits, between northeastern Australia and New Guinea, thus becoming the first cross-cultural experimental psychologist (Deregowski, 1998). In recognition of Rivers’ pioneering work, the first section of this chapter will focus on vision.

Color Perception

Early work on the perception of color among different cultures typically reported that language is related to how different cultures sort color tiles. Rivers found that peoples from the Torres Straits area (Murray Island, Seven Rivers, Kuwai, and Mabuag) would sort color tiles into groups based on language (Slobodin, 1978). For example, inhabitants of Murray Island (whose language only has words for the colors black, white, and red) typically grouped green and blue tiles together. These findings were typical of other cultures (and languages) being studied at the time, and prompted the Whorf Hypothesis, which explicitly states that language determines our experience.

However, research has not fully supported this hypothesis. Rosch (1973) examined the color discrimination of the Dani tribe of Papua, New Guinea, and determined that although the language only has two terms (one for all dark colors and one for all light colors), the Dani were able to discriminate several colors from one another. This occurred even though, when given a sorting task, members of the Dani tribe typically sorted the color tiles into two groups. Davies and Corbett (1997) examined color sorting of native speakers of English, Russian, and Setswana.Though Russian has two words for blue (one for light blue and one for dark blue), the sortings from English and Russian speakers were very similar. The Setswana speakers, however, tended to sort the blues and greens together, and they used only one word for these colors. It seems, then, that language does not drive perception, but perhaps the importance of having particular words for different colors in a language is dependent upon the need for communicating those colors amongin dividuals.

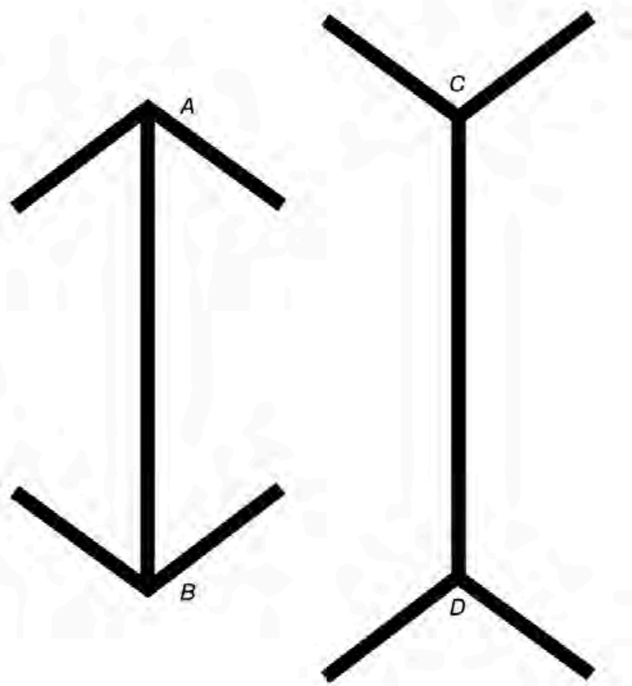


Figure 13.1 Line segment AB is typically perceived to be shorter than line segment CD, though they are the same length.

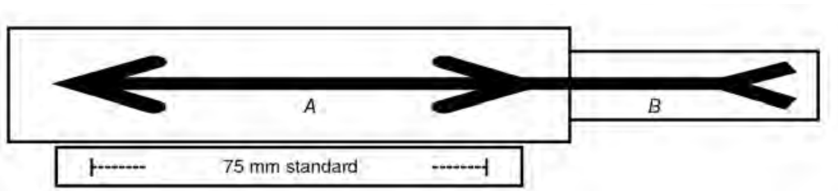


Figure 13.2 Diagram of apparatus used by Rivers. The segment with divergent arrows (B) was to be extended to match the segment formed by the convergent arrows (A).

The Müller-Lyer Illusion

When you first look at Figure 13.1, which of the lines appears longer? German psychiatrist Franz Müller-Lyer created this illusion in 1889 (Bermond & Van Heerden, 1996). Many people tend to judge the line segment on the left as shorter than the line segment on the right (the two lines are actually the same length—you can measure them with a ruler to confirm this).

Rivers sought to determine the effect of the Müller-Lyer illusion on three groups of Murray Islanders: men, boys, and girls. At the time it was believed that the Murray Islanders (being less “civilized”) would be more susceptible to the illusion (i.e., make greater errors). Participants were given a brass slide with convergent arrowheads (set at a standard length of 75 mm, and depicted as segment “A”) that contained an inner slide with a divergent arrowhead at one end (see Figure 13.2).

Rivers tested the three groups of Murray Islanders (men, boys, and girls)and compared their performance to three groups of English participants (students, adults, and schoolchildren). Interestingly, the Murray Islanders performed better than their English counterparts (they more accurately slid the guide so that the line segments had equal length).

Are these results reliable? Rivers believed that the differences were due to differences in culture between these groups (Slobodin, 1978). However, to be sure that culture is indeed the responsible factor, the result would have to be replicated—it must be shown that the result is consistent. Segall, Campbell, and Herskovits (1966) sought to determine whether culture was responsible for differences in performancen on the Müller-Lyer stimulus, using 15 pictorial depictions of the illusion.Participants judged whether line A was longer or if line B was longer. They tested more than 1,300 people in 17 different groups, including children (aged 6–11) from 12 of the groups. Most of the participants (more than 1,000) were from 10 different African countries; one small sample comprised Europeans in South Africa, another small sample included Hanun o people in the Philippines, and 264 individuals were included in two American samples. Segall et al. found substantial differences among the groups. Data were collected in terms of the “point of subjective
equality” (PSE) or “percent error greater than the standard”—referring to the percentage greater line AB had to be before it was judged equal to line CD (the typical error made by participants is to choose line AB

as being the longer, when in fact the two lines are equal in length; see Figure 13.1). The PSE is then determined as the percentage of increased length line AB must be before participants begin correctly identifying it as being the longer line. Kalahari Bushmen and adult workers in South African gold mines showed virtually no effect of the illusion at all (their PSE score was 1, meaning that they correctly judged when the two line segments were of equal length). The groups most susceptible to the illusion were the two American samples: a group of university students and children and adults from Illinois.

This pattern of results clearly demonstrated differences between groups. Moreover, the results also showed that children (regardless of group) were more susceptible to the illusion than adults, with the proportional difference between children and adults for any cultural group being fairly systematic (the correlation between children's and adults' ratings for all groups was 0.81). Segall et al. (1966) proposed the "carpentered world hypothesis," which states that children who grow up and live in squared, city-block environments and rectangular buildings are more susceptible to the illusion (Figure 13.3). A second hypothesis suggested that differences in experience with pictures and drawings can explain group differences, although Segall et al. argued that this hypothesis did not fit their data as well.

How could one determine whether the differences reported by Segall et al. (1966) are due to culture (specifically, a carpentered world) or due to genetics? (It is apparent that the groups studied by Segall differed genetically.) One way to attempt to answer this question would be to select a pair of identical twins, then raise one in a "carpentered" environment and the other in a "non-carpentered" environment. Of course, there are probably ethical reasons why this should not be done (a good thing, too!). Pedersen and Wheeler (1983) did the next best thing—they tested 20 members of the Navajo Indian tribe, 10 of whom lived until at least age 6 in a hogan (the typical Navajo rounded house), and 10 of whom lived in a rectangular house. The results were consistent with predictions from the carpentered world hypothesis—those Navajo students reared in rectangular houses were more susceptible to the Müller-Lyer illusion than those raised in the hogan. Other studies, incorporating Chinese participants, have also shown support for the carpentered world hypothesis (Dawson, Young, & Choi, 1973).

Interestingly, most studies have used pictures (e.g., Segall et al., 1966) rather than the original hand-held apparatus incorporated by Rivers (illustrated in Figure 13.2). Bonte (1962) tested both methods

of presenting the Müller-Lyer illusion on three groups of participants. The first group consisted of 150 Mbuti Pygmies from the Ituri rainforest located in the (now) eastern Democratic Republic of the Congo (formerly known as Zaire). The Mbuti are hunter-gatherers, living in small grass huts low to the ground, spending their lives almost exclusively in theforest. The second group was made up of 450 Bashi, who lived in the central Democratic Republic of the Congo. The participating Bashi lived near a large lake giving them a view of the horizon. They are largely agricultural people, living in small round huts. The third group consisted of 92 adult Europeans.

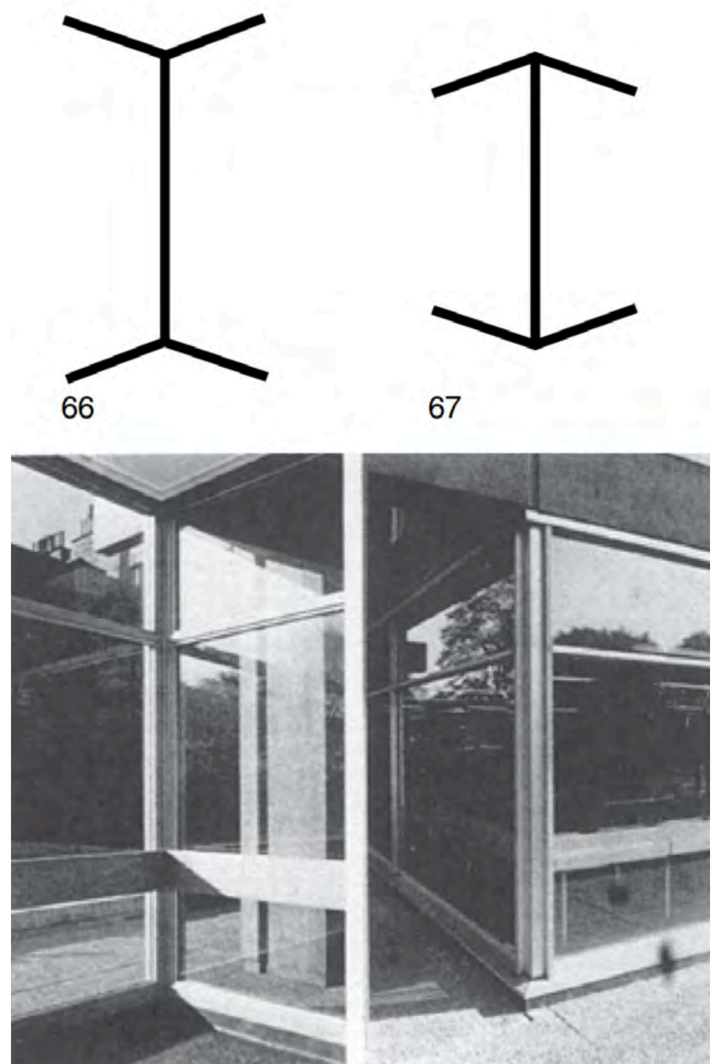


Figure 13.3 A real-world depiction of the Müller-Lyer illusion in a "carpentered worldsetting." Retrieved from http://www.cycleback.com/muller_lyer_gregory.gif. Reproduced by permission of Richard L. Gregory.

The Mbuti were unable to perform the Müller-Lyer task using the picture stimuli, so they were excluded from that analysis. Results revealed that using Rivers' apparatus, there was no difference in responses to the Müller-Lyer task. However, when using the pictures, Europeans were more susceptible to the illusion. You may recall that the differences obtained by Rivers were much smaller than those obtained by Segall. The discrepancies in Bonte's results (as compared to Segall) have been explained by methodological differences. For example, the Rivers apparatus (Figure 13.2) creates an artificial vertical line intersecting the line segments to be compared, which does not represent the original illusion [Rivers also saw this problem (Slobodin, 1978), and later created an apparatus that hid the line formed by the meeting point of the two movable pieces]. Furthermore, Bonte presented the picture version using several stimuli per page, rather than one stimulus per page. She also used ink that faded with use, and failed to randomize the sequence of stimuli presentation (presenting length differences in ascending order—0%, 5%, 10%, etc.). Finally, Bonte did not explain how instructions were given to the non-English-speaking groups, and she combined children and adults. (She did explain that presenting stimuli one per page, in different orders, would be an improvement in the data collection process.) These were exactly the kinds of changes employed by Segall et al. (1966). In addition, Segall et al. reported a strict procedure for administering the task, incorporated experimenters who were prepared for fieldwork, and gave test trials for each illusion used, to ensure comprehension. Though Bonte's results did partially support the results of Rivers, the work of Segall et al. (1966) demonstrated the importance of strict control in implementing a research design, incorporating repeated replication, and conducting thorough data analysis to support the hypothesis that ecological cues, especially experienced during the first 10 years of life, are largely responsible for the perception of the Müller-Lyer illusion.

The Ponzo Illusion

A second size-depth illusion is shown in Figures 13.4–13.6. Created by (and named for) the Italian psychologist Mario Ponzo in 1913, the illusion depicts two converging lines (typically in the vertical plane) with two parallel horizontal lines intersecting the converging lines at different points. Though the two horizontal lines are of equal length, respondents typically judge the line closer to the convergent point as longer. A real-world example of this is shown in Figure 13.5 (also known as the "railway illusion").

Researchers have also reported cultural differences in the susceptibility of different groups to this illusion (Brislin, 1974; Brislin & Keating, 1976; Segall et al., 1966; Smith, 1973). Though the data collected by Segall et al. were inconclusive, Smith found differences among three groups (N = 30) of Xhosa tribesmen (a group of undergraduates at a local South African university, a group of urban dwellers, and a group of rural dwellers). The rural dwellers lived in villages consisting of small rounded huts in an area described as an open vista. Smith hypothesized that the most "acculturated" group (the undergraduates) would be most susceptible to the Ponzo illusion. Results supported this hypothesis; the undergraduates were most susceptible and the rural dwellers the least susceptible. Unfortunately, there is no report whether the three groups of Xhosa men differed with respect to their surroundings while growing up, making it difficult to suggest that these results support the carpentered world hypothesis. However, to the extent that these differences may be assumed, the data would support this hypothesis.

The situation became clearer in a study performed by Brislin (1974). He compared a group of individuals from Guam to a group from the mainland United States. At the time, Guam had very few long, straight roads, and no railroads. Furthermore, the vistas were short due to either hills or trees. Brislin tested participants using standard two-dimensional representations of the Ponzo illusion drawn on cards (see Figure 13.4). The results were consistent with the ecological cue (or "carpentered world") hypothesis; participants from Guam were less susceptible to two-dimensional depictions of the Ponzo illusion than were the mainland Americans. Brislin and Keating (1976) sought to replicate these results in an environmental context. They reasoned that if exposure to open vistas and man-made environments was responsible for the susceptibility to the Ponzo illusion, then the illusion should be just as effective in a more natural setting. They compared a sample of

21 mainland U.S. students (all from urbanized areas) with 21 Pacific Islanders (all participants were between 22 and 40 years of age). The Pacific Islanders each had lived a minimum of their first 18 years on their home island. The islands represented had environments similar to that of Guam (described earlier) and included American Samoa, Fiji, Kauai, Marshals, Maui, Palau, Ponape, Solomons, Tonga, Truk, and Western Samoa. In addition, the researchers tested 10 participants (aged 22–40 years) from urbanized areas of the Philippines as a third comparison group. Brislin and Keating created the "natural" setting by using boards that were each 3.2 m long, set up as the converging lines of the Ponzo illusion. A board 80 cm long (the standard) was placed near the apex, with comparison boards ranging in length from 77.6 to 92.8 cm in length. A wooden house served as the background to the scene, and participants stood 13.2 m away from the display at a point equidistant from the ends of one of the 3.2 m boards (resulting in the horizontal version of the Ponzo illusion).

The results replicated those of the earlier study performed by Brislin (1974). The participants from the United States were more susceptible to the illusion (as were participants from urban areas of the Philippines). Both these groups were significantly different from the Pacific Islanders. Furthermore, Brislin assessed the reliability of judgments using this procedure, testing 12 participants 2 months later. The correlation between test–retest judgments was $r = .75$, suggesting a consistent finding.

In another study investigating effects of age, schooling, and environment on perception of the Ponzo illusion in Moroccan males aged 6–22, Wagner (1977) analyzed the interaction among these three variables. When seen in pictures depicting it in relatively "natural" settings (a railroad track or a field), the Ponzo illusion produced increased susceptibility in older participants, and schooling and urban environments produced increased susceptibility for these same conditions. The results of these studies (Brislin, 1974; Brislin & Keating, 1976; Wagner, 1977) once again support an ecological cue hypothesis. The major difference between groups was the environments in which they were reared, and not education differences (all participants were attending post-baccalaureate courses in Hawaii), except for Wagner's participants, whose educational experience seemed to increase vulnerability to the illusion. These results also indicated that the Ponzo illusion persists under either two-dimensional or three-dimensional conditions.

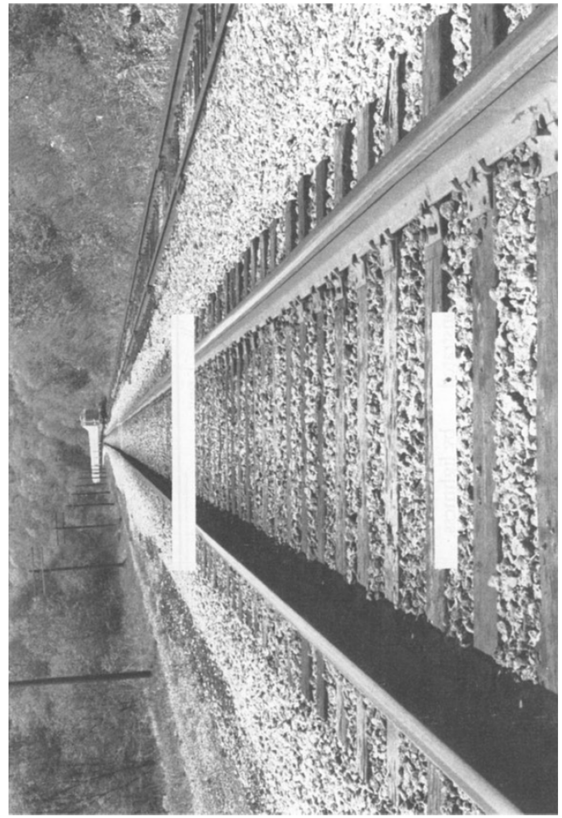


Figure 13.5 Railway version of the Ponzo illusion. Retrieved from http://www.ichardgregory.org/papers/brainmodels/brain_model_fig7.jpg. Reproduced with thepermission of Richard L. Gregory

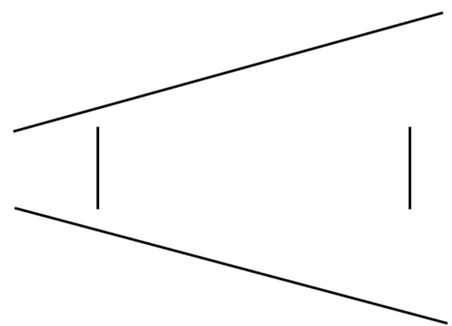


Figure 13.4 The Ponzo illusion, in which the top line is perceived as longer than the bottom line.

Moreover, these cues appear to be artifacts of constructed environments: straight paved roads, railroad tracks, and city-block matrices that give rise to the size-distance inference that objects farther away are larger than they appear. This inference would develop to a lesser degree in persons not exposed to great distances in their home environments. Interestingly, research has shown that differential exposure to environmental cues for the Ponzo illusion can also produce differing responses in nonhuman animals (e.g., Nakagawa, 2002). Curiously, however, Segall et al. (1966) reported that differences with respect to a similar perspective illusion were inconclusive.

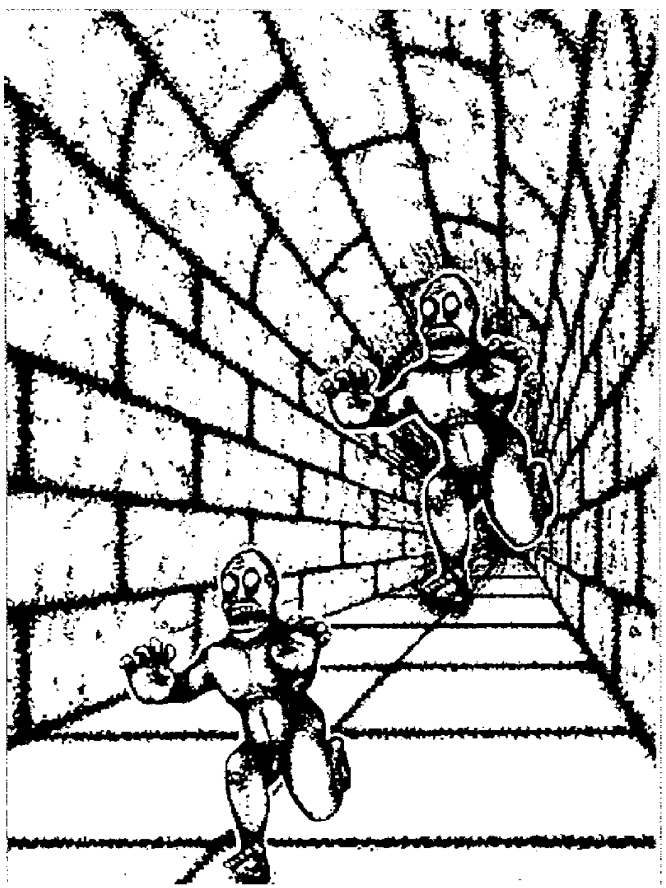


Figure 13.6 Popular variation on the Ponzo illusion. This drawing depicts several picture cues for depth: (a) relative height, (b) overlap and (c) linear perspective. "Monster" image from Mind Sights: Original Visual Illusions, Ambiguities, and Other Anomalies, by Roger Shepard. Copyright ©1990 by Roger Shepard. Reprinted by arrangement with Henry Holt and Company, LLC

Picture Perception: Perceiving Depth in Pictures

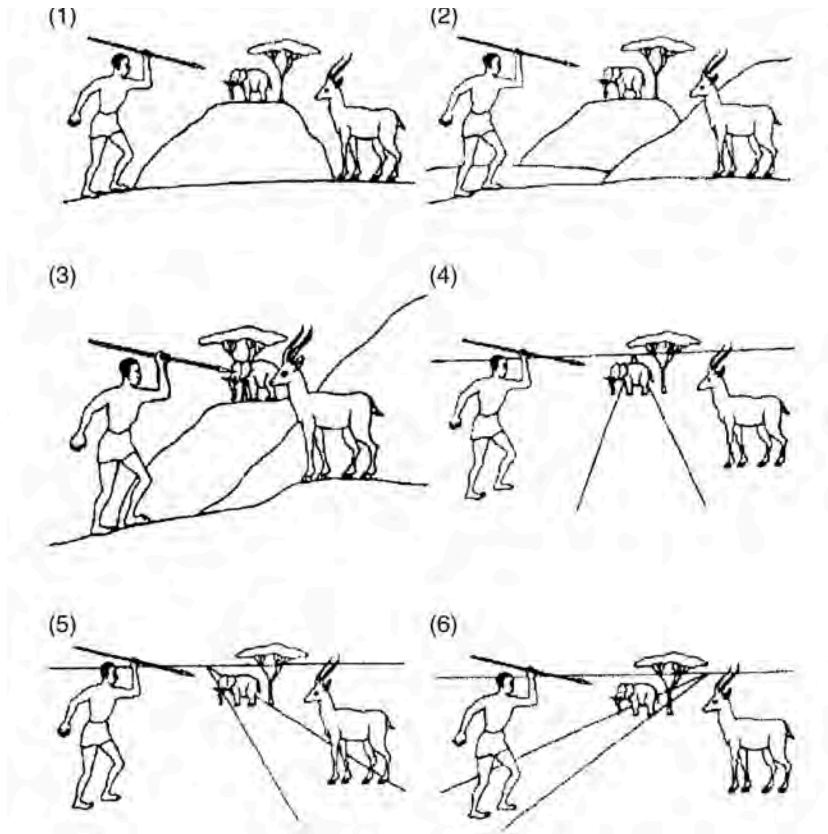
Beyond the fact that the previously discussed illusions are depicted in line drawings, it will prove interesting to consider differences in the perception of whole pictures. There has been a considerable number of reports by missionaries, explorers, and anthropologists describing how different cultures interpret images in pictures and photographs (e.g., Kidd, 1904; Livingstone, 1857), and a long history of interest in pictures, spanning millennia (Halverson, 1992). These writers have reported how pictures or photographs were not well perceived, or perceived with some initial difficulty, by people who were not experienced with two-dimensional depictions of three-dimensional scenes. Thus, Kidd (1904), writing about the Kafir of South Africa, related "The natives are frequently quite incapable of seeing pictures at first, and wonder what the smudge on the paper is there for" (p. 282). According to these reports, children often perceived the image before adults, who after some instruction also could recognize objects such as a dog or ox. Other groups have reacted quite strongly to the sight of pictures, especially of slides projected on a large screen. Livingstone (1857) gave a rather interesting account of one such episode:

> **Shinte was most anxious to see the pictures of the magic lantern … he had his principal men and the same crowd of court beauties around him as at the reception. The first picture exhibited was of Abraham about to slaughter his son, Isaac; it was shown as large as life, and the uplifted knife was in the act of striking the lad; the Balonda men remarked that the picture was much more like a god than the things of wood or clay they worshipped … The ladies listened with silent awe; but when I moved the slide, the uplifted dagger moving towards them, they thought it was to be sheathed in their bodies instead of Isaac's. "Mother, Mother!" all shouted at once, and off they rushed helter-skelter, tumbling pell-mell over each other, and over the little idol-huts and tobacco-bushes; we could not get one of them back again. (Ch. 16, Jan. 19)**

Thus, it seems apparent that pictures were at one extreme (at least initially) not seen at all, to the extreme of believing they are real. However, it should also be noted that in one instance the background was a small and glossy rectangle (the photographs) while in the other projections were made on a life-size wall or screen (Deregowski, 1999). More recent work has included scientific efforts to understand how people of differing cultures and backgrounds perceive pictorial stimuli.

Some of the pioneering cross-cultural experimental work on the perception of pictures was performed by Hudson (1960). Hudson was interested in how depth in pictures would be interpreted—specifically, the pictorial cues of relative size, overlap (or interposition) and linear perspective (see Figure 13.6 for an explanation of these cues). Hudson showed a series of pictures (like those in Figure 13.7) to 273 children and 289 adults in the Union of South Africa. The adults consisted of skilled and unskilled male mine workers with varying amounts of schooling. All
the children attended school, and were in grades 1–12. One group of adults were teachers from area schools. The adults varied also in their territorial origin, which included South Africa, South West Africa, the High Commission Territories, Federation of Rhodesias and Nyasaland, East Africa, Mozambique, and Angola. Data were not reported by region, but by whether the sample was of African or European descent and whether participants had experienced formal schooling.

Hudson (1960) showed his participants the line drawings of various hunting scenes (Figure 13.7), first asking them to name all the elements depicted (to ensure they understood what the pictures represented). He then asked several questions about relations that were depicted, such as "What is the man doing?" and "What is nearer the man, elephant or antelope?" If participants answered "antelope" to the latter question, for example, they were classified as "three-dimensional" (3D) perceivers. Hudson found that educated people, both black and white (including school children and teachers) made significantly more 3D responses than unskilled laborers (whether schooled or not), and that within the unskilled laborers group those with schooling made more 3D responses. Hudson concluded from these data that formal schooling was an important factor in determining whether a person would be a 3D perceiver of pictures. Hudson's picture test was used on many different tribal groups within Africa (presumably without formal schooling), with the majority of these investigations revealing that children and adults from these cultures tended not to perceive depth within these types of pictures (Deregowski, 1972).

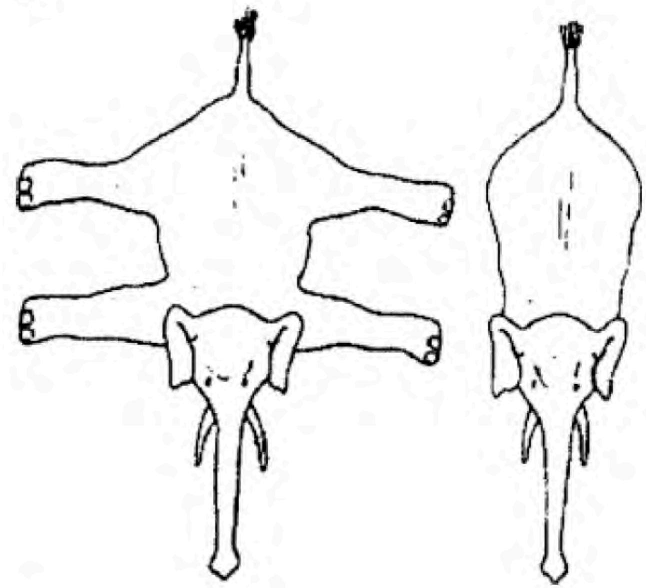


In a second study, Hudson (1962; as cited by Deregowski, 1999) displayed images like those depicted in Figure 13.8a to 40 mine laborers from South Africa. Hudson asked the miners which of the two versions of the elephant they preferred. All but one of the miners preferred the "spread-eagle" version of the elephant. This is not wholly unique to these tribesmen, as this means of drawing is also depicted in the artwork of West Canadian Indians (Figure 13.8b), artwork depicted on an urn excavated near the Polish-Baltic coast and dating to the first century BCE, and in artwork from other cultures (Deregowski, 1999).

Kilbride and Robbins (1969) set out to replicate the findings of Hudson (1960) and to determine acculturation effects other than schooling that might be responsible for perceiving 3D representations in pictures. They presented 104 rural dwelling Baganda and 118 urban dwelling Baganda the Hudson picture test. The rural Baganda lived on the northern and western shores of Lake Victoria in Uganda. This group were mostly farmers, having little or no access to television, movies, or magazines, and had an average of 3.36 years of schooling. In contrast, the urban group (living in Kampala, a city of more than 200,000 inhabitants) reported having television sets in their homes (10%), owning cameras (14%), regularly reading magazines (89%) and averaging 7.47 years of schooling. Occupationally, this group included teachers, administrators, nurses, engineers, clerks, and secretaries. Results indicated that even when controlling for education differences, the urban group showed a greater tendency to be 3D perceivers. Thus, both formal education and urbanization (similar to that of Western culture) appear to influence the tendency for an individual to be a 3D perceiver.

Not all the picture research has involved samples only from Africa. Jahoda and McGurk (1974b) tested the linear perspective cue by comparing 60 schoolchildren from Glasgow, Scotland, 60 urban schoolchildren from Hong Kong, 48 "boat" children from Hong Kong (these children spent most of their lives on junks, and often experienced delayed or very limited schooling), and 59 schoolchildren from rural villages near Salisbury, Rhodesia. All participants viewed a picture similar to that in Figure 13.9 (Jahoda & McGurk, 1974a). One picture depicted only elevation as a depth cue, one employed elevation plus texture, one used elevation plus linear perspective, and one employed elevation, linear perspective, and texture as depth cues. Two female drawings were added to each picture along the diagonal depicting depth—girl-girl, girl-woman, woman-girl, and woman-woman (these two figures were identical except for size, with the larger representing the woman). Up to five different age groups (and thus levels of schooling) were tested from each sample. Each participant's task was to place two dolls on a green board (a physical model representing a 3D depiction of the picture) so as to represent the accurate size and spatial relationships depicted in the picture (see Jahoda & McGurk, 1974a, for a complete description of this task).

(a)



(b)

Figure 13.8 (a) Example of the stimuli used by Hudson (1962). From Deregowski, J. B., "Pictorial perception and culture." © (1972) by Scientific American, Inc. All rights reserved. (b) Artistic "split" drawing of a bear by the Tsimshian Indians of the Pacific Northwest. From Deregowski, J. B., "Pictorial perception and culture." © (1972) by Scientific American, Inc. All rights reserved.

Replicating the results discussed earlier (Hudson, 1960; Kilbride & Robbins, 1969), the Scottish sample and the Rhodesian sample improved with age for both size and spatial relationships. However, this effect did not occur in either of the Hong Kong groups with respect to size. With respect to spatial relationships, the urban Hong Kong children did show an age effect, but the boat children did not. Of more interest to the present chapter is the difference in results between groups (not analyzed by Jahoda and McGurk). The urban groups (from Scotland and
urban Hong Kong) had the advantage when making size judgments, while the two groups from Hong Kong were better at spatial relationships. This is a surprising finding in light of the work of Hudson, who hypothesized that schooling was the major factor in perception of pictures. However, the Hong Kong groups showed little and no age-school effect for the urban and boat children, respectively. In other words, the ability to make size and spatial judgments for the Hong Kong children seemed to occur before schooling began; there is something else in their culture—which we will discuss in the following section—that seems to be responsible.

Bovet and Vauclair (2000) conducted a wide-ranging survey of research on picture recognition, not only in humans, but also in nonhuman animals. They concluded that picture recognition is present in humans from an early age, but that it is facilitated by previous exposure to pictures—Numerous researchers have concluded that, although na ve subjects can quickly learn to recognize objects in pictures, they may find the process effortful or stressful (e.g., Deregowski, Muldrow, & Muldrow, 1972). In addition to experience with pictorial stimuli, Bovet and Vauclair reported that familiarity with objects portrayed in pictures, and other characteristics (e.g., the presence of motion) of the stimuli contribute to individual responses.

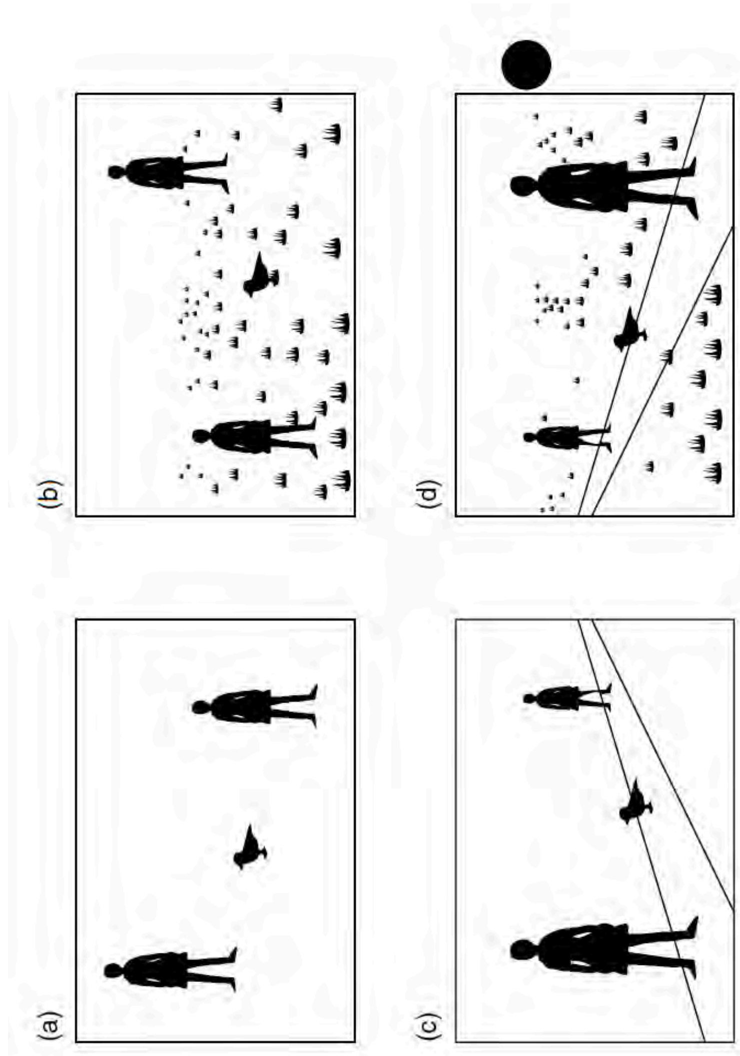


Figure 13.9 Pictures used by Jahoda and McGurk (1974a). Participants represented the size and spatial relationships in a 3D model (see text for details). Reprinted by permission of Gustav Jahoda.

Picture Perception: Context and Wholeness

More recent research on cultural differences with respect to pictures has focused less on cues for depth and more on context and "wholeness." For example, Norenzayan, Smith, Kim, and Nisbett (2002) investigated categorization differences among European Americans, Asian Americans, and East Asians. They hypothesized that Asians (who are more socialized to focus on interdependence within their culture) would attend more to family type characteristics than to single-rule based characteristics. Participants viewed two groups of objects like those presented in Figures 13.10a and b and attempted to determine the group to which each target was most similar. One hundred fifty-seven male and female students (52 European Americans, 52 Asian Americans, and 53 East Asians of both Chinese and Korean descent) rated the similarity of 20 stimuli. The results suggested that Asian Americans and East Asians were much more likely to judge similarity based on family resemblance (the whole stimulus) rather than one defining feature shared in common (the strategy employed by the European Americans).

Further evidence supporting the hypothesis that East Asians attend more to the "whole" rather than specific features of a stimulus comes from the work of Kitayama, Duffy, Kawamura, and Larsen (2003). They presented 20 undergraduate university students from Japan and 20 from the United States the line drawing task described in Figure 13.11. Results revealed that Japanese students made fewer errors in the relative task, while Americans made fewer errors in the absolute task. This occurred even when the researchers instructed the participants to draw the absolute length of the line or the proportional length of the line! Participants could not overcome their pre-existing bias for drawing the line—with the Japanese students emphasizing the relational nature of the task, and the Americans the absolute.

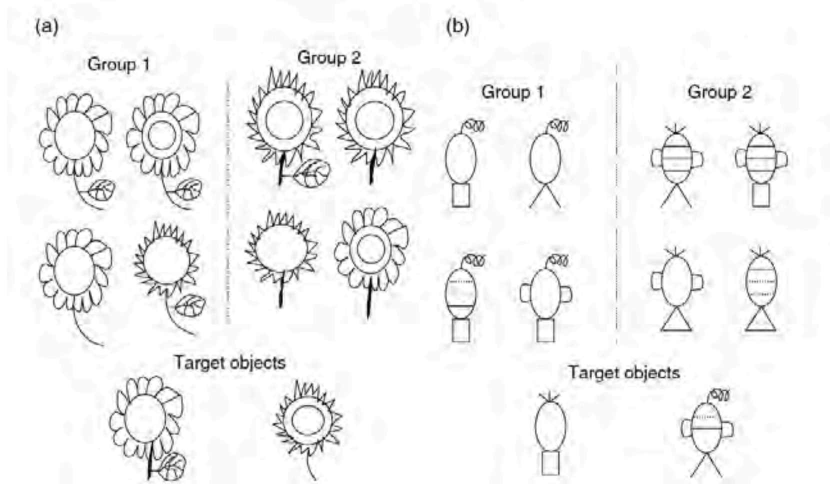


Figure 13.1 Line segment AB is typically perceived to be shorter than line segment CD, though they are the same length.

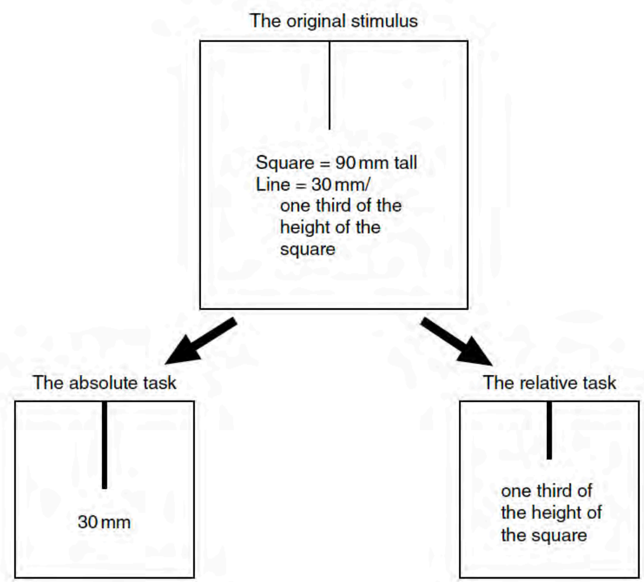


Figure 13.2 Diagram of apparatus used by Rivers. The segment with divergent arrows (B) was to be extended to match the segment formed by the convergent arrows (A).

The results of these two studies suggest that East Asians attend more to the entirety or “whole” of a stimulus than do Americans. If this hypothesis is true, then it should occur in other, real-world contexts as well. Replications to test such hypotheses are performed to establish the ecological validity of a finding—obtaining a similar result under more naturalistic conditions. Masuda and Nisbett (2001) showed Japanese and American participants video clips of displays like that in Figure 13.12, and asked them to write a description of what they saw. Japanese participants were much more likely to begin their descriptions with a summary of the context (e.g., stationary objects in the display), whereas American participants tended to describe salient objects in the display (i.e., objects that were moving).

Overall, Japanese participants reported nearly 60% more contextual information. Furthermore, in a follow-up recognition task that incorporated either the same, novel, or no background, Japanese participants were influenced by the background while American participants were not (providing a novel background impaired Japanese participants’ recognition of salient objects more than it did American participants’ recognition).

Masuda, Gonzalez, Kwan, and Nisbett (2008) also explored the perception of “wholes” and context in photography. Participants (37 Caucasians, 6 African Americans, 22 Taiwanese, 7 Koreans, 5 Japanese, and 12 Chinese) were instructed to take 4 portrait photographs of a model (sitting or standing in either a lab or an atrium setting). All participants were shown how to use the zoom lens and change focus on a digital camera, and all pictures were taken 9 ft. from the subject. The findings were fascinating. Americans took portraits that depicted the face on average 35% larger than photographs taken by East Asians—a finding consistent with artists’ paintings in each culture. American artists tend to emphasize the individual in portraits, and to be generally more object-oriented, whereas East Asian artists tend to portray individuals as part of a larger context, and to be generally more context-inclusive (Masuda et al., 2008). These findings were replicated by Phillips et al. (2017) using a procedure very similar to that of Masuda et al. (see Figures 13.13a and b for photos taken by Americans and Asian-Americans, respectively).

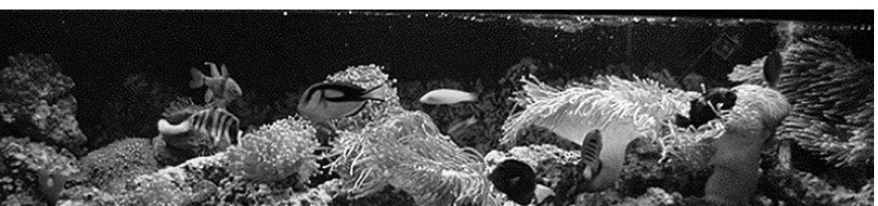


Figure 13.12 Example of the type of scene from video clips shown to participants by Masuda and Nisbett. Clips lasted approximately 20s and were shown twice before data were collected. Photo ©William Phillips.

In addition, a second study by Phillips et al. also showed this result when the setting was changed to a more natural environment. Confederates approached students at picturesque locations on a campus and asked them to take a photo of the confederates as part of a photography class project (participants were unaware it was a sychology experiment). Consistent with earlier results, Asian American students included more context (i.e., the face was smaller in the photo) than European-American students.

Greater context is not only preferred by East Asians in photographs and paintings, but in their own productions as well. Wang, Masuda, Ito, and Rashid (2012) reported that East-Asian students included more information in conference posters and in electronic portals, as well as preferring more information on these products.

(a) (b)

Figure 13.13 (a) An example of the type of photograph taken by Americans. (b) An example of the type of photograph taken by Asian-Americans.Photos ©William Phillips.

Conclusion

The preceding pages briefly highlight more than 100 years of psychological research pertaining to differences among cultures in their perception of color, visual illusions, pictorial depictions of depth, and the perception of "wholeness" in pictures and photographs. Time and again, the data support the hypothesis that variables associated with cultural differences (both physical and social) contribute to perceptual differences found between groups. Thus, color sorting differences among cultures can be attributed to differences in language and vocabulary. Language does not influence the physiology of our perceptual systems per se, but it does drive the relations we see among objects, leading to differences in attention, organization, and other cognitive processes. The relevance of this finding does not suggest that one language is more "primitive" than another, but rather illustrates that language meets the adaptive needs of those who employ it in a particular cultural context.

The carpentered world hypothesis that physical environments (or ecological cues that relate to culture) affect our perception has been used to explain cultural differences in the Müller-Lyer and Ponzo illusions. Again, these conclusions do not imply that one culture is superior to another, but that our cognitive systems are adaptable to a variety of environments, and that our perceptual responses will vary accordingly. Moreover, this plasticity of cognitive functioning seems to be related more to exposure at a young age, than to education, as indicated by the research of Pedersen and Wheeler (1983), and that of Brislin (1974) (both of which controlled for education). The case is similar for the perception of depth in pictures. Interpretation of pictures is related to how pictures are used within a culture (whether pictures and paintings are purely ornamental and decorative or used as a means of communication), paired with ecological cues available from the environment.

Finally, socialization may be responsible for differences in perception and cognitive organization among cultures. East Asians consistently attend more to the context and wholeness of a scene, whereas Americans attend more to salient features or objects. This may be related to the interdependence of East Asians versus the independence stressed by Western culture. Another example of socialization as a mechanism occurs in the way Chinese mothers speak to their infants, in contrast to American mothers (Tardif, Shatz, & Naigles, 1997). Chinese mothers tend to emphasize verbs, whereas American mothers emphasize nouns. This could lead Chinese children to attend more to relationships among objects in an entire scene (holistically), rather than to salient objects in a scene (analytically). Again, socialization leads to differences in cognitive structure, highlighting that these structures are largely shaped by culture (Nisbett & Miyamoto, 2005).

In this chapter we have examined only a few of the fascinating perceptual phenomena that researchers have studied over many years. And, as we have seen, it is not sufficient to simply describe perceptual differences between cultures. Particular aspects of exposure within cultures—education, specific forms of experience, the cultural emphasis on the context (or the individual), the role of relationships, and many more—are important influences on perceptual processes. We thus need continued research aimed toward unraveling these influences, studies that "unpackage" (Matsumoto, 2006; Whiting, 1976) these variables and expand our understanding.

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Emotion and perception: the role of affective information

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Visual perception and emotion are traditionally considered separate domains of study. In this article, however, we review research showing them to be less separable than usually assumed. In fact, emotions routinely affect how and what we see. Fear, for example, can affect low-level visual processes, sad moods can alter susceptibility to visual illusions, and goal-directed desires can change the apparent size of goal-relevant objects. In addition, the layout of the physical environment, including the apparent steepness of a hill and the distance to the ground from a balcony can both be affected by emotional states. We propose that emotions provide embodied information about the costs and benefits of anticipated action, information that can be used automatically and immediately, circumventing the need for cogitating on the possible consequences of potential actions. Emotions thus provide a strong motivating influence on how the environment is vperceived.

Introduction

To scientists who study perception as well as to those who study emotion, the idea that emotion routinely alters perception may seem completely foreign.Most of us assume quite reasonably that as we look at a hill, for example, the steepness of the incline in our visual image is more or less the steepness of the hill in the world. The reality, however, is that the incline is far less steep than it appears (most people perceive a 5° hill to be 20° or more).[1,2] Moreover, our perception of the steepness will change from one occasion to the next depending on our mood.[3] For example, when we are feeling sad, we will perceive the hill to be steeper than when we are feeling happy. Such findings indicate that the perception of spatial layout is in fact influenced by non-optical factors, including emotion.

In this article, we review evidence of a variety of emotional influences on visual perception. Rather than a single, general mechanism that explains them all, a number of processes appear to be involved. Thus, we discuss candidate explanations as we review specific findings. The emotional phenomena discussed include effects on early visual processes, global versus local perceptual focus, susceptibility to visual illusions, and perceptions of natural environments. In addition, as emotions have both bodily and motivational components, we also touch
on perceptual influences of bodily and motivational states. For example, both emotion and motivation appear to prepare the visual system to detect relevant aspects of the environment by making them easier to see.4,5 And both emotional and bodily states appear to regulate visual perception of spatial layout. We propose a functional view in which emotional influences on perception can be seen as evolving in the interest of minimizing negative and maximizing positive outcomes, a view consistent with the ‘affect-as-information’ hypothesis.6,7 More generally, we propose that emotion influences perception in the interest of resource maintenance.

The reader will note that, although this article concerns emotion and perception, we consider only emotional influences on perception and not the reverse. However, it should be understood that perception is also fundamental to emotion. Indeed, many emotions arise immediately upon the perception of emotionally evocative stimuli, some requiring more interpretation (rising gas prices) and some less (snakes, spiders). But exploration of those phenomena requires a separate treatment (for a review of relevant conceptions, see Ref 8).

Fear and Orientation Discrimination

Emotional arousal guides attention so that people's attention tends to be drawn to objects that are arousing. Indeed, some years ago, Herbert Simon[9] proposed that a chief function of emotion is to interrupt and reorder processing priorities. Thus, even the most avid chess player is likely to stop his game upon noticing that his house is on fire. As we shall see, some of the important influences of emotion on perception are mediated by attention, but emotion can also influence pre-attentive perceptual processes. This fact was discovered by Phelps, Ling, and Carrasco10 using an orientation discrimination task. The task consisted of showing four sinusoidal gratings simultaneously, in which three of the patterns (distracters) were oriented vertically and one (the target) was tilted 8° clockwise or counter-clockwise. The grating contrast levels were varied on each trial. Participants were to locate the target as quickly aspossible. The patterns were preceded by a rapidly presented face displaying either a fearful or a neutral expression. The logic of the experiment was that if emotion enhances perception, discrimination should improve following exposure to a fearful face. The results supported that hypothesis: contrast sensitivity at threshold improved by 1%following a fearful face. Examples of stimuli at the contrast thresholds for the fearful and neutral groups are shown in Figure 1 along with the fearful and neutral faces (which show the psychologist Paul Ekman posing the two expressions).

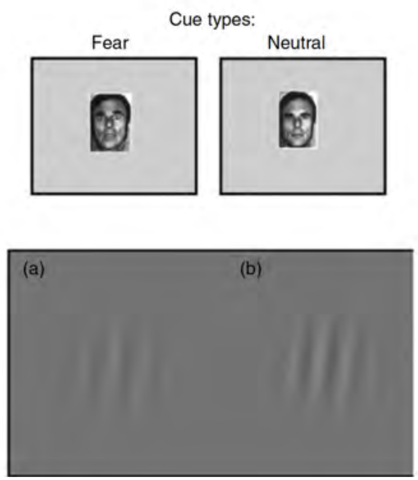


FIGURE 1 | The impact of emotion and attention on perception. The gratings shown represent the contrast threshold (i.e., the contrast necessary to perform the orientation discrimination task at 82% accuracy) in each condition: (a) fearful face, peripheral cue (b) neutral face, peripheral cue.

In a second experiment, the authors10 asked whether emotion had really changed perceptual sensitivity or whether instead the fearful and neutral faces had differentially influenced covert attention. To find out, they took attention out of the equation by presenting the fearful or neutral face in the same quadrant as the subsequent target grating would appear (instead of in the middle of the screen as in Experiment 1). But again, exposure to a fearful face increased contrast sensitivity, even though attentional shifts were no longer involved. Hence, the authors
could conclude that,[10]

> **. . .the mere presence of a fearful face increased contrast sensitivity. . . . [and] Emotion actually affects how see.**

In addition, they found that the facial expressions had to be emotionally meaningful—if the faces were inverted, the effect disappeared. The authors proposed that this effect is probablythe result of feedback from the amygdala to the early visual cortex, as well as to regions that enhance attention. The amygdala responds to significant stimuli, including fearful faces, rapidly and prior to awareness. A fearful face indicates that there may be a threat in the environment, but it gives no information as to its form or location, so enhanced contrast sensitivity might aid in detecting the threat.[10]

Other research shows that high-level goals can also influence the responsivity of the amygdala to affective stimuli. The amygdala is believed to respond to affective stimuli more or less automatically, but evidence shows that responses depend on the current relevance of affective stimuli.11 In an imaging study, participants were asked to rate either the positive or negative aspects of 96 famous names (Adolph Hitler, Paris Hilton, Mother Theresa, George Clooney). The results showed that when evaluating positive aspects, the amygdala responded only to the names of people that a given participant liked, and when evaluating negative aspects, the amygdala responded only to the names of disliked people. Thus, the automatic affective reactions of the amygdala were guided by the current goal of the individual. It is unclear whether the amygdala itself filtered information for motivational significance or whether top-down processes did so before information reached the amygdala. But the results encourage a view of the brain in which highand low-level processes continually interact—a view within which it becomes less surprising that emotion can affect perception.

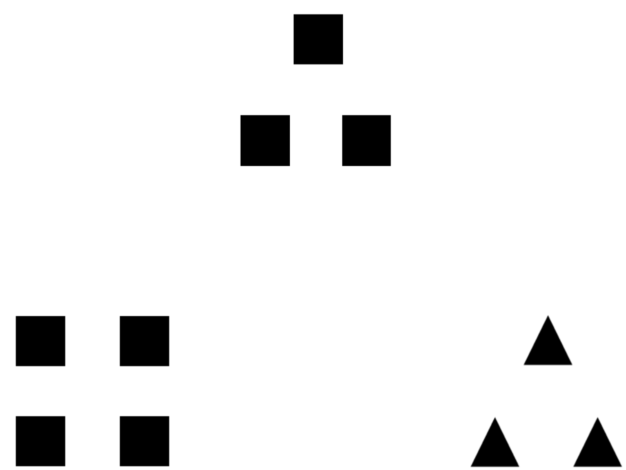
Mood and Global–Local Perception

People sometimes say that a person ‘can’t see the forest for the trees’. In doing so, they imply an incompatibility between perceptions of details and perceptions of wholes. Some conditions encourage global perception and some encourage local perception, but people generally show a tendency to process globally. This is apparently not true of autistic individuals[12] or of individuals in certain cultures[13] who more readily see local details.

Emotion also influences whether people focus on the forest or the trees. After hitting his head during a parachute jump, the psychologist Easterbrook[14] noted that his spatiotemporal field seemed to shrink.[15] With this experience in mind, he later proposed that stress narrows atttention. Fifty years later, many findings support this idea as well as the extension that positive emotion broadens attention.[16,17] Relevant research sometimes employs standard tests to measure global and local perception. On the Kimchi test, respondents are shown a target geometric figure and asked which of two comparison figures is most similar to it.[18] As shown in Figure 2, the target might be three small squares arranged in the overall shape of a triangle. People then choose which of two comparison figures is most similar. One comparison figure is a triangle composed of small triangles, and the other is a square composed of small squares. A local response would be to choose the figure with squares, because the target figure had been composed of squares. A global response would to choose the figure with triangles, because the overall shape of the target figure had been a triangle. When investigators induce happy or sad moods (e.g., by having participants spend a few minutes writing about a happy or sad event from their lives), participants in happy moods often adopt a global perceptual style, whereas those in sad moods adopt a local perceptual style.[19]

Another standard method, the Navon procedure, involves measuring reaction times to large or small letters.[20] For example, a large ‘L’ might appear made up of many smaller ‘Ts’. Respondents might be asked to indicate as quickly as possible whether they see an ‘L’ on a given trial. Comparing the reaction times to detect letters appearing as global stimuli and those appearing as local stimuli yields a measure of whether global or local perceptual styles are dominant.

Some research findings using this measure suggest that although global processing occurs in generic positive moods, states in which a specific object elicits approach motivation (e.g., hope) can lead to local rather than global responses.[21] Still other research findings suggest that rather than a dedicated relationship between affect and perceptual style, positive affect may facilitate and negative affect may inhibit whatever orientation is most accessible in a given situation. In many situations, a global focus is dominant,[20] a tendency sometimes called the ‘global superiority effect’. It is possible, then, that affect influences whether one focuses on the global forest or on the local trees simply because positive affect says ‘yes’ and negative affect says ‘no’ to the (generally more accessible) global focus. A test of that hypothesis used cognitive priming techniques to alter whether a global or a local orientation was momentarily more accessible.22 The results showed that when local responding was made especially accessible, the usual result was reversed. Positive affect then led to a focus on details and sad moods to a focus on the big picture. It appears, therefore, that positive affect may facilitate whatever the dominant orientation is rather than being specifically tied to a global focus. Thus, whether one focuses on the global forest or the local trees is indeed influenced by one’s current emotional state. However, rather than reflecting a direct connection to perception, these data indicate that positive affect can empower (and negative affect can inhibit) either a big or a small view, depending on which is dominant in a given situation.



Mood and The Ebbinghaus Illusion

The tendency for negative affect to lead to a local perceptual style is also evident in research on visual illusions. For example, the Ebbinghaus illusion (Figure 3) involves a visual contrast effect in which the same target circle appears smaller when surrounded by big circles and bigger when surrounded by small circles. The illusion is very compelling, but recent research shows that sad moods reliably reduce the effect.[23] In the same research, sad moods were found to reduce context effects and increase the accuracy of judgments of the temperature of lukewarm water after exposure to hot or cold water and of the weight of a 1-kg box after lifting a heavier box.

A similar tendency for sad mood to lead to the exclusion of contextual stimuli is evident in studies of semantic priming.[24] Whereas people are usually slightly faster to identify words after a brief exposure to a word similar (compared to dissimilar) in meaning, this does not occur for individuals in induced sad moods, even though such mild states do not slow responding overall. This phenomenon is interesting in the current context because it suggests that emotional factors may have similar effects on perceptual and conceptual processes. Explanations have stressed that sad moods interfere with the usual relational processing (processing incoming information in relation to current mental context), leading to item-specific or referential processing.[24] That explanation is also compatible with the idea that negative affect narrows attention.[15,16]

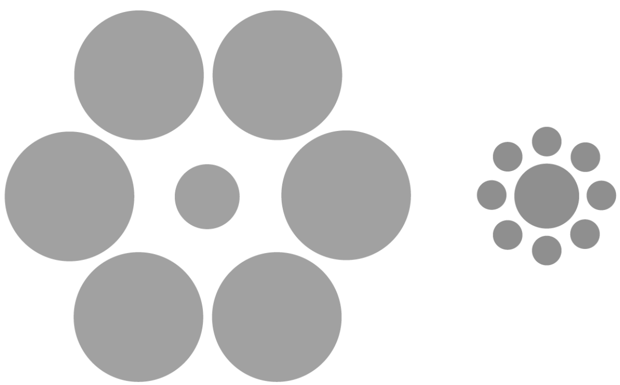


FIGURE 3 | The Ebbinghaus Illusion. The circles in the middle of these two figures are the same size, but in their respective contexts, the one on the left looks smaller than the one on the right.

Emotion and Attention

The studies we have reviewed show that emotional and motivational factors can regulate global versus local orientations to visual stimuli and whether or not perception includes or excludes contextual stimuli. But, as noted above, the same is also true when the stimuli are conceptual rather than sensory. For example, individuals feeling happy are more likely to use stereotypes and other categorical information when forming impressions of others. By contrast, when forming impressions, people feeling sad focus on behavioral or other detailed information and tend not to use global categories.[25–27] Such results may indicate that the influences of affect on global–local perception and conception are mediated by attention.Attention is sometimes thought of as a spotlight that directs limited processing resources to the most Studies examining the role of emotion in relevant stimuli.[28,29] If affect signals value[30] or motivational significance.[31] then we might expect affect to influence attention. For example, activating an affective attitude leads to attitude-consistent judgments[32] by biasing attention toward attituderelevant stimuli.[33]

Studies examining the role of emotion in attention have sometimes employed a spatial probe task for measuring attention. In the spatial probe task, two words are presented briefly in different locations followed by a dot probe in one of the locations. If an emotion-relevant word attracts attention, the dot appearing in that location will be detected faster than a dot appearing in the other location. Speed of response to the dot is thus a usefulmeasure of selective attention.[32] Some of the research using this technique has been conducted by clinical psychologists interested in the effects of anxiety. The general finding is that fear and anxiety bias attention toward threatening stimuli, including words and pictures.[34,35] Selective attention may thus serve to facilitate the processing of threat information.[28] But of course, if affect governs attention and attention in turn governs affect, then when affect draws people's attention to possible dangers, it is likely to induce stress and anxiety.[36]Positive affective reactions signal opportunities rather than dangers, raising the question of whether positive affect also directs attention. Indeed, evidence from dot probe studies indicates that positive moods bias attention toward positively valued stimuli.[37] As a result, positive affect should make rewards easier to detect, just as anxiety facilitates threat detection. Of course, attending to the upside, rather than the downside, of events is also likely to elevate mood and subjective well being.

Top-Down Effects Of Motivation And Emotion

Vigilance

Traditionally, the study of perception has stressed low level, bottom-up visual processes. But research suggests that higher level processes may play a role as well. A recent study demonstrated top-down effects of emotional information on face perception.[38] The study involved a binocular rivalry task, in which a different image is presented to each eye—for instance, a face and a house. In that task, only one image is consciously experienced at a time, and which image is seen tends to alternate every few seconds. The images essentially compete for dominance, the more important or relevant image being perceived relatively longer. In this experiment, faces became more dominant in the rivalry task after being paired with descriptions of negative social information, such as, that the person lied, stole, or cheated. The results suggest that gossip and other social information may tune the visual system, aiding in the detection of persons who should be avoided without requiring any direct negative experience with them. This idea that the emotional significance of objectsmay make them easier to see has a long and interesting research history, as we see next.

Goals

Years ago, the 'New Look' in perception proposed that perception should be influenced by motivation. For example, Bruner and Goodman39 reported an experiment in which a sample of poor children from the Boston slums perceived coins to be larger than did children from wealthier Boston families. The same effect did not appear for similarly sized cardboard disks, leading the authors to conclude that motivation can influence perceptions of size, making motivationally relevant objects easier to see. At the time, the idea that visual perception, our window to objective reality, might be guided by subjective desires was seen as quite unacceptable. Moreover, when the New Look was elaborated to include predictions from Freudian theory, it was soundly rejected by many investigators.

But the basic hypothesis that motivation might affect perception has since been revisited. Recent evidence shows that, for example, people who are thirsty perceive a glass of water as taller than those who are not thirsty.[5] And when typically neutral goals, such as gardening, are made positive by pairing them with positive stimuli, tools associated with the goal (such as a shovel) appear larger.[5] Similarly, smokers deprived of cigarettes tend to overestimate the length of a standard cigarette.[40] Other findings also indicate that ambiguity in visual stimuli (e.g., a stimulus that could be seen either as the letter 'B' or as the number '13'), will tend to be resolved by seeing the stimuli in a way that leads to reward in an experimental situation.[41]

In related research, participants who had agreed to walk on their campus wearing a large, embarrassing sign underestimated the distance to be walked.42 The authors reasoned that the misperception of distance was a way of reducing the cognitive dissonance of having freely chosen to engage in such an unpleasant action. Consistent with the original New Look logic, such data again suggest that goals can tune the visual system to see the world in motivationally consistent ways (for more on the social psychology of perception, see Ref [43]). Whereas most of the emotional effects we have discussed have been evident only in limited, somewhat artificial laboratory settings, this experiment and the research to be discussed in the remainder of this review concern perception in the world.

Spatial Perception

Emotional effects in real-world environments may be more pervasive than most people realize. It is often assumed that one of the primary goals of the visual system is to recreate the environment, forming a representation in the brain that is as accurate as possible. However, research over the past [10] or 15 years has demonstrated that this is not the case. Rather than reproducing pictures inside the brain, research results indicate that what we perceive is a systematically altered version of reality. Part of what we 'see' is the opportunities for and costs of acting on the environment. For example, the ground is perceived relative to its walkability and to the bioenergetic costs that this action would incur. However, these nonvisual influences are not limited to energy-related factors: emotions too are a source of nonvisual information that affects visual perception. Moreover, the influences of such nonvisual information generally appear oriented toward such beneficial consequences as conserving energy, attaining goals, or avoiding danger.

In the following sections,we first review research showing the role of extra-visual influences in the perception of spatial layout. We then review research indicating that emotions may serve a similar function, and are integrated into perception in a similar manner.

Bioenergetic Information

When one leaves the gym fatigued, the distance between the gym and one's car may look greater than it did on the way in. The effect is not obvious, because we can be in only one state at a time and have no way of directly comparing how the environment looks in two different states. But if one's perception of the distance was assessed in a covert manner both before and after exercising, one might be surprised at the difference.

This example illustrates what might be called the 'bioenergetics' of perception. 'Bioenergetics' refers to the study of the flow and transformation of energy within an animal and between an animal and its environment. A substantial and growing body of research indicates that people integrate bioenergetic information into their perceptions of spatial layout (for reviews see Ref [44,45]). For example, hills appear steeper and distances appear greater when metabolic energy is low or when the anticipated energy costs of climbing a hill or walking a given distance are increased.45 Thus, people perceive hills to be steeper when they are fatigued, in poor physical condition, or anticipating greater effort,[1,2] and they also perceive distances to be greater when anticipating increased effort.[46,47] Some experiments manipulated the anticipated effort of climbing a hill by having participants wear a heavy backpack loaded with 20% of the participants' weight.[2] Compared to the estimates of control participants, the added weight of the heavy backpack increased estimates of the steepness of hills and of the distances to targets.

Prior experiments allowed us only to infer that bioenergetic factors were responsible for such perceptual changes. More recent research has directly assessed the role of bioenergetics in perceptions of spatial layout by manipulating blood glucose levels.[48] (Glucose is the primary source of energy for immediate muscular action, and the sole source of energy for the brain[49,50]).

Some participants were given a beverage sweetened with glucose, while others received a beverage with artificial sweetener. The results indicated that a mentally taxing task (shown to deplete blood glucose51) made a hill look especially steep for those given only an artificially sweetened drink, whereas an energy-rich, glucose-sweeteneddrink yielded perceptions of the slant that were not so exaggerated. A second experiment replicated these results, adding

measures of individual differences on a host of bioenergetically relevant properties. Thus, in addition to the effects of experimentally induced variations in glucose, participants reporting fatigue, poor sleep quality, stress, and negative mood also xerceived hills to be steeper. Across both glucosemanipulation groups, individuals with characteristics associated with a reduced energy state perceived the hill as steeper. These findings have recently been replicated for distances as well.[52]

Bolstering the earlier results, these studies confirm that bioenergetic information may be integrated directly into conscious visual perception. Why should that be the case? Such an arrangement seems sensible if we keep in mind that vision evolved to support survival, rather than to provide a geometrically accurate picture of the environment. For animals that must perform a careful balancing act between energy intake and energy expenditure in order to avoid starvation, conserving energy is critical, especially when reserves are low. An explicit cognitive computation of the running balance between available resources and anticipated costs would be impossible for most animals and prohibitively expensive in time and energy for humans. Alternatively, the relevant information might simply be incorporated directly into perception. The steeper a hill looks or the farther a distance appears, the less inviting climbing or traversing it becomes. The incorporation of bioenergetic information into visual perception could thus help the organism achieve an 'economy of action' effortlessly, unconsciously, and instantaneously.[44]

It should be noted that these effects occur only for explicit perception—perceptions of which we have conscious experience. In various experiments by Proffitt and colleagues, explicit perception is assessed by asking participants to verbally report the steepness of a hill in degrees or by performing visualmatching tasks. When assessed by such verbal or visual-matching measures, hills tend to seem steeper than they really are. But apparent steepness can also be assessed with a motoric measure, a palm board, in which a board is adjusted to match the incline of a hill by touch rather than by looking at the board. Unlike verbal and visual-matching response measures, motoric responses tend to be quite accurate. An explanation of this discrepancy emphasizes that vision supports two very different functions. Explicit perception incorporates a conscious motivating factor to economize action, whereas an implicit stream of visual information guides effective actions in the environment.53 It may be adaptive for explicit perceptions of slant and distance to become inflated when resources are low in order to regulate the motivation for costly action. But it would not be adaptive for implicit perceptions also to become inflated, leading tomotoric responses that were poorly calibrated with the environment (for an in depth discussion of this subject, see Ref [44,45]].

It is reasonable to ask whether these and the many other observed effects on perception of spatial layout reflect actual perception, or are response biases (e.g., participants saying that the hill looks steeper even though it looks the same to everyone). Relevant evidence comes from several recent studies. First, indirect measures of perceived distance demonstrate effects consistent with perceptual changes but not explicable as post-perceptual response biases. For example, consider that objects within reach with a tool are reported as closer than the same objects out of reach when one lacks a tool (direct measure).[54] In this context, when a triangle is projected across the reaching boundary (such that the farthest point is within reach with a tool and beyond reach without one) the triangle appears shorter only to those reaching with a tool (converging indirect measure).55 Second, it is the intended action of the perceiver that determines whether or not there will be a perceptual change. In a clear and decisive experiment, viewers were primed to expect to either walk to a target or throw a beanbag to a target by repeating several trials of one task.47,56 Next, they walked on a treadmill for several minutes. This manipulation causes a recalibration of the relationship between walking effort and forward movement. For the few minutes following, it leads blindfolded participants to walk beyond an intended target location. In the experiment, after viewing the target, participants donned a blindfold and were instructed to blindwalk to the target.

Thus, whereas all participants responded to the target in the same manner, they had viewed the target with different intentions. Those who had intended to walk exhibited the usual effect of the treadmill manipulation, walking farther than those who had viewed the target with the intent to throw.An additional experiment accounted for potential practice effects by repeating the procedure without the treadmill manipulation: there was no effect. Thus, it was clear that the perceptual change must occur at the time of viewing (perception), and not during the response (post-perceptual response bias).

Emotion And Perception Of Spatial Layout

If post-workout fatigue alters one's perceptions when leaving the gym, how might a hill appear to someone who has to climb it on the way to work on a Monday morning when grumpy and unhappy about going to work? Would the same hill look different on a Friday when the sun is shining, the birds are chirping, and the person is happy about prospects for the impending weekend? If feeling exhausted affects perception, as indicated earlier, what about feelings of emotion? Following from the affect-as-information hypothesis,[6] we argue that affective information is integrated into visual perception in a similar manner. Just as information reflecting one's bioenergetic state is integrated into perceptions of the environment, information from one's emotions may also.

Affect As Information

The 'affect-as-information' hypothesis6,7 is an account of the influence of affect, mood, and emotion on attention, judgment, and thought. It emphasizes the idea that affect provides information, and because the information is embodied, it is also motivating. Affective experiences are often characterized as having two dimensions, valence (pleasant vs unpleasant) and arousal (excited vs calm). According to the 'affect-as-information' account, pleasant–unpleasant feelings are embodied information about value (goodness vs badness), whereas excited-calm feelings are information about importance or urgency.22,57

Emotions are generally thought of as momentary states organized around perceptions that some event, action, or object is good or bad in some way.58 Moods are also affective states, but whereas emotions are generally about something specific, the objects of moods, if any, are less salient. Rather than being a signal of something in the environment, moods often simply represent the state of the organism itself.

Moods may thus provide information important for regulatory action. Thus, feeling listless, tired, or sad saps any motivation for enterprise or adventure; whereas feeling energetic, optimistic, or happy may lead one out of the safety of one's cave, home, or hotel room and into the world.

Indeed, evolutionary biologist Randy Nesse59 concludes

> that mood exists to regulate investment strategies, so that we spend more time on things that work, and less time on things that don't.

As we shall see, one way that mood and emotion can exercise this regulation is by influencing perceptions of spatial layout in a manner similar to that of bioenergetic information.

Sadness

A series of experiments[3] asked whether people feeling sad would perceive a hill to be steeper than people feeling happy. In some experiments, mood was induced by having people listen to either happy or sad music through headphones as they viewed a hill. In others, mood was induced by having people outline, with the intent of later writing a story about a happy or sad event in their lives. Not only did perceptions of the hill differ for the groups made happy or sad, as predicted, but variations of mood within the groups had significant effects as well. Thus, for participants in the sad group, those who were sadder perceived the hill as even steeper. In addition, the results showed that current mood state, rather than more general affective traits, was the specific factor that predicted changes in perception.

The aspect of mood that was important in this study3 was valence rather than arousal. We suggest that the experience of unpleasant affect when looking uphill was experienced as a burden, as it produced effects similar to those observed when people made similar judgments while wearing a heavy backpack. Affect and emotion thus also appear to carry information about the energy costs of potential actions.

Emotional Information Transcends the Moment

A system in which perceptions are modulated by the energy available may be useful for making decisions about action. But this arrangement handles only decisions about currently visible obstacles. And as mood states may also reflect current resources, their role in decision making may also be limited. Emotions, on the other hand, are reactions to objects that need not be physically present. Absent objects may be represented symbolically so that they can be from the past, the future, or one's imagination. Emotions can thus inform decisions about a range of situations with long term as well as immediate implications.

Fear

Fear, on the other hand, concerns not one's current resources, but also the possibility of resource loss, a possibility leading to vigilance and caution. Whereas sadness influences perceptions of incline when hills are viewed from the bottom, fear might influence apparent steepness when hills are viewed from the top. To assess that possibility, some research participants were asked to estimate the slant of a hill in a state of mild fear induced by standing on a skateboard at the top of the hill (prevented from rolling by chocking the wheels).60 Those in a control condition stood on a stable wooden box of equivalent dimensions. Standing on a wobbly skateboard as opposed to a stable box made the hill look steeper. Moreover, in both skateboard and box conditions, fear levels were positively correlated with perceptions of slant. It was known from prior research1 that people generally perceive steep hills to be even steeper when viewing them from the top than from the bottom. In addition to differences in the visual angle involved in looking down versus up a hill, such overestimation may thus also involve some level of fear elicited by the possibility of falling down the hill.

The role of fear in perception of spatial layout was next assessedmore directly by having people judge heights by looking down. The weak-in-the-knees, wobbly, suddenly lightheaded feeling that results from inching up to the edge of a high cliff or the roof of a building is one that probably everyone has experienced at some point. In relevant research, fearful individuals were found to overestimate the distance from a balcony to the ground, relative to non-fearful individuals.[61] Extreme fear of heights, acrophobia, is one of the most common phobias, and recent findings suggest that acrophobics may in fact perceive the world differently from the rest of us. People with acrophobia may get this feeling not so much as an overreaction to viewing heights as from perceiving heights to be greater than those of us without the phobia.

To assess this possibility, individuals who were either high or low in acrophobic symptomswere asked to look down from a balcony and estimate the distance to the ground.[61,62] As expected, participants in the group with high acrophobic symptoms perceived the height to be greater. A similar study in which emotional arousal was manipulated found that increased arousal led to still more elevated height perception.63 That people perceive a height to be greater when viewed from above than from the ground is not new,64 but these results imply that a fear of falling may be involved.

Conclusion

Traditionally, the study of perception has been quite distinct from the study of emotion. Psychologists have tacitly viewed perception, cognition, emotion, and other basic processes as separable phenomena to be studied in isolation. Increasingly, however, we are coming to see relevant areas of the brain and the processes they support as highly interactive.

Such interaction is clearly evident in the studies of emotion and perception reviewed in this article. Not only is it possible for emotion to influence perception, but also in fact it seems to happen quite frequently—across many levels of visual perception and in response to a variety of affective stimuli. Affective valence and arousal carry information about the value and importance of objects and events, and the studies we have reviewed indicate that such information is incorporated into visual perception of one's environment.

Thus, we noted that fear increases the chances of seeing potential threats, that positive moods encourage one to maintain one's current way of looking at things, and that negative moods encourage a change. Research indicates so that objects in the environment with emotional and motivational relevance draw attention and may become more easily detected by appearing larger. We reviewed evidence that perception is systematically altered in ways that may aid goal attainment and that emotion can alter the perception of spatial layout to motivate economical action choices and deter potentially dangerous actions. The coupling of affect and perception in this way thus allows affective information to have immediate and automatic effects without deliberation on the meaning of emotionally evocative stimuli or the consequences of potential actions.

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Wayfinding Signage for People with Color Blindness

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Color plays an important role in conveying information through communication systems such as signage and electronic devices. However, people who are color-blind often have difficulties understanding that information because most systems are designed for people who can distinguish colors. The purpose of this study is to propose color combinations for wayfinding signage.

in public areas that are discriminable and esthetically pleasing for people with and without color blindness. By using a simulation method, this study examined how people with color blindness perceive eight hues of red, green, blue, yellow, orange, purple, cyan, and chartreuse on the natural color system color chart. It also investigated how the current wayfinding signage in Seoul is friendly to the color blind and presented examples of color-blind-friendly color combinations by applying color functions and color harmony theories. This study helps people with color blindness, by offering design professionals insight into more inclusive wayfinding signage that will be of use to people with and without color blindness.

Introduction

Color is an important means of conveying information. It plays a vital role in most information communication systems, including signage, books, maps, websites, and electronic devices. However, as most of these systems are designed for people who can distinguish colors, people with color blindness often find it difficult to read or understand information (Flück, 2006; Harwahyu, Manaf, Ananto, Wicaksana, & Sari, 2013).

Color blindness, or color vision deficiency, is the inability to perceive differences between certain colors. Globally, about 1 in 12 men (8%) and 1 in 200 (0.5%) women sees color differently from most of the population (National Eye Institute [NEI], 2015). In the United States, about 10.5 million men have trouble distinguishing red from green. This makes it difficult to read traffic lights, choose colored objects, read color-coded information, and perform some educational activities (NEI, 2015). Color blindness is not considered a disability under the Americans with Disabilities Act, unlike visual impairment (Larson, 2018). However, considering that 8% of men see color differently, they should be accommodated in the design of public spaces.

As people with color blindness are unable to distinguish some combinations of colors, it is critical to avoid these color combinations in wayfinding signage. Design professionals should ensure that color combinations applied to wayfinding signage are clearly visible and readable to all people—including those who are color blind. However, despite the growing emphasis on universal and inclusive design principles that require providing all people equal access to information, people with color blindness have often been overlooked in the design of wayfinding signage (Wong, 2011).

Given the significant number of people with color blindness and growing importance of universal and inclusive design, the purpose of this study is to propose color combinations for wayfinding signage that are discriminable and esthetically pleasing for people with and without color blindness, using a simulation method. The present study examines how people with color blindness view eight hues on the natural color system (NCS). It then investigates how wayfinding signage in the public space accommodates people with color blindness and offers examples of color combinations for wayfinding signage based on the color functions (Kim, Choi, Park, & Lee, 2001; Portillo & Dohr, 1993) and color harmony theories (e.g., Chevreul, 1839; Itten, 1970; Munsell, 1921; Ostwald, 1931) that accommodate people who are color blind. This study is a preliminary study for the follow-up research that will empirically examine the actual perceptions of proposed color combinations from people with and without color blindness. This study will therefore answer the following research questions:

> R1. How do tints, shades, and tones of eight hues on the NCS color chart appear to people whocare color blind?
>
> R2. How friendly is the current wayfinding signage to people who are color blind?
>
> R3. What are the recommended color sets in wayfinding signage for people who are color blind?

Literature Review On Color Theory

Color Basics

Color theory is a body of guidelines about the application of color including the definition of color, color mixing, color combinations, and the effects of color scheme (Decker, 2017). There are two methods of mixing colors: additive and subtractive. The additive color process produces colors by combining colors, primarily red, green, and blue; the subtractive color process is used for spectral colors in pigments with red, yellow, and blue as primaries. The secondary colors are made by mixing two primary colors, so the secondary colors of pigment colors are orange, green and purple. The pure primary or secondary colors (without the addition of white or black) are called “hue,” “value” is the lightness or darkness of a color, and “saturation” is the purity of a color (Mahnke & Mahnke, 1987). A “tint” is a lightened version of a hue which is created by adding white to the pure hue; a “shade” is a hue which is darkened by adding black. “Tone” is a hue mixed with gray or its complement.

Color Harmony

Color harmony refers to the principles of color combinations that are esthetically pleasing and harmonious. Color theory emerged in the eighteenth century, and since then many color theorists have formulated principles of color harmony (Table 1). Chevreul’s (1839) color harmony theory was based on the harmony of contrasting colors. He equated maximum contrast of the complementary colors with

maximum harmony (Westland, Laycock, Cheung, Henry, & Mahyar, 2007). Chevreul promoted red-green, orange-blue, and yellow-violet as complementary pairs. Almost a century later, Munsell’s (1921) theory indicated that two colors on opposite sides of the hue wheel are harmonious, that two or more colors that are adjacent to each other on the color wheel are analogous harmonious, and that neutral colors used together are harmonious. Ostwald’s (1931) theory demonstrated that colors harmonize when colors have the same amount of black and white or equal hue content (Weingerl & Javoršek, 2018). More recently, influenced by Chevreul, Itten (1970) theorized color contrasts for successful color harmonies: of hue, of light and dark, of saturation, of warm and cool, of complements and of simultaneous contrast.

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Color Order System

The color order system is a systematic arrangement of colors based on certain rules for the ordering and denotation of colors (Choudhury, Ali, Masud, Nath, & Rabban, 2014; Nemcsics & Caivano, 2015). The first modern color order system is Munsell’s (1921). Based on hue, value, and chroma, the Munsell system consists of 10 hues (i.e., five principal and five intermediate), a value scale ranging from 0 (for black) to 10 (for white), and chroma scale ranging from 0 (for neutral) up to 14 (for the strongest) to define color. Munsell’s color order system is the internationally used standard system.

The NCS is preferred in European countries (Ware, 2012). In NCS, all colors are represented in terms of their degree of closeness to four elementary colors: yellow (Y), red (R), blue (B), and green (G). In the NCS color space, the horizontal view is a color circle with the four colors. Each color is expressed as a combination of letters and numbers. For example, Y20R means colors in this hue have 20% resemblance to red and 80% resemblance to yellow. A vertical section through the color space is the NCS Color Triangle, which shows different nuances of the hue. The points of the triangle represent the whiteness (W), blackness (S), and chromaticness (C) of the color. The scales are divided into 100 steps for each, which can be perceived as percentages in the color circle.

The major difference between the NCS and Munsell's color system is that NCS is based entirely on the phenomenology of human perception rather than on color mixing, which makes it much easier to identify the color by name. Considering that the NCS is based on the way people view colors and is considered more convenient to communicate internationally (Natural Color System, n.d.), this study used the NCS color chart for color-blind simulation.

Table 1. Color harmony theory.

	Theory	Colors are harmonious when
Munsell (1921)	Complementary harmony	Complementary colors on the color wheel are used together
	Analogous harmony	Colors adjacent to each other on the color wheel are used together
	Neutral color harmony	Neutral colors are used together
Ostwald (1931)	Gray harmony	Colors with the same amount of black and white are used
	Equal hue harmony	Colors with equal hue content are used
Chevreul (1839)	Complementary contrast	Maximum contrast of complementary colors creates maximum harmony
Itten (1970)	Color contrast	• Value contrast: light and dark values of color are used together • Saturation contrast: pure, intense colors and dull, diluted colors are used together • Hue contrast: different hues are used together • Extension contrast: small bright spot contrasts with a large area of darkness • Warm/Cool contrast: warm and cool colors are used together • Complements: two complementary colors are used together • Simultaneous contrast: opposing colors are placed next to each other, creating the illusion of vibration

Color Function

Color serves many important functions in visual communication. Several researchers have already discussed color functions. Portillo and Dohr (1993) discussed five of those functions:

- Composition: color used as compositional element in interior design shapes space.
- Communication: people communicate with and interpret color meanings, which are vital in color planning.
- Preference: designers' and clients' subjective likes and dislikes in color affect the design process.
- Response: human behavioral responses are influenced by color. The relationship between color and the human response is tangible but has not been established empirically.
- Pragmatics: practical situations are reflected by color in design and planning. Limitations in expressing color ranges due to resource constraints, preconditions, maintenance, and sustainability factors must be factored into color planning.

The color function correlation model developed by Kim et al. (2001) identified eight major functions of color in visual communication, which are correlated with each other (Figure 1).

- Safety: Color can signify danger or alert people to physical hazards. Colors can be used for safety diagnosis, safety classification, and safety maintenance. High contrast in hue, brightness, or saturation can draw the attention.
- Identification: Color can distinguish or highlight objects or information. This function is particularly important for maps or signage.
- Esthetic: Color evokes feelings. Colors are used to elicit esthetically positive or negative visual impressions in a variety of ways. Color can create an esthetically pleasing visual world.

- Symbolic: Color conveys symbolism and meanings. Color can deliver symbolic meanings in art, design, and architecture. Different cultures have similarities in color symbolism.

- Physical, physiological-psychological, and therapeutic: The proper use of color improves people's emotions, health, and well-being.

- Camouflage: Vibrant colors enhance identification, but softer downplays it. Some insects and animals change their colors to protect themselves by blending into their environment.

Figure 1 Seoul colors: 10 signature colors, 50 district colors, and 250 current colors (
Source: Seoul Metropolitan Government).

Kim et al.'s (2001) color function model depicts the correlations among the eight functions of color. For example, identification and concealment should be considered equally as some colors in a composition should be subdued to highlight other colors to maximize the effects of color. Thus, several functions of color should be carefully considered in the color planning process. The five color functions of Portillo and Dohr (1993) show how people understand and perceive colors, and the role of colors in the design process. Kim et al.'s (2001) eight color functions described their effects on design by defining how people perceive colors applied to various designs and how they affect people physically and psychologically. As color composition and color meanings play important roles in wayfinding signage, Portillo and Dohr's (1993) color function criteria on communication and composition provide a broader concept for wayfinding signage. More specific functions to be considered in wayfinding signage are users' safety, the legibility of signage, and the harmony with the surrounding environment. Safety is important for regulatory signage, such as traffic signs, stop signs, emergency evacuation routes, or warning signs. Identification is important for informational or directional signs. Esthetics should be a factor in promotional, informational, or instructional signs. Therefore, to ensure users' safety, the legibility of signage, and the harmony with the surrounding environment, three functions—safety, identification, and esthetic among Kim's eight functions of color—appear to be central to the design of wayfinding signage. In developing a signage color design that accommodates people who are color blind, this study considers color's safety, identification, and esthetic functions.

Color Blindness

Types of Color Blindness

Color blindness is "an abnormal condition characterized by the inability to clearly distinguish different colors of the spectrum" Color blindness can be acquired or inherited. It can be caused by accidents or diseases of retina or optic nerve, but most color blindness is an inherited disorder resulting from deficiency or damage to one or more of the cone cells responsible for color discrimination in the human eye. The retina contains rods and cones. Rods are very sensitive to dim light and perceive the lightness of the object; cones are sensitive to bright light and color. There are three types of cone cells based on wavelength of light: L-cones (red), M-cones (green), and S-cones (blue). People with normal color vision have all three cone cells, but those who are color blind are missing one or more.

Red-green color blindness is the most common type, followed by blue-yellow color blindness. Red-green color blindness is a reduced sensitivity to red light caused by missing or defective Lcones (protanopia or protanomaly), or a reduced sensitivity to green light due to missing or defective M-cones (deuteranopia or deuteranomaly). People with these types of color blindness have difficulty distinguishing between reds, greens, and oranges and perceive that blues and yellows stand out. Blue-yellow color blindness (tritanopia or tritanomaly) is rarer than red-green color blindness. It is caused by absent or weakened S-cones. People with these types of color blindness have difficulty distinguishing some blues from greens and some yellows from violet. Total color blindness is the condition in which a person is unable to see any color at all; to them the world is in shades of black and white (monochromacy or achromatopsia). This is due to impaired or absent retinal cones. Total color blindness is extremely rare.

Red-green color blindness is the most common type, followed by blue-yellow color blindness.

Considering that deuteranopia (red-green color blindness) accounts for most color blindness (Olson & Brewer, 1997), this study is limited to red-green color blindness.

Impact of Color Blindness

Color-vision deficiency can have a significant impact on daily activities like cooking, driving, reading, and shopping (Color Blindness, n.d.; Skupien, 2013). People who are color blind are likely to wear mismatched socks or clothing, or they may be unable to distinguish their toothbrush from someone else's. In addition, they have difficulty distinguishing data marked with differently colored highlighters, determining whether or not their electronic devices are fully charged or reading maps (Ananto, Sari, & Harwahyu, 2011; Skupien, 2013).

People who are color blind also face restrictions when choosing a field of study or career (Color Blindness, n.d.; Harwahyu et al., 2013). Some of them are precluded from careers in the military, creative design, and fashion industry (Skupien, 2013). In some cases, a final physical test has identified job applicants as color blind, so they were not offered a job (Harwahyu et al., 2013).

Color Blind Simulation

The color blindness simulator emulates the vision of people with color blindness. Most studies on color blindness (e.g., Brettel, Vi not, & Mollon, 1997; Capilla, Dıez-Ajenjo, Luque, & Malo, 2004; Machado, Oliveira, & Fernandes, 2009) have used computerized simulations. Some studies have focused on color-blind users for online sites, navigation system, or reality systems (e.g., Ananto et al., 2011; Jefferson & Harvey, 2007; Keene, 2015; Pugliesi & Decanini, 2011; Wong, 2011). For example, Jefferson and Harvey (2007) demonstrated the use of algorithms as adaptive technologies through simple interfaces and evaluated the effectiveness of the methods through psychological experiments with simulated color blindness and standard color vision tests. Wong (2011) analyzed how people who are color blind perceive colors by using simulating programs such as Adobe Photoshop, Adobe Illustrator, and Vischeck. Ananto et al. (2011) designed the user interface of a color-blind aid system using image processing techniques and applying augmented reality.

Wayfinding Signage For Color Blindness

Wayfinding signages are information systems that orient people in the physical environment and help them navigate from place to place (Society for Experiential Graphic Design, 2014). There are four types of wayfinding signage: identification, directional, information, and regulatory (Dwight, 2008). When quick and easy navigation is the priority, color is an ideal element to make the signs stand out. Signage should complement its environment when there is a desire to minimize visual clutter (Calori & Vanden-Eynden, 2015).

People with color blindness claim that wayfinding signage has caused difficulty for them (Skupien, 2013). They struggle with GPS maps, colored bus routes, campus maps, stop sign, traffic lights, and streetlights (Skupien, 2013). According to Steward and Cole (1989), many people with color blindness could not distinguish the colors of traffic lights and often confused traffic signals with street lights. People who are color blind often miss road signs when there is not much contrast between the background of the signage and street lighting (Cole & Lian, 2006). As some colors appear the same to persons who are color blind, it can be hard for them to read maps, navigation systems, or signage (Skupien, 2013).

Considering that about 8% of males and about 0.5% of females have some form of color vision deficiency, it is important to respect their right to receive information (Skupien, 2013). As a part of universal design, color universal design is a new concept that originated in Japan in 2001 (Okabe & Ito, 2008). Color universal design eliminates color-related barriers for people with color vision deficiency and promotes color-blind-friendly design. Color universal design ensures that information is conveyed accurately by using colors suitable for all, with or without color blindness (EIZO Corporation, 2006).

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Color universal design emphasizes that any color presentation should be visually friendly as well as appealing by using easily identifiable color schemes, colors with a combination of different shapes, positions, and patterns, and identifying color names. In Japan, UK, and United States, there is an increase in device designs that take into accont diverse types of color vision based on color universal design principles (DIC Corporation, n.d.; EIZO Corporation, 2006).

According to Skupien (2013), although some people who are color blind might believe that they have a disability, they are reluctant to be categorized as such. To support their right to information, color universal design should be incorporated into visual communication systems. However, although some studies stress the accessibility of the people with color deficiency to maps or incar route guidance systems (e.g., Jenny & Kelso, 2007; Pugliesi & Decanini, 2011; Skupien, 2013), few studies have explored color-blind-friendliness of wayfinding signage. To fill this research gap, this study examines (1) how tints, shades, and tones of eight hues on the NCS color chart appear to people who are color blind, (2) how friendly the current wayfinding signage is to people who are color blind, and (3) what the recommended color sets are in wayfinding signage for people who are color blind.

Methodology

Study Site

The selected site for the study was Seoul, the capital of South Korea. In October 2007, the World Design Organization, dedicated to promoting the industrial design profession, selected Seoul as a World Design Capital of 2010. As the World Design Capital 2010, Seoul implemented design activities and international design events to advance urban design leadership and national growth through design (World Design Organization, 2019).

Seoul initiated its Design Seoul project to recreate the city streetscape based on its unique natural environment and traditional Korean culture. Seoul has developed three graphic symbols for the city branding: colors, a font, and a mascot. To designate Seoul colors, Seoul City first collected major colors that have been used in traditional Korean architecture, landscape, or cultural objects around Seoul. Among 250 current colors initially collected, Seoul City selected 50 colors as Seoul district colors, and designated 10 colors as official signature colors of Seoul among 50 district colors (Seoul Metropolitan Government, n.d.). Figure 1 presents 250 Seoul current colors, 50 Seoul district colors, and 10 signature colors. To support the mission of Design Seoul and to create a more inclusive and universally accessible urban environment, the present study selected Seoul as the study site.

Research Design

A computerized simulation method was used to examine how people with color blindness perceive colors and to develop color combination examples for color-blind-friendly wayfinding signage in the following way:

1. Sample collection: Samples of the current wayfinding signage of a public area in Seoul were collected.
2. Simulation of sample signage: Collected samples were simulated to examine color blindness vision using a simulation program.
3. Development of color combination: Color-blind-friendly color combination examples were developed based on color functions and color harmony theories.
4. Application of color combinations on wayfinding signage: Color-blind-friendly color combination examples were applied to wayfinding signage in Seoul.

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Sample Collection

Samples of existing wayfinding signage in Seoul were collected from the Gwanghwamun area, which is the center of the Seoul Metropolitan area. The Gwanghwamun is a busy historical and cultural center for citizens and tourists. Traffic and tall buildings fill the area, but so do pedestrian-friendly open urban spaces, cultural spaces, and historical parks.

Fifty signs on designated blocks in Gwanghwamun were selected and photographed; 10 were traffic signs, 14 were directional or identification signage, and 26 were signboards or advertising signs.

Simulation of Sample Signage

There are many web-based color-blind simulation tools available online such as Coblis, Colorblindly, or Colorblind web page filter. However, these tools could have problems with color accuracy due to color transfer in the process of uploading and simulating the images online. To control the color transfer from one medium to another, this study used the Vischeck plug-in, which provides more accurate and sophisticated simulation for color analysis. As Vischeck runs on Adobe Photoshop, it reduces the number of steps that might cause color transfer.

All samples of signage collected from Gwanghwamun were simulated for deuteranopia (redgreen color blindness), the most common type of color blindness.

Development Of Color Combination Examples

To develop more color-blind-friendly color combinations for wayfinding signage, color functions (Kim et al., 2001) and color harmony theories (i.e., Chevreul, 1839; Itten, 1970; Munsell, 1921; Ostwald, 1931) were considered. Among the eight functions of color in the color function model (Kim et al., 2001), safety, identification, and esthetic were chosen as the most important.

Safety

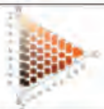
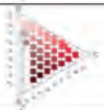
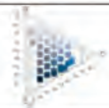
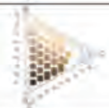
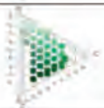
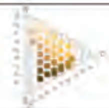
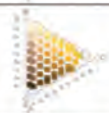
For both pedestrians and drivers, color combinations of wayfinding signage should maximize safety. Two or more colors with high contrast in hues or values are recommended to make the signage clearly visible and distinguishable (Lomperski, 1997). In this study, Munsell's (1921) complementary harmony theory, Chevreul's (1839) value contrast and complementary contrast theories, and Itten's (1970) color contrast theories were applied to develop color combination examples. For all complementary color pairs, a natural value range of hues was also considered to provide maximum contrast. For example, yellow and purple have greater distance of value, whereas red and green hue values are closer. These contrasts were carefully considered to support safety function of wayfinding signage for people with and without color blindness (Table 1).

Identification

The identification function of wayfinding signage should be supported by the color combination to convey information easily and clearly in a crowded urban environment. The signage also should stand out from its surroundings. Color combinations with high value contrast will meet this criterion (Lomperski, 1997). This study considered Munsell's (1921) neutral color harmony theory, Ostwald's (1931) gray harmony theory, Chevreul's (1839) value contrast theory, and Itten's (1970) color contrast theories to create high contrast between figure and ground for good legibility (Table 1).

Esthetic

Color combinations for wayfinding signage should benefit from color's ability to create an esthetically appealing city environment. In this study, Munsell's (1921) neutral color harmony and monochromatic armony theories, Ostwald's (1931) equal hue harmony and similar hue harmony theories, and Chevreul's (1839) harmony of similarity theory were considered to support esthetic function of the signage in Seoul (Table 1).

Color	Normal vision	Color-blind vision*	Analysis
1.Y			▪ Yellows appear yellow-red for the color blind ▪ Saturation levels are similar for both kinds of vision
2.Y50R			▪ Oranges look dull with less saturation for the color blind
3.R			▪ Reds look neutral with almost no red (very low saturation) for the color blind
4.R50B			▪ Purples look blue with no red at all for the color blind ▪ Similar saturation level for both kinds of vision
5.B			▪ Blues look grayish blue for the color-blind
6.B50G			▪ Blue-greens look like less saturated yellow-reds with no green at all for the color blind
7.G			▪ Greens look very similar to yellows (Y on NCS) for the color blind
8.G50Y			▪ Yellow-greens look yellow-red with no green at all for the color blind ▪ Similar saturation

[1] Deuteranopia color blindness.

Figure 2 Comparisons of eight NCS colors between color blindness and normal vision.

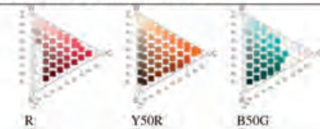
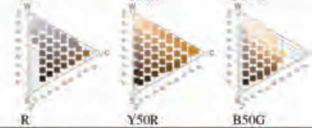
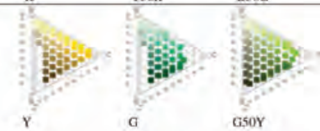
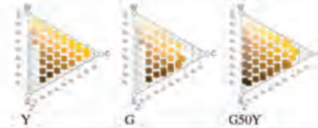
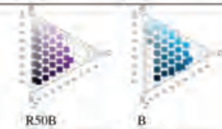
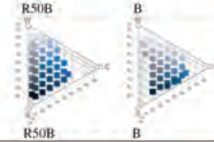
Non-recommended Color Combinations		
1. R-Y50R-B50G	Normal Vision	
	Color Blindness*	
2.Y-G-G50Y	Normal Vision	
	Color Blindness*	
3.R50B-B	Normal Vision	
	Color Blindness*	

Figure 3 Color combinations that should be avoided for color blindness.

Results

Simulation Results Of Eight Hues On Ncs Color Chart

Figure 2 presents the simulation results of comparison between normal and color blind vision for eight hues on the NCS color chart consisting of red (R), green (G), blue (B), yellow (Y), orange (Y50R), purple (R50B), cyan (B50G), and chartreuse (G50Y). To people who are color blind, yellows (Y) look yellow-red, oranges (Y50R) look dull, reds (R) look neutral, purples (R50B) look blue, blues (B) look dull gray, cyans (B50G) completely disappear and look yellow-red with no green, greens (G) completely disappear and look yellow, and chartreuses (G50Y) look yellow with no green.

The simulation results revealed that some color combinations should be avoided because they can cause confusion for people who are color blind. Figure 3 presents three examples of color combinations that should therefore be avoided

1. Reds (R)-oranges (Y50R)-cyans (B50G): People with color blindness perceive reds (R), oranges (Y50R), and cyans (B50G) very similar to oranges (Y50R), so they find it difficult to distinguish among reds (R), oranges (Y50R), and cyans (B50G) when they are used together.

2. Yellows (Y)-greens (G)-chartreuses (G50Y): People with color blindness perceive these three colors as almost the same, so they have trouble distinguishing yellows (Y), greens (G), and chartreuses (G50Y) when they are used together.

3. Purples (R50B)-blues (B): As both purples (R50B) and blues (B) are perceived as blue, people who are color blind can find it difficult to distinguish these two colors when they are used together.

The results of the simulation revealed that some color combinations are color-blind-friendly. Figure 4 presents three color combinations that are recommended .

1. Yellows (Y)-blues (B): Although yellows (Y) look redder and blues (B) look grayish to the color blind, both yellows (Y) and blues (B) look very close to their original hues. As yellows (Y) and blues (B) are complementary colors, the color blind can easily distinguish the two.

2. Yellows (Y)-purples (R50): Although purples (R50B) look blue to the color blind, yellows (Y) and purples (R50B) are good color combinations with high contrast.
3. Purples (R50B)-chartreuse (G50Y): Purples (R50B) look blue while chartreuses (G50Y) look orange (Y50R) in color-blind vision. They are good complementary high-contrast colors for the color blind.

Simulation Results Of Sample Signage

Among 50 signage samples, three traffic signs and four wayfinding signs were not color-blindfriendly because of poor legibility due to low value contrast between colors. Figure 5 presents two samples that were not color-blind-friendly. The images in Figure 5 show the red color coding disappearing because red appears neutral to the color blind.

Development and Application of Color Combination Examples

Two examples of color-blind-friendly color combinations were developed for safety, identification, and esthetic functions (Kim et al., 2001) by applying color theories (i.e., Chevreul, 1839; Itten, 1970; Munsell, 1921; Ostwald, 1931). Each color combination set was applied to wayfinding signage examples in Seoul

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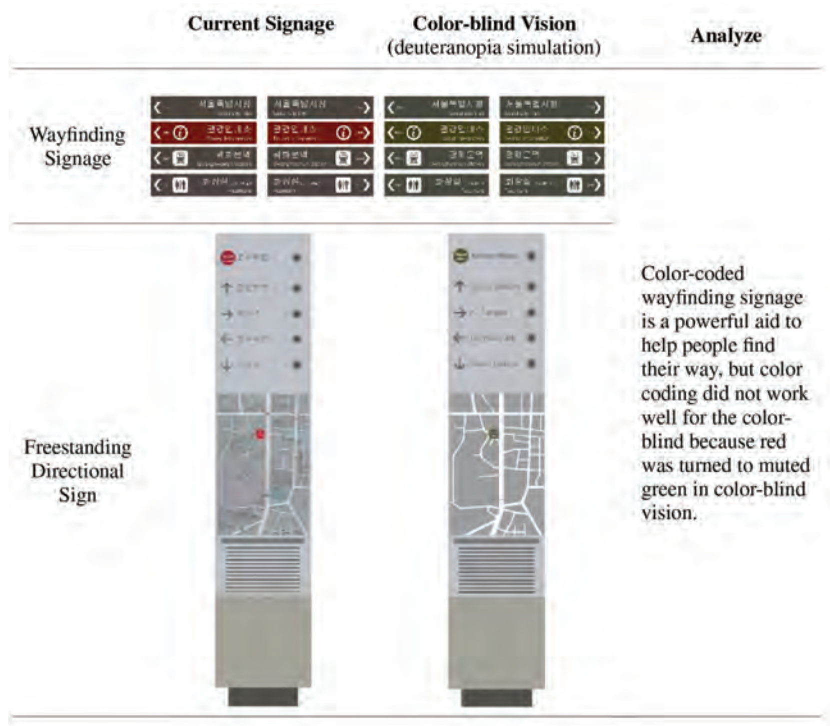
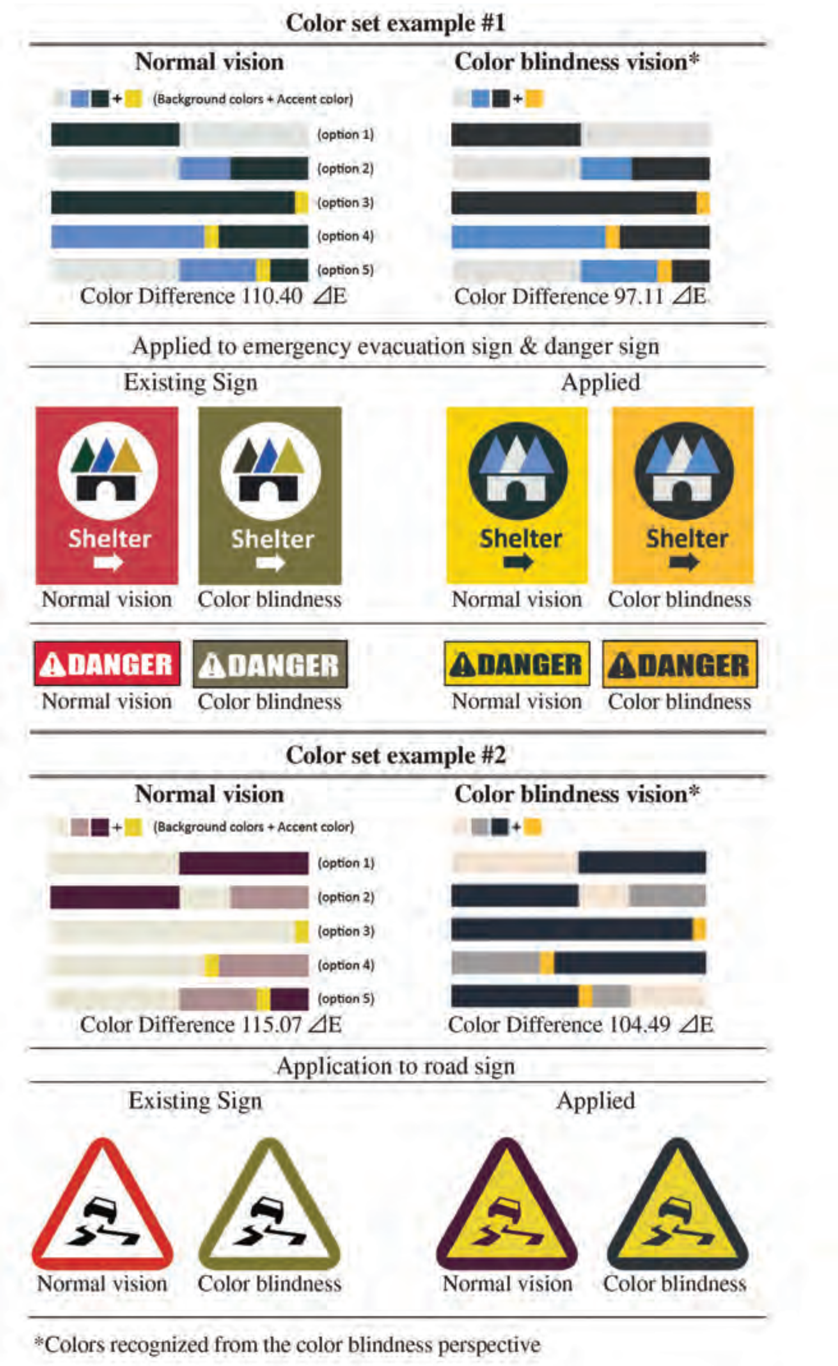
Color set 1 used the contrast of yellow with blue, which yields color difference value of 110.40 E for normal vision and 97.11 E for the color blind. Color set 2 used the complementary colors of purple and yellow, yielding the color difference value of 115.07 E for the normal vision and 104.49 E for the color blind. Considering that the color difference value for the road sign colors ranges from 40 E to 120 E (U.S. Department of Transportation, 2009), the values for both color sets allow the signs to stand out and draw attention of people who are and are not color blind.

Figure 6 also presents the examples of signs in which examples 1 and 2 are applied. The emergency evacuation route sign, danger sign and the slippery road sign have a bright red background or borders that can draw immediate attention from people who are not color blind. However, the red looks dull green and is hard to see by people who are not color blind. When the color set examples are used, these signs can be easier for people who are color blind to see.



Color Combinations Examples for Identification

Figure 7 presents two examples. Color sets for identification (e.g., directional signs, signposts, or signs designating facilities, space, or floors) should be both legible and complementary to their surroundings. Color set 1 used a contrast of orange against a gray gradient, yielding color difference values of 75.48 E for normal vision and 76.38 τE for the color-blind vision. Color set 2 used blue against a brown gradient, yielding the color difference values of 54.02 E for the normal vision and 36.39 E for the color-blind vision. The color difference values for both sets are in good range for the identification signs and both color sets are perceived by the color blind very similarly to the original colors.



Two sets of color combinations were applied to Seoul's subway entrance sign and freestanding directional sign. The subway entrance sign has a dark green background with yellow and white lettering which is easy for people who are not color blind to see, but people who are color blind see dark green as dark gray. Both dark green and dark gray are hard to read in poor light. When applying color set 1, light gray background with orange graphic symbol and dark gray text is perceived as similar gray background with muted orange graphic symbol and dark gray text to people with color blindness. By applying color set 1, the subway entrance sign can be more colorblind- friendly. Color set example 2 was applied to a freestanding directional sign. The existing sign of Seoul used red as a highlight against the gray background, but people with color blindness might have a difficult time reading it because they see red as a yellowish color with low value and low chroma. When color set 2 is applied, the sign is easier to see and read by people who are and are not color blind.

Color Combinations for Esthetics

Figure 8 presents two examples. For both sets of color combinations, the author used the official Seoul colors that Seoul city specified. To support the esthetic function of wayfinding signage (e.g., promotional, instructional, or informational signs, directories, or maps), the signage colors should be visually pleasing and blend in with the environment by avoiding any garish color palettes.

Color set example 1 used similar brown color palettes to induce harmony with nature and the surroundings by using the Seoul colors. The simulation results show the color set is perceived very similarly by people with color blindness. For color set 2, the background color and highlight color are all in the green color palette to blend into nature. People with color blindness perceive greens as yellows, resulting in higher contrast in values and chroma. The color set 2 was applied to wayfinding signage in Seoul. The wayfinding signage of Seoul along with the simulated color-blind vision is presented in Figure 8. The sign has a burgundy background with white text to highlight one destination; a gray background with white text was used for the others. Because burgundy is perceived as dark green, which is similar to dark gray, it may be hard for people with color blindness to distinguish the highlighted signage. By applying color set 2, the signs are legible to people with and without color blindness, and are also esthetically pleasing. The green color palette also helps the wayfinding signage to blend into the natural surroundings.

Discussions

The present study examined how people with color blindness perceive eight hues on the NCS color chart and which hues are and are not recommended for them. Then the existing signage in Seoul was analyzed to determine if it was color-blind-friendly, and presents examples of color-blindfriendly color combination sets that support the safety, identification, and esthetic functions of color based on color harmony theories (Chevreul, 1839; Itten, 1970; Munsell, 1921; Ostwald, 1931).

The results of color simulation of eight hues on NCS color chart revealed that reds (R) look neutral with almost no red and three hues of chartreuse (G50Y), green (G), and cyan (B50G) were perceived similarly as yellow or less saturated orange; purples (B50R) were perceived as blues (B). Therefore, it is not recommended to use the combinations of reds (R)-oranges (Y50R)-cyans (B50G), yellow (Y)-greens (G)-chartreuses (G50Y), and purples (R50B)-blues (B) for people who are color blind.

Previous studies have studied people who are color blind to create more color-blind-friendly systems for maps, website, in-car route guidance and navigation using computerized simulation programs (e.g., Ananto et al., 2011; Jefferson & Harvey, 2007; Jenny & Kelso, 2007; Keene, 2015; Pugliesi & Decanini, 2011). In this study, the simulation method was used to examine differences between color-blindness and normal vision, and to visualize how people who are color blind see colors. By simulating eight hues on the NCS color chart, this study drew comparisons between normal and colorblind visions for all tints, shades, and tones of each hue. Furthermore, the simulation method was effective tool to examine the combinations of hues that are and are not recommended.

The analysis of the signage in Seoul revealed that seven out of 50 signage samples were not color-blind-friendly. One of the main reasons was the use of red for highlighting, alerting, or drawing attention. However, as red almost lost its hue from the perspectives of people with red-green color blindness, the effects and representations of signage were missed.

According to Cole and Lian (2006), road and traffic signs are difficult for people who are color blind to see, due to the lack of contrast between the backgrounds of signs and the lighting. It takes longer for people who are color blind to ascertain the significance of color on signage because some colors appear the same (Skupien, 2013). As color universal design and previous studies have suggested (Jenny & Kelso, 2007; Okabe & Ito, 2008; Skupien, 2013), it is helpful to include supplemental forms of information such as color names, graphic symbols, or patterns to make maps, GPS systems, graphic presentation, or cautionary warnings intelligible to the color blind. However, it is also important for design professionals to avoid using problematic color combinations in signage to support safety and wayfinding ability of drivers and pedestrians alike.

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This study proposed color-blind-friendly color set examples that support the safety, identification, and esthetic functions of wayfinding signage. The major colors were chosen given that it is hard for people with red-green color blindness to distinguish red, orange, cyan, green, and chartreuses although they can differentiate blue. The color combinations were designed based on the color harmony theories (i.e., Chevreul, 1839; Itten, 1970; Munsell, 1921; Ostwald, 1931). This study provided some examples of applying color combinations to actual wayfinding signage in Seoul. These color combinations might not be readily applicable to regulatory signs which must comply with local codes. These applications might inconvenience people who are not color blind. When designing the color combination, it is important to balance the needs of the 8% of people with color blindness against those of the 92% of people without it. Both groups have the right to information (Jenny & Kelso, 2007). The application examples offer design professionals insight into more color-blind-friendly signage design. It is hoped that designers and policy makers will use the findings of this study to be more mindful of the needs of people with color blindness and reduce some of the barriers that they face.

Conclusion

Color is becoming an increasingly important means of conveying information. Consequently, people who are color blind are facing even more difficulties as many color applications are still designed only for people with normal vision in mind. Currently, 1 in 12 Caucasian males (8%) is color blind, which is a high proportion of the population. For example, in a space used by about 10,000 people (assuming a 50–50 split between men and women), approximately 400 users are color blind. However, this study found that problematic color combinations are currently used in public areas' wayfinding signage. Considering that users of public spaces always include people who are color blind, design professionals should pay more attention to avoiding problematic color combinations and instead use color-blind-friendly color schemes when designing public spaces and commercial spaces.

The results of this study can be used to raise designers' awareness about problematic color combinations for people with color blindness. Interior designers should pay more attention to people with color blindness in order to create barrier-free designs for public spaces. Careful thought must be given to color-blind-friendly color combinations not only for wayfinding signage, colored objects, and color-coded information, but also for color schemes of interior spaces to ensure that people who are color blind are not at a disadvantage. Especially careful consideration must be given to the red and green complementary color scheme, which is a common problem when used together; the use of blue and purple together is also frequently overlooked as a problematic combination.

This study provided essential guidelines for creating accessible color combinations by proposing examples of color combinations that are effectively discriminable and esthetically pleasing for people with and without color blindness based on color theories. Although these color-blindfriendly color combinations are just some examples developed based on Seoul colors, this study provided interior designers with some valuable insights into more inclusive color designs that will be of use to people with and without color blindness.Theoretically, this study contributes to the body of knowledge in universal and inclusive design literature by focusing on the population with color blindness. Despite the increasing importance of universal and inclusive design principles that require providing all people equal access to information, people with color blindness have often been overlooked. By filling this research gap, this study has offered some valuable resources for research in the universal design of color in the interior design discipline.

Although this study made theoretical and professional contributions, this study has the following limitations. It was conducted in Seoul and the main colors were chosen from Seoul's official colors. Although this study applied established color theories to create harmonious color combinations, the proposed color sets are only some of many possible color-blind-friendly examples. These proposed color sets should be cautiously applied to the actual signage by considering local codes, purpose of signage, surrounding environment, and user characteristics. Future research is recommended to develop more diverse sets of color-blind-friendly color combinations and propose examples of other types of signs for different locations. Another limitation of the study is that this study used only simulation analysis of collected photos and recommended color combinations without empirically measuring the actual effects of design by collecting data from human subjects. Therefore, the actual effects of recommended color combinations were not validated empirically by users. Future studies should verify the results of this study by examining how the recommended color combinations are actually perceived by people with and without color blindness.

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The effect of print size on reading speed in dyslexia

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This article details a study which predicted that across a wide range of print sizes dyslexic reading would follow the same curve shape as skilled reading, with constant reading rates across large print sizes and a sharp decline in reading rates below a critical print size. It also predicted that dyslexic readers would require larger critical print sizes to attain their maximum reading speeds, following the letter position coding deficit hypothesis. Reading speed was measured across twelve print sizes ranging from Snellen equivalents of 20/12 to 20/200 letter sizes for a group of dyslexic readers in Grades 2 to 4 (aged 7 to 10 years), and for non-dyslexic readers in Grades 1 to 3 (aged 6 to 8 years). The groups were equated for word reading ability. Results confirmed that reading rate-by-print size curves followed the same twolimbed shape for dyslexic and non-dyslexic readers. Dyslexic reading curves showed higher critical print sizes and shallower reading rate-by-print size slopes below the critical print size, consistent with the hypothesis of a letter-position coding deficit. Non-dyslexic reading curves also showed a decrease of critical print size with age. A developmental lag model of dyslexic reading does not account for the results, since the regression of critical print size on maximum reading rate differed between groups.

Developmental dyslexia, a learning disability specific to reading, affects an estimated 5% of children in school. Reading requires processing of both the visual information from the page and the linguistic information that the print represents. Over a century of research on causal factors in developmental dyslexia has emphasised either one or the other of these processes, beginning with theories of visual causation. Morgan (1896) coined the inability to read in children as ‘congenital word blindness’, while Orton (1928) described the phenomenon of ‘strephosymbolia’ (twisted symbols), where children could read mirror-image writing more easily. The current view of dyslexia holds that reading failure is caused by a linguistic deficit in coding phonemes (individual speech sounds) within words, and thereby in accessing and manipulating these phonemic codes as required on a wide range of tasks (phonological processing) (Snowling, 2000). This view holds that a phonological processing deficit impedes a child’s ability to develop phoneme awareness, to learn grapheme-phoneme correspondence rules, and to decode words (Liberman et al., 1974; Stanovich & Siegel, 1994). The theory accounts for many cases of developmental dyslexia, but there are individuals with dyslexia who do not demonstrate a severe phonological deficit (Wolf & Bowers, 1999; Lovett, Steinbach & Frijters, 2000). Also, remediation programmes aimed at training phonological skills are often but not entirely successful (Lyon & Moats, 1997; Torgesen, 2000). This suggests a need for alternative or additional accounts of causal factors in dyslexia.

Recent evidence shows that subtle impairments in visual processing characterise some individuals with dyslexia. Specifically, impaired processing is found for low spatial and high temporal frequency visual stimuli (Lovegrove et al., 1980; Martin & Lovegrove, 1987; Talcott et al., 1998; but see also Skottun, 2000; Walther-Muller, 1995). The most robust of these findings indicates a particular problem with visual motion processing (Cornelissen et al., 1994; Demb et al., 1998; Talcott, Hansen, Elikem & Stein, 2000; Everatt, Bradshaw & Hibbard, 1999). Low spatial frequency, high temporal frequency and motion information are carried primarily via one of two parallel retino-cortical pathways in the human visual system: the magnocellular pathway. Thus, a unifying theory of visual factors in dyslexia holds that there is a magnocellular channel deficit. Neuroanatomic (Galaburda & Livingstone, 1993; Livingstone, Rosen, Drislane & Galaburda, 1991) and fMRI (Eden, van Meter, Rumsey, Maisog & Zeffiro, 1996; Demb, Boynton & Heeger, 1997) evidence consistent with this hypothesis corroborates the perceptual findings. Yet it is still unclear whether these visual deficits represent a correlate or a cause of reading problems. A direct causal link between vision and dyslexia is suggested by findings and observations where reading under demanding visual conditions, such as with small print, leads to declines in reading performance by dyslexic individuals.

Cornelissen et al. (1991) found that reading errors decreased with larger print size for reading disabled children with poor binocular control, suggesting a causal link between a stressed visual system and reading impairment. Our previous study (O'Brien, Mansfield & Legge, 2000) also implicated a potential effect of print size, where dyslexic readers require larger print sizes than normal readers to achieve their maximum reading speed. The print size effect was observed between subjects where the group difference in reading speed was greatest with small print, but the number of participants with repeated measures data across print sizes was too small to warrant a firm conclusion. Skottun (2001) noted the importance of demonstrating a parametric dependence of dyslexic reading on a visual variable, and pointed to this potential print size effect in our data. Such an effect would support a link between vision and dyslexia because a purely phonological explanation would not predict an effect of print size.

It is possible that larger print size facilitates dyslexic reading by increasing the visibility of spatial frequencies critical for letter recognition (Solomon & Pelli, 1994) or reading (Legge, Pelli, Rubin & Schleske, 1985). In addition, it is possible that dyslexic readers require a wider spatial-frequency bandwidth for reading than the two cycles per letter measured by Legge et al. (1985). For example, with larger letters, more distinguishing letter features may be available within the two cycle/character critical bandwidth for reading. Dyslexic readers may require more or different sets of features to distinguish between letters within words either because they are less efficient at picking up this visual information than skilled readers, or because their memory store of letter templates to match to incoming information is less well established Other related factors that could be ameliorated with larger print include lateral masking ('crowding') effects, that may be greater in dyslexic readers (e.g. Geiger & Lettvin, 1987, but see also Klein et al., 1990), or differences in visual span, that is, the number of letters recognisable in a glance (Legge, Ahn, Klitz & Luebker, 1997; Legge, Mansfield & Chung, 2001).An alternative account of observed print size effects is that they could result from a general magnocellular deficit, which has been proposed to interfere with letter position coding (Cornelissen et al., 1998a, 1998b). The magnocellular channel provides the primary input to the dorsal occipito-cortical pathway, the so-called 'where' pathway that carries information about an object's position in space (Mishkin, Ungerlieder & Macko, 1983). For reading, fidelity of the magnocellular channel should help to localise correctly the serial position of letters within words, and a dysfunction could lead to improper letter localisation and therefore reading errors (Cornelissen & Hansen, 1998). In this case, it may not be the visibility of certain letter features, but instead their relative position within words that is affected by the size of the letters. It could be that deficient position signals have a bigger impact for very small letters whose relative position is harder to identify, and so may result in poorer reading performance with small print. A magnocellular dysfunction in dyslexic reading has also been related to deficits in visual attention (Iles,Walsh & Richardson, 2000; Pammer & Wheatley, 2001). This theory proposes specific problems with serially focusing attention, either through rapid attentional capture or with attentional disengagement (Valdois, Bosse & Tainturier, 2004). In this regard, Pammer, Lavis, Hansen and Cornelissen (2004) found evidence that problems with attentional focusing contribute to anomalies in relative position coding in dyslexia. Specifically, they found that accurate symbol string recognition was negatively affected by adjacent symbol reversals. Thus, while attentional disturbances could affect reading in their own right, visual attention deficits may manifest as letter position coding errors as well.To study in detail the trend that we found previously for group differences of print size effects on reading performance, we compared reading rates as a function of print size for groups of children with and without dyslexia. We measured reading rate across a range of twelve print sizes from 0.2 to 1.0 logMAR (corresponding to a range of 20/12 to 20/ 200 Snellen letter sizes, or 0.037 cm to 0.582 cm in x-height values) for each individual, and fit the reading rate by print size curves with a two-limb fit that has been found to characterise skilled reading (Mansfield, Legge & Bane, 1996). The two-limb fit captures how reading rates are typically constant across a range of large print sizes, then drop off rapidly below a critical print size (for example, see Figure 1).

If dyslexic readers have a magnocellular deficit that impacts letter position coding, we would expect to see a threshold effect of print size, where letter position coding is accurate and contributes to word recognition only above that threshold, and position coding breaks down for very tiny letters. Our method also allowed us to investigate the alternative possibility that dyslexic readers have a preferred print size that facilitates faster reading, rather than the normal broad range, possibly related to idiosyncrasies in their sensitivity to different spatial frequencies.

Method

Participants

Thirty-four children (22 dyslexic and 12 non-dyslexic) between 6.3 and 10.4 years of age participated in the study. The children were recruited from first to fourth grade classrooms at public schools in the vicinity of Boston, Massachusetts. Classroom teachers identified children who were either struggling readers or who were average readers in their class. Screening measures, including standardised reading and brief intelligence tests, were administered to all children. The children with dyslexia made up a sub-set of children taking part in a larger-scale intervention project (Morris, Wolf & Lovett, 1996) and they satisfied exclusionary criteria of being primary English speakers, and being free of any neurological or psychological disorders and visual or hearing impairments. They met either a low achievement or a discrepancy eligibility criterion of developmental dyslexia. Low achievement was defined as scoring one standard deviation below the norm on either the Woodcock Reading Mastery Test-Revised (WRMT-R). Basic Skills or Total Reading clusters, or on the average of the WRMT-R Word Identification, Word Attack and Passage Comprehension sub-tests and the Wide Range Achievement Test-3 (WRAT-3). Reading sub-test. A discrepancy was defined as a significant difference of at least one standard deviation between achievement on any of these three composite reading scores (WRMT-R Basic Skills, Total Reading or the average score described above) and ability (based on Full Scale IQ from either the Kaufman Brief Intelligence Test (KBIT), the Wechsler Intelligence Scale for Children (WISC-III) (Wechsler, 1991) or the Wechsler Abbreviated Scale of Intelligence (WASI) (Wechsler, 1999)).[1] Six children met a low achievement criterion, six met a discrepancy criterion and ten met both criteria. The nondyslexic children were administered the WASI and the same WRMT-R sub-tests as the children with dyslexia. Non-dyslexic children scored within the normal range on these reading measures. Table 1 provides each participant's grade, age, gender, IQ and reading scores.

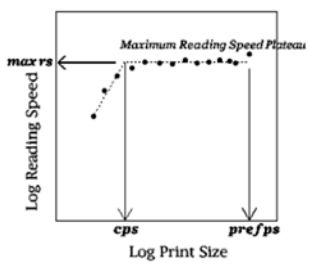

Figure 1. Diagram of reading speed-by-print size curve, showing a two-limb fit with parameters of maximum reading speed for large print sizes (max rs), and critical print size (cps), below which reading speed drops off dramatically.

Note: Also depicted is the preferred print size supporting the single fastest reading speed (pref ps) on the reading speed plateau.

Because the dyslexic children's reading ability was generally one or more years below their grade level, the non-dyslexic comparison group was chosen to match them with regard to reading level instead of grade level in school. Thus, the non-dyslexic group was younger (Mean age57.6, Mean grade level52.0) than the dyslexic group (Mean age58.9, Mean grade level52.8) (F(1,32)521.4, po0.01 for age, and F(1,32)56.5, p50.02 for grade). There was overlap in the ages and grade levels between the groups: dyslexic children were enrolled in Grades 2 to 4 and non-dyslexic children were enrolled in Grades 1 to 3. Comparison between both reading matched and grade matched controls could thereby be made for some of the children in the dyslexic group. Therefore, data for the groups are presented both by chronological grade and reading grade equivalent levels (based on word identification scores from the WRMT-R). While grade level differed between the groups, word reading grade equivalent level did not differ (F(1,32)50.4, p50.53, non-dyslexic Mean52.6 (SE50.87), dyslexic Mean52.8 (SE50.66)). Likewise, word identification raw scores did not differ between the groups (F(1,32)52.6, p50.12, non-dyslexic Mean544.7 (SE54.82), dyslexic Mean552.1 (SE52.24)).

Table 1. Age, grade, gender, IQ and reading measures for each participant (ND = non-dyslexic, D = dyslexic).

Subj.	Grade	Age (yrs)	Gender	FSIQ	VIQ	NVIQ	WRMT-R Basic Skill	Criterion (dyslexia)
ND1	1	6.9	M	107_a	108	104	95	none
ND2	1	6.6	M	107_a	95	118	107	none
ND3	1	6.8	F	88_a	98	83	98	none
ND4	2	7.7	F	91_a	100	86	102	none
ND5	2	7.9	F	102_a	101	102	94	none
ND6	2	7.8	F	82_a	80	86	100	none
ND7	2	7.6	F	96_a	93	99	105	none
ND8	3	8.3	M	98_a	109	86	105	none
ND9	3	8.2	F	94_a	99	90	99	none
ND10	3	8.7	F	91_a	94	90	96	none
ND11	3	8.5	M	93_a	108	81	106	none
ND12	1	6.3	F	97_a	95	99	111	none
D1	3	9.5	F	84_b	79	93	84	LA
D2	3	9.6	F	102_b	101	103	81	BOTH
D3	3	9.1	F	106_b	110	102	85	DISC
D4	2	8.8	F	95_b	92	99	82	BOTH
D5	3	9.3	M	103_b	107	98	87	DISC
D6	4	10.0	F	91_b	93	91	85	LA
D7	3	8.8	M	117_b	110	123	89	DISC
D8	4	10.0	F	97_b	99	95	86	BOTH
D9	4	10.0	F	120_b	112	125	85	DISC
D10	3	9.3	M	78_b	84	75	83	LA
D11	4	10.4	M	108_c	109	106	76	BOTH
D12	2	8.2	M	83_c	92	77	76	BOTH
D13	2	8.8	M	97_a	96	98	75	BOTH
D14	2	8.1	M	94_a	82	108	78	BOTH
D15	2	7.9	M	92_a	89	96	86	LA
D16	2	8.5	F	81_a	80	86	73	BOTH
D17	3	9.2	M	108_a	98	117	79	BOTH
D18	2	7.5	M	129_a	133	119	95	BOTH
D19	3	9.2	F	88_a	89	91	85	LA
D20	2	8.1	F	104_a	105	103	93	DISC
D21	2	8.1	M	89_a	98	84	84	LA
D22	2	8.0	M	98_a	102	93	88	DISC

Notes: IQ measures include full-scale (FSIQ), verbal (VIQ) and non-verbal (NVIQ) quotients based on the $WASI_a$, $WISC\text{-}III_b$, or $KBIT_c$. Basic Skill reading scores from the WRMT-R are compound standard scores from the Word Identification and Word Attack sub-tests. For participants with dyslexia, definitional criteria are also given (LA = low achievement criterion met, DISC = discrepancy criterion met, BOTH = both low achievement and discrepancy criteria were met).

Procedure

Children were asked to read aloud sentences presented as black print on white paper. Each sentence was printed on its own page in a flip book. The sentence was presented by flipping the page after the child indicated that he/she was ready. Sentences were constructed so that all had 60 characters, including spaces between words and at the end of each line, formatted into three lines of left-right justified text in Times-Roman font, similar to the MNREAD sentences of Mansfield, Legge and Bane (1996) (see Appendix). Sentences were presented at a viewing distance of 40 cm. This was maintained by verifying the viewing distance throughout the reading trials. A black card extending 40 cm from the flip book was placed on the table at which the children sat. The edge of the black card was aligned with the child's face, and they were told to keep their head in place 'in line with the card', just as they would keep their feet at the free-throw line when playing basketball. Any trials where the children leaned over the line were rerun with a different sentence. Thirteen levels of print size were presented in descending order ranging from 1.0 to 0.2 logMAR in 0.1 logMAR steps – i.e., from 0.582 to 0.037 cm x-heights corresponding to Snellen ratios from 20/200 to 20/12. There were two to three trials per print size.

Children read a practice sentence first, and were told that the letters would get smaller on each trial. They were instructed to read each sentence as quickly as they could, and to read as many words as they could see even if they thought they were guessing. Time to read each sentence was recorded with a stopwatch, commencing when the page was flipped and finishing when the child completed reading the last word. Reading errors were noted and used to calculate reading rates as correctly read words per minute. Sessions were also audio-taped to verify reading errors.

Results

Individual data

Each participant's raw data was plotted as reading rate (correct words read per minute) as a function of print size. These data were fit with a two-limb function, where a flat portion signified maximum reading speed above a critical print size, and where reading speed dropped off rapidly below the critical print size (CPS). The individual plots yielded maximum reading speeds and critical print sizes for each individual. Examples of typical individual reading speed by print size plots in Figure 2 show that the two-limb function provided a good fit to dyslexic as well as non-dyslexic readers, supporting the hypothesis that dyslexic print size-by-reading rate curves follow the typical two-limbed form.Estimates of goodness of fit for the two-limb function did not differ between groups (RMS error, p50.58), so the two-limb function provided an equally good fit for both groups. R-squares for all fits were significant (po0.05) with the exception of one nondyslexic child (ND7). Inspection of this child's data indicated that her print size-byreading speed plot did show the typical two-limb shape. One dyslexic participant's (D18) print size-by-reading speed plot did not show the typical two-limb shape; his reading speed was fairly flat across the range of print sizes. Examination of the two-limb fit parameters revealed that this child was an outlier with regard to critical print size. This participant's critical print size was more than three standard deviations above the group mean, and was estimated to be higher than the largest print size tested. This participant's data was therefore not included in the group analyses.

Maximum reading speed and critical print size were compared between dyslexic and non-dyslexic groups. To determine whether a specific print size facilitated dyslexic reading exclusively, the fastest single reading speed upon the maximum reading speed plateau was obtained for each participant. The print size at which this fastest rate occurred and the magnitude of its difference from the plateau was compared between groups.

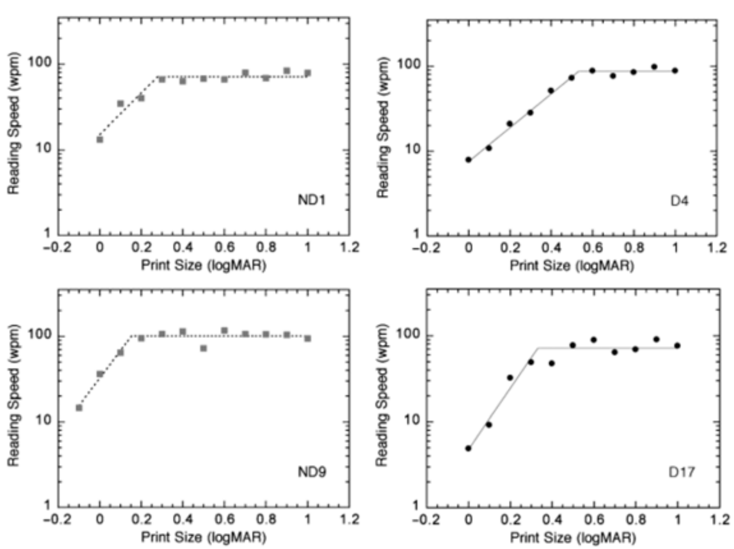

Figure 2. Examples of individual reading speed-by-print size curves shown with two-limb fits for two nondyslexic and two dyslexic readers.

Group comparisons

Our primary interest was to investigate visual factors in dyslexic reading independent of general reading ability level. To this end the groups were selected to have comparable reading level skills, and they therefore differed in age (the dyslexic group was older). In addition, we used word reading scores (WRMT-R word identification raw scores) as a covariate in the between group analyses of print size to statistically control for reading skill. We also report separate tests covarying age and IQ, since IQ has been found to account for sensory detection threshold differences in reading disability (Hulslander et al., 2004).

MANCOVAs were run on two sets of dependent variables: (1) those from the two-limb fits (maximum reading speed, critical print size), and (2) those from the point of the single fastest reading speed (the print size supporting the fastest rate, and its difference from the reading speed plateau). Each analysis used a between factor of group (dyslexic versus non-dyslexic) and covaried word identification scores.

For the first MANCOVA, the omnibus effect for group was significant (Wilk's Lambda F(1,29)511.2, po0.001). Subsequent univariate tests revealed significant group differences in maximum reading speed (adjusted means of 109.1 wpm (SE55.7) versus 81.9 wpm (SE54.2) for non-dyslexic and dyslexic groups, respectively)

(F(1,30)514.1, p50.001), and critical print size (adjusted means of 0.136 logMAR (SE50.04) versus 0.258 logMAR (SE50.03) for non-dyslexic and dyslexic groups respectively) (F(1,30)57.0, p50.013). This 0.122 log unit difference in critical print size corresponds to a factor of 1.32 difference in critical print sizes: that is, the dyslexic group required letters that were 32% larger than the controls to achieve their fastest reading speeds. Group means are presented by grade level (Table 2) and by reading grade equivalent (Table 3). It should be noted that critical print size differs from reading acuity, which is the smallest letter size for which one can read anything at all. The groups' reading acuities, as determined with a letter-by-letter method described in Mansfield, Legge and Bane (1996), also differed with word identification covaried (F(1,30)510.4, po0.01).

Individual maximum reading speed and critical print size data are plotted as histograms by group, grade and grade equivalent in Figure 3. Interestingly, the histograms show the trend across all the subjects of a decrease in critical print size with grade level. For older children, the threshold for attaining maximum reading rates was lower (i.e. occurred at smaller print sizes). The critical print size distributions for the dyslexic group were shifted to higher thresholds (i.e. larger print) when compared to the controls of either the same chronological grade or reading grade level. In some cases, this shift to a higher critical print size for dyslexic readers was related to a shallower slope on the descending limb of the curve fit. A between-group ANCOVA with the word identification covariate showed a significant group difference in slopes (F(1,30)54.2, p50.04, mean slopes of 5.2 (SE50.67) and 3.5 (SE50.50) for non-dyslexic and dyslexic groups, respectively). As Figure 4 shows, the group difference in slopes occurs primarily for early readers at word reading levels equivalent to Grades 1 and 2.

With age and full-scale IQ entered as covariates into the MANCOVA investigating the two-limb fit parameters, the same pattern of results emerges where the groups differ significantly in maximum reading speed and critical print size. When IQ alone is covaried in the MANCOVA, the group differences are no longer significant. This follows the findings of Hulslander et al. (2004), where full-scale IQ accounted for the relation between auditory and visual processing with word reading. Here, though, IQ was not significantly correlated with either maximum reading speed or critical print size over the whole group. Within the dyslexic group the two-limb fit parameters did not differ between groups with or without an IQ-achievement discrepancy or between groups of low achievers versus average achievers. Comparing the dyslexic children who met a low achievement criterion only with those who met a discrepancy criterion only and those who met both criteria showed that those meeting both criteria had the highest critical print sizes (Mean50.306), followed by the discrepancy only group (Mean50.202) and then the low-achievement only group (Mean50.179). Thus, the group with lower IQ, the low achievement group, also had the lowest critical print size of dyslexic sub-groups. So a lower IQ does not appear to account for higher critical print size.

The second MANCOVA revealed no significant group differences for either the print size supporting the fastest reading speed or the magnitude of the difference between the single fastest reading speed and the speed on the plateau. This was true when the magnitude of the reading speed difference was normalised according to one's maximum rate on their plateau (determined from the two-limb fits) or to the standard deviation of speeds about their plateau. In other words, the group effect was not significant when the magnitude difference was entered in words per minute, as a percentage of the plateau speed or in individual standard deviation units. In fact, the group means tend in the opposite direction than predicted: the non-dyslexic mean shows larger increases from the reading speed plateau (26.1 wpm (SE52.7)) than the dyslexic mean (22.6 wpm (SE52.0)). This same pattern of results was obtained when age and full-scale IQ were entered as covariates instead of word identification scores.

Lastly, we investigated the relationship between maximum reading speed and critical print size to see whether those dyslexic children with more severe reading difficulty (e.g. those with the slowest reading rates) also had larger critical print sizes. Across all participants, maximum reading speed and critical print size were significantly correlated (r5 0.436, p50.01), but only remained significant within the non-dyslexic group (r5 0.818, p50.001), and not the dyslexic group (r5 0.227, p50.32) (see Figure 5). Screening for apparent outliers revealed only two participants (one dyslexic and one non-dyslexic) with residuals above two standard deviations. Removing both of these individuals from the analysis did not change the pattern of the outcome: the non-dyslexic correlation was significant (r5 0.865, po0.001), and the dyslexic correlation was not (r5 0.424, p50.06), although there was a trend. The correlation for non-dyslexics was still significantly larger than that for the dyslexics (z0 difference52.01, po0.05).

Table 2. Means (standard deviations) of two-limb fit parameters by group and grade level. Maximum Reading Speed is reported in words per minute, and critical print size and reading acuity in logMAR units.

	Maximum reading speed		Critical print size		Reading acuity	
Grade	Dyslexic	Non-dyslexic	Dyslexic	Non-dyslexic	Dyslexic	Non-dyslexic
1		61.97 (40.5)		0.237 (0.13)		0.206 (0.17)
2	62.45 (28.8)	102.56 (23.9)	0.302 (0.15)	0.177 (0.15)	0.237 (0.18)	0.036 (0.09)
3	107.17 (27.3)	124.94 (26.9)	0.201 (0.16)	0.090 (0.07)	0.015 (0.9)	−0.035 (0.06)
4	112.87 (14.5)		0.176 (0.10)		0.006 (0.09)	

Table 3. Means (standard deviations) of two-limb fit parameters by group and reading grade equivalent (based on word identification scores).

READING	Maximum reading speed		Critical print size		Reading acuity	
GRADE EQUIV.	Dyslexic	Non-dyslexic	Dyslexic	Non-dyslexic	Dyslexic	Non-dyslexic
1	23.34	44.88 (26.6)	0.452	0.295 (0.06)	0.685	0.263 (0.15)
2	81.46 (29.3)	102.56 (23.9)	0.265 (0.16)	0.177 (0.15)	0.135 (0.18)	0.036 (0.09)
3	118.16 (28.6)	112.43 (8.5)	0.168 (0.07)	0.098 (0.06)	−0.023 (0.04)	0.004 (0.03)
4	117.25 (7.5)	163.31	0.100 (0.08)	0.028	−0.053 (0.04)	−0.120

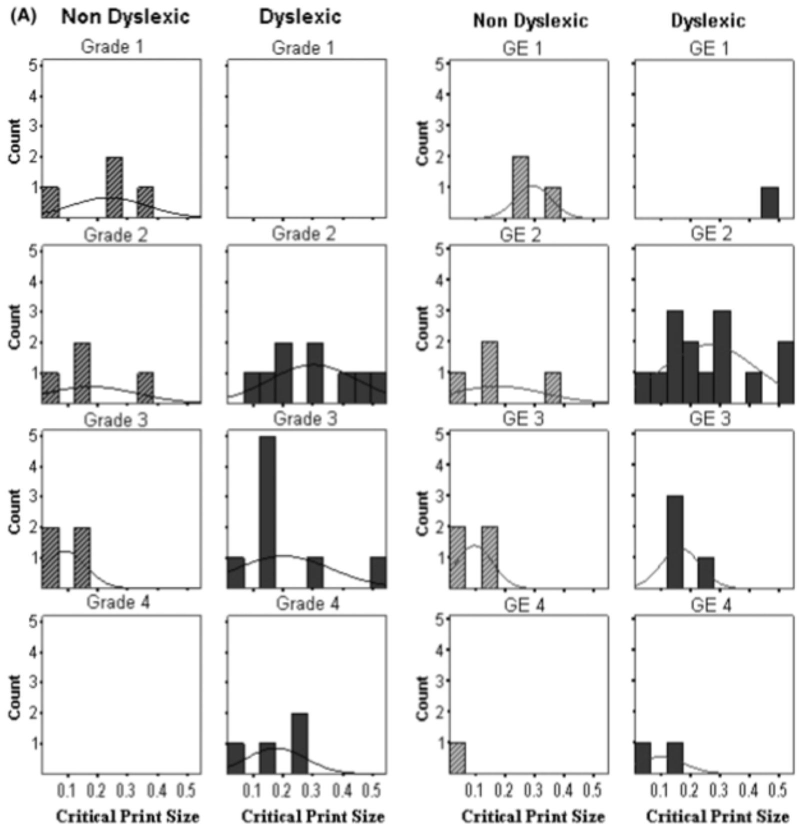

Figure 3a. Histograms of individual data from the two-limb fits. Notes: Plots of (A) critical print size (logMAR) and (B) maximum reading speed (wpm) are shown separately for group by grade level (left columns) and for group by reading grade equivalent (GE) (based on word identification scores) (right columns). Grades corresponded to the following ages: Grade 1 (age 6), Grade 2 (ages 7 and 8), Grade 3 (ages 8 and 9), Grade 4 (age 10).

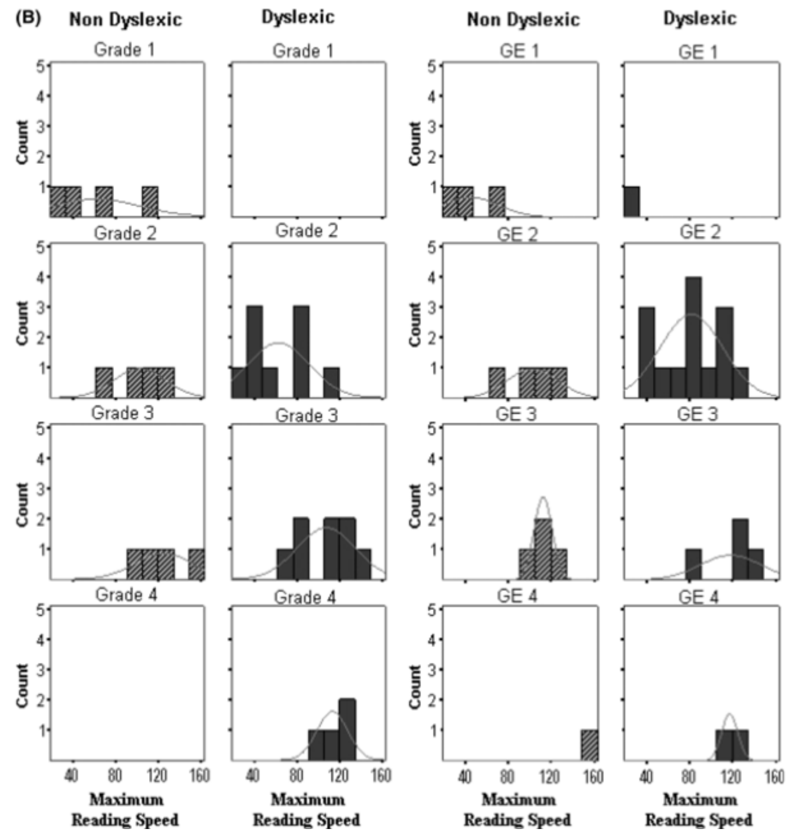

Figure 3b. Histograms of individual data from the two-limb fits.

Discussion

Dyslexic and non-dyslexic children demonstrated similar profile shapes of reading rate across print size, profiles that follow the typical two-limb shape found previously for adults (Mansfield, Legge & Bane, 1996). We found a similar consistency of curve profiles between dyslexic and non-dyslexic readers when we measured reading rates by luminance contrast of text and background (O'Brien, Mansfield & Legge, 2000). Thus, print size and print contrast are visual variables for which dyslexic reading speed exhibits the same qualitative dependence – a two-limb shape that typifies skilled reading.

Although the dyslexic profiles had the normal shape, two characteristics of the twolimb fits did differ for the dyslexic readers. As expected, their maximum reading speed along the plateau was slower than that of the non-dyslexic readers even though they were older and with control for word identification skill. Also, their critical print sizes were larger than those of the controls, indicating that they needed larger print to support maximum reading rates. The group difference in critical print size was partially due to a difference in slopes of the descending portion of the two-limb fits. Dyslexic readers' shallower slopes were moderately correlated with larger critical print sizes (r5 0.58).These results confirm the hypothesis that dyslexic print size-by-reading rate curves have the typical two-limbed form but larger critical print sizes, and refute the alternative hypothesis of a monotonic increase of dyslexic reading rates with increasing print size. What could theoretically account for these results? Reading words with very small letters may prove difficult either because the letters are hard to identify or because it is hard to determine where they appear in the word. Models of reading hold that both letter identification and letter position coding play important roles in word identification (e.g. Adams, 1979; Estes & Brunn, 1987). Thus, slow, inaccurate word identification with small letters could be due to either compromised letter identification or letter position coding. Letter recognition and reading normally require a critical spatial frequency bandwidth. The idea that dyslexic readers need larger print to compensate for a higher or broader spatial frequency bandwidth for reading does not account for the findings, since one would expect reading performance to keep improving with increasing print size if this were the case. Likewise, the idea that dyslexic readers may have a particular print size where reading performance peaks, due to differential sensitivity to specific spatial frequencies, was also not borne out. There were no points above critical print size where reading was more efficient for the dyslexic readers.

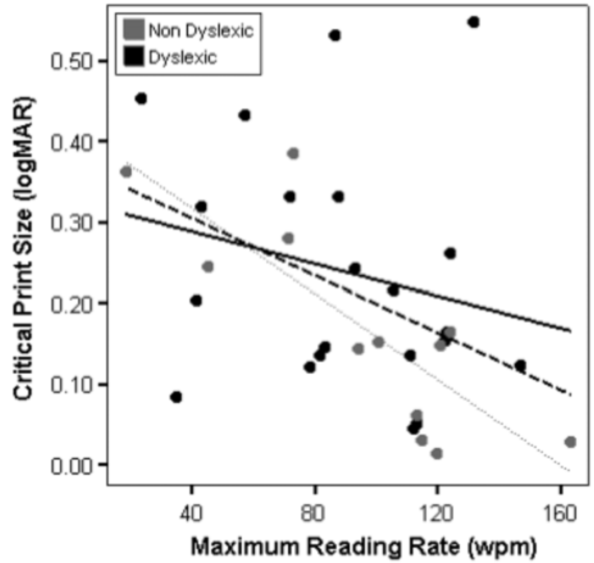

Figure 5. Regressions of critical print size on maximum reading speed for all subjects (dashed line), and for dyslexic (solid line) and non-dyslexic (dotted line) groups.

Letter recognition alone is not sufficient for word identification and reading; rather inter-letter effects also need to be taken into account. Knowing the position of a letter relative to the other letters in a word is necessary for correct word identification; for example, distinguishing the orthographic input of 'trap' versus 'tarp' or 'part' requires correctly locating the spatial arrangement of the letters in the word. The magnocellular channel may carry a code for the relative position of each letter in the word; for instance, [t-1], [r-2], [a-3], [p-4]. This channel may contain more noise in dyslexic readers, so the numbers for 'r' and 'a' in our example may contain some uncertainty (e.g. for position 2 in the word there is a 60% chance it is the 'r' that I saw and a 40% chance it is the 'a'). Cornelissen and Hansen (1998) describe how relative letter position information is contained within an intermediate spatial scale of the visual stimulus (i.e. the print), while information about whole words and letter features is carried by coarse and fine scales, respectively. For very tiny print, the fine spatial scale must become too small to resolve critical features, so letters cannot be identified and the acuity limit is reached. Just above this point, letters can be resolved but may not be ordered correctly because of noise (spatial uncertainty) in the codes for spatial position. Theoretically, greater relative position noise in dyslexia may contribute to slow reading in general, and could cause dyslexic reading to be more susceptible to deterioration with small print: meaning dyslexic readers should have slower maximum reading speeds and higher critical print sizes. The present results are consistent with a dyslexic magnocellular-letter position coding deficit.

Other related accounts of inter-letter effects on word reading include crowding, visual attention and visual span. Crowding, or lateral masking, refers to the hindering of letter recognition when a letter is flanked by other letters. The difference in curve shape for dyslexic readers could be because of greater susceptibility to crowding effects, especially if their recognition of isolated letters is already inaccurate or slow. Indeed, previous studies have found greater crowding effects for dyslexic readers (Atkinson, 1999; Geiger & Lettvin, 1987). Klein and D'Entremont (1999) found greater interference between far flankers than near ones for dyslexics, which they attributed to differences in visual attentional filtering. While it is unclear how visual attention differences per se could account for the present print size effect in dyslexia, two theories are relevant. First, visual attention could be the cognitive module that mediates between magnocellular function at the physiological level and position coding for letters in words (e.g. see Pammer et al., 2004). Second, visual attention may impact the visible window of text while reading. Ans, Carbonnel and Valdois (1998) developed a connectionist model of reading that uses a visual attention window, wherein maximal parallel processing occurs, and which is modified in size based on reading mode. The attentional window in this model can be narrowed to focus on smaller portions of orthographic input if needed. This notion of a reader's attentional control over the number of letters processed at a glance may be related to the concept of visual span, the number of letters one can recognise at a glance (O'Regan, Levy-Schoen & Jacobs, 1983). Legge et al. (1997, 2001, 2002) systematically studied visual span size with regard to print size, and found that visual span decreases with very small and very large letters, and that reading speed covaries with the size of the visual span. Normally, smaller visual spans (in characters) are found for print sizes smaller than the critical print size. The present finding of a difference in curve shape for dyslexic readers could be because of a difference in their visual span. That is, we would predict that dyslexic visual spans may continue to increase with increasing print size to a somewhat larger print size (corresponding to the increased critical print size), and the size of the visual span may be smaller than normal even above the critical print size. These potential differences in visual span may be related to inter-letter effects such as crowding or attentional resolution.

While each of these theoretical accounts – position coding, crowding, visual attention or visual span – could contribute to the present print size effect for dyslexic readers, the theories are not mutually exclusive; rather they are likely to be related.

For example, imprecise letter position coding could result from attentional disturbances or increased crowding effects in dyslexia. Huckauf and Heller (2002) demonstrated that crowding effects could be explained by position uncertainty rather than interactions of adjacent letter forms. Teasing apart letter position coding and crowding effects on dyslexic reading would require further study by independently manipulating print size and letter spacing. Furthermore, both position uncertainty and crowding effects may contribute to the extent of one's visual span for reading.

It is also possible that a magnocellular deficit could be manifest as slower reading with small text in the present study because of oculomotor factors. The magnocellular visual pathway has neural connections with areas involved in eye-movement programming (e.g. the superior colliculus). Because reading, as in the present study, requires a succession of saccadic eye movements, a magnocellular deficit could have an impact at this level instead of or in addition to a letter-position coding deficit. Producing eye movements within text with small print may be especially difficult, as Kowler and Anton (1987) found that very small saccades may take longer to produce. The present study cannot speak to this possibility. An investigation comparing print size effects of text presentations with and without required eye movements (e.g. normal page-formatted text versus rapid serial visual presentation (RSVP)) would be required to differentiate these effects.

Because the dyslexic group was older in the present sample, one could speculate that the characteristic differences of the two-limb curves result from a general developmental lag, where dyslexic readers behave like younger non-dyslexic readers with regard to having slower maximum reading rates and higher critical print sizes. That the groups still differed when reading level was controlled runs counter to this claim. We chose to 'equate' the reading groups on isolated word identification, although other factors may be developmentally relevant as well. Furthermore, a developmental lag model would be strongly supported if the dyslexic and non-dyslexic data fell on the same critical-print size-by-maximum-reading-rate regression line, but this was not the case either. The dyslexic group showed a lack of a correlation between these variables, whereas the nondyslexic group showed a fairly strong correlation. This implies some de-coupling of the maturational influences that normally tie the two variables together. Here, the slowest dyslexic readers did not necessarily require larger print size thresholds to attain theirmaximum reading speed, whereas slower non-dyslexic readers did.

One might also expect that if general intelligence accounts for sensory processing differences in dyslexia, then those with lower IQ would show the greatest impact on sensory processing (i.e. they would have higher critical print sizes). However, this did not appear to be the case with the group we tested. It was the children with higher IQ and an IQ-achievement discrepancy who actually had the highest critical print sizes.

Lastly, it is of interest in understanding the development of normal reading behaviour that the non-dyslexic group showed effects of age on critical print size as well as maximum reading speed. Increasing reading rates with age conforms to previous findings of a linear increase between 10 and 20 wpm per grade (Carver, 1990; Tressoldi, Stella & Faggella, 2001). We are not aware of any previous research findigs showing the developmental change in critical print size. Our data showed that critical print sizedecreases with age, suggesting younger children need larger print to optimise reading performance. It is noteworthy that reading materials for early, very young readers generally have larger print than texts for older children. We also found a negative
correlation between reading speed and critical print size, showing that in general slower non-dyslexic readers required larger print size to support their maximum reading speed. The finding that dyslexic readers require larger print size to attain their maximum reading speed has implications for the type of print that educators select for these children (e.g. see Hughes & Wilkins (2002) regarding general recommendations for print size and spacing in children's books for group reading). print sizes.

Note

1. All children with dyslexia were administered the KBIT at screening and either the WISC-III or the WASIafter screening as part of their participation in the intervention project. Although the KBIT shows high correlation with the two Wechsler measures of intelligence (0.78 (Prewett, 1995), and 0.89 (Hayes, Reas & Shaw, 2002), respectively), the Wechsler scales show higher validity than the KBIT in clinical samples (Chin et al., 2001; Thompson, Brown, Schmidt & Boer, 1997). Therefore these measures are reported for the dyslexic group and were used to calculate discrepancy scores. KBIT scores are reported for two children whose WISC-III or WASI scores were not obtained.

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BIBLIOGRAPHY

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INRODUCTION

The Bitbrain team, (September 19, 2018).What is attention, types and disturbances. Retrieved April 15,2021, from https://www.bitbrain.com/blog/what-is-attention-types

Wolfe, J. M. & Horowitz, T. S. Five factors that guide attention in visual search. Nat. Hum. Behav. 1, 0058 (2017).

Ou, L.C., Luo, M.R., Sun, P.L., Hu, N.C. and Chen, H.S. (2012), Age effects on colour emotion, preference, and harmony. Color Res. Appl., 37: 92-105. https://doi.org/10.1002/col.20672

Lee, H., Lee, E. and Choi, G.-s. (2020), Wayfinding Signage for People with Color Blindness. Journal of Interior Design, 45: 35-54. https://doi.org/10.1111/joid.12169

Castelhano MS, Henderson JM. The influence of color on the perception of scene gist. J Exp Psychol Hum Percept Perform. 2008 Jun;34(3):660-75. https://doi.org/10.1037/0096-1523.34.3.660 PMID: 18505330.

O'Brien, B.A., Mansfield, J.S. and Legge, G.E. (2005), The effect of print size on reading speed in dyslexia. Journal of Research in Reading, 28: 332-349 https://doi.org/10.1111/j.1467-9817.2005.00273.x

Camgöz, N., Yener, C. and Güvenç, D. (2002), Effects of hue, saturation, and brightness on preference. Color Res. Appl., 27: 199-207. https://doi.org/10.1002/col.10051

Manav, Banu. (2013). A Research on Light-Color Perception: Can Visual Images Be Used Instead of 1/1 Model Study for Space Perception?. Psychology. 04. 711-716. 10.4236/psych.2013.49101.

Phillips, W.L. (2019). Cross-Cultural Differences in Visual Perception of Color, Illusions, Depth, and Pictures. In Cross-Cultural Psychology, K.D. Keith (Ed.). https://doi.org/10.1002/9781119519348.ch13

Zadra, J.R. and Clore, G.L. (2011), Emotion and perception: the role of affective information. WIREs Cogn Sci, 2: 676-685. https://doi.org/10.1002/wcs.147

Carbon, C. C. 2016b Integration of user-centric psychological and neuroscience perspectives in experimental design research. In Experimental Design Research (ed. P. Cash, T. Stanković & M. Štorga). Springer.

Carbon, C. C. 2014 Understanding human perception by human-made illusions. Frontiers in Human Neuroscience 8 (566), 1–6. doi:10.3389/fnhum.2014.00566.

IT ALL STARTS WITH LIGHT

EFFECTS OF HUE, SATURATION, AND BRIGHTNESS ON PREFERENCE

1. Birren F. Color and human response. New York: Van Nostrand Reinhold; 1978.

2. Chevreul ME. The principles of harmony and contrast of colors and their application to the arts. Rev. ed. West Chester (PA): Schiffer; 1987.

3. Munsell AH. A grammar of color. Birren F, editor. New York: Van Nostrand Reinhold; 1969.

4. Itten J. The elements of color. Van Hagen E, translator; Birren F, editor. New York: Van Nostrand Reinhold; 1970.

5. Guilford JP. The affective value of color as a function of hue, tint and chroma. J Exp Psychol 1934;17:342–370.

6. Smets G. A tool for measuring relative effects of hue, brightness and saturation in color pleasantness. Perceptual and Motor Skills 1982; 1159–1164.

7. Eysenck HJ. A critical and experimental study of color preferences. Am J Psychol 1941;54:385–391.

8. Helson H, Lansford T. The role of spectral energy of source and background color in the pleasantness of object colors. Appl Opt 1970;9:1513–1562.

9. Camgo z N. Effects of hue, saturation, and brightness on attention and preference [dissertation]. Ankara (Turkey): Bilkent University; 2000.

10. Ishihara S. Ishihara's tests for colour-blindness. Concise ed. Tokyo: Kanehara Shuppan; 1975.

11. Adobe Photoshop [computer program]. Version 4.0. San Jose (CA): Adobe Systems; 1996.

12. SAS [computer program]. Version 6.12. SAS/STAT User's guide. Release 6.03 ed. Cary (NC): SAS Institute; 1999.

13. Guilford JP, Smith PC. A system of color-preferences. Am J Psychol 1959;72:487–502.

14. Sivik L. Studies of color meaning. Man-Environment Systems 1975; 5:155–160.

15. Washburn MF, Grose SL. Voluntary control of likes and dislikes: the effects of an attempt voluntarily to change the affective value of colors. Am J Psychol 1921;32:284–289.

16. Reddy TV, Bennett CA. Cultural differences in color preferences. Proceedings of the Human Factors Society, 29th annual meeting; 1985. p 590–593.

17. Wijk H, Berg S, Sivik L, Steen B. Color discrimination, color naming and color preferences in 80-year olds. Aging—Clinical and Experimental Research 1999;11(3):176–185.

18. Granger GW. An experimental study of color preferences. J Gen Psychol 1955;52:3–20.

19. Saito M. Blue and 7 phenomena among Japanese students. Perceptual and Motor Skills 1999;89(2):532–536.

THE INFLUENCE OF COLOUR ON VISUAL SEARCH TIMES IN CLUTTERED ENVIRONMENTS

Bemmaor, A. and Mouchoux, D. (1991) Measuring the short term effect of in-store promotion and retail advertising brand ales: a factorial experiment. Journal of Marketing Research 28, 202–14.

Berns, G.S., Cohen, J.D. and Mintun, M.A. (1997) Brain regions responsive to novelty in the absence of awareness. Science 276, 1272–5.

Bloch, P. (1995) Seeking the ideal form: product design and consumer response. Journal of Marketing 59, 16–29.

Boynton, R.M. (1988) Color vision. Annual Review of Psychology 39, 60–100. Carter, R.C. (1982) Visual search with color. Journal of Experimental Psychology 8, 127–36.

Danger, E.P. (1987) The Colour Handbook: How to Use Colour in Commerce and Industry. Aldershot: Gower Technical Press.

Davidoff, J. (1991) Cognition Through Color. Cambridge, MA: The MIT Press.

Davies, I.R.L. and Corbett, G.G. (1995) A practical field method for identifying probable basic colour terms. Languages of the World 9, 25–36.

Duncan, J. and Humphreys, G.W. (1989) A resemblance theory of visual search. Psychological Review 96, 433–58.

D'Zmura, M. (1991) Color in visual search. Vision Research 31, 951–66.

Eriksen, C.W. and Spencer, T. (1969) Rate of information processing in visual perception: some results and methodological considerations. Journal of Experimental Psychology Monograph 79, 1–16.

Frontiers (1996) Planning for consumer change in Europe 1996/1997. Journal of Brand Management 4, 100–07. Gorn, G.J., Chattopadhyay, A., Yi, T. and Dahl, D.W. (1997) Effects of color as an executional cue in advertising: they are in the shade. Management Science 43, 1387–400.

Inman, J.J. and Winer, S. (1998) Where the Rubber Meets the Road: A Model of In-store Consumer Decision Making. Cambridge, MA: Marketing Science Institute. Inman, J.J., McAlister, L. and Hoyer, W.D. (1990) Promotion signal: proxy for a price cut? Journal of Consumer Research 17, 74–81.

Kahn, B.E. and McAlister, L. (1997) Grocery Revolution: The New Focus on the Consumer. Reading, MA: Addison-Wesley. Kirsch, I. and Lynn, S.J. (1999) Automaticity in clinical psychology. American Psychologist 54, 504–15.

Lewin, K. (1951) Field Theory in Social Science. New York, NY: Harper. Megaw, E.D. and Richardson, J. (1979) Target uncertainty and visual scanning strategies. Human Factors 21, 303–16.

Park, C.W., Iyer, E.S. and Smith, D.C. (1989) The effects of situational factors on in-store grocery shopping behavior: the role of store environment and time available for shopping. Journal of Consumer Research 15, 422–33.

Taft, C. and Sivik, L. (1991) Stability and variability of colour meaning associations: across national comparison. G teborg Psychological Reports 22.

Thompson, E., Palacios, A. and Varela, F.J. (1992) Ways of coloring: comparative color vision as a case study for cognitive science. Behavioral and Brain Science 5, 1–74.

VISUAL ATTENTION

FIVE FACTORS THAT GUIDE ATTENTION IN VISUAL SEARCH

1. Hyman, I. E., Boss, S. M., Wise, B. M., McKenzie, K. E. & Caggiano, J. M. Did you see the unicycling clown? Inattentional blindness while walking and talking on a cell phone. Appl. Cognitive Psych. 24, 597–607 (2010).

2. Keshvari, S. & Rosenholtz, R. Pooling of continuous features provides a unifying account of crowding. J. Vis. 16, 39 (2016).

3. Rosenholtz, R., Huang, J. & Ehinger, K. A. Rethinking the role of top-down attention in vision: effects attributable to a lossy representation in peripheral vision. Front. Psychol. http://dx.doi.org/10.3389/fpsyg.2012.00013 (2012).

4. Wolfe, J. M. What do 1,000,000 trials tell us about visual search? Psychol. Sci. 9, 33–39 (1998).

5. Moran, R., Zehetleitner, M., Liesefeld, H., Müller, H. & Usher, M. Serial vs. parallel models of attention in visual search: accounting for benchmark RT-distributions. Psychon. B. Rev. 23, 1300–1315 (2015).

6. Townsend, J. T. & Wenger, M. J. The serial-parallel dilemma: a case study in a linkage of theory and method. Psychon. B. Rev. 11, 391–418 (2004).

7. Egeth, H. E., Virzi, R. A. & Garbart, H. Searching for conjunctively defined targets. J. Exp. Psychol. Human 10, 32–39 (1984).

8. Kristjansson, A. Reconsidering visual search. i-Perception http://dx.doi.org/10.1177/2041669515614670 (2015).

9. Wolfe, J. M. Visual search revived: the slopes are not that slippery: a comment on Kristjansson (2015). i-Perception http://dx.doi.org/10.1177/2041669516643244 (2016).

10. Neider, M. B. & Zelinsky, G. J. Exploring set size effects in scenes: identifying the objects of search. Vis. Cogn. 16, 1–10 (2008).

11. Wolfe, J. M., Alvarez, G. A., Rosenholtz, R., Kuzmova, Y. I. & Sherman, A. M. Visual search for arbitrary objects in real scenes. Atten. Percept. Psychophys. 73, 1650–1671 (2011).

12. Kovacs, I. & Julesz, B. A closed curve is much more than an incomplete one: effect of closure in figure-ground segmentation. Proc. Natl Acad. Sci. USA 90, 7495–7497 (1993).

13. Taylor, S. & Badcock, D. Processing feature density in preattentive perception. Percept. Psychophys. 44, 551–562 (1988).

14. Wolfe, J. M. & DiMase, J. S. Do intersections serve as basic features in visual search? Perception 32, 645–656 (2003).

15. Buetti, S., Cronin, D. A., Madison, A. M., Wang, Z. & Lleras, A. Towards a better understanding of parallel visual processing in human vision: evidence for exhaustive analysis of visual information. J. Exp. Psychol. Gen. 145, 672–707 (2016).

16. Duncan, J. & Humphreys, G. W. Visual search and stimulus similarity. Psychol. Rev. 96, 433–458 (1989).

17. Koehler, K., Guo, F., Zhang, S. & Eckstein, M. P. What do saliency models predict? J. Vis. 14, 14 (2014).

18. Koch, C. & Ullman, S. Shifts in selective visual attention: towards the underlying neural circuitry. Human Neurobiol. 4, 219–227 (1985).

1

9. Itti, L., Koch, C. & Niebur, E. A model of saliency-based visual attention for rapid scene analysis. IEEE T. Pattern Anal. 20, 1254–1259 (1998).
20. Itti, L. & Koch, C. A saliency-based search mechanism for overt and covert shifts of visual attention. Vision. Res 40, 1489–1506 (2000).

21. Bruce, N. D. B., Wloka, C., Frosst, N., Rahman, S. & Tsotsos, J. K. On computational modeling of visual saliency: examining what's right, and what's left. Vision Res. 116, 95–112 (2015).

22. Zhang, L., Tong, M. H., Marks, T. K., Shan, H. & Cottrell, G. W. SUN: A Bayesian framework for saliency using natural statistics. J. Vis. 8, 1–20 (2008).

23. Henderson, J. M., Malcolm, G. L. & Schandl, C. Searching in the dark: cognitive relevance drives attention in real-world scenes. Psychon. Bull. Rev. 16, 850–856 (2009).

24. Tatler, B. W., Hayhoe, M. M., Land, M. F. & Ballard, D. H. Eye guidance in natural vision: reinterpreting salience. J. Vis. 11, 5 (2011).

25. Nuthmann, A. & Henderson, J. M. Object-based attentional selection in scene viewing. J. Vis. 10, 20 (2010).

26. Einhäuser, W., Spain, M. & Perona, P. Objects predict fixations better than early saliency. J. Vis. 8, 18 (2008).

27. Stoll, J., Thrun, M., Nuthmann, A. & Einhäuser, W. Overt attention in natural scenes: objects dominate features. Vision Res. 107, 36–48 (2015).
28. Maunsell, J. H. & Treue, S. Feature-based attention in visual cortex. Trends Neurosci. 29, 317–322 (2006).

29. Nordfang, M. & Wolfe, J. M. Guided search for triple conjunctions. Atten. Percept. Psychophys. 76, 1535–1559 (2014).

30. Friedman-Hill, S. R. & Wolfe, J. M. Second-order parallel processing: visual search for the odd item in a subset. J. Exp. Psychol. Human 21, 531–551 (1995).

31. Olshausen, B. A. & Field, D. J. Sparse coding of sensory inputs. Curr. Opin. Neurobiol. 14, 481–487 (2004).

32. DiCarlo, J. J., Zoccolan, D. & Rust, N. C. How does the brain solve visual object recognition? Neuron 73, 415–434 (2012).

33. Vickery, T. J., King, L.-W. & Jiang, Y. Setting up the target template in visual search. J. Vis. 5, 8 (2005).

34. Neisser, U. Cognitive Psychology (Appleton-Century-Crofts, 1967).

35. Treisman, A. & Gelade, G. A feature-integration theory of attention. Cognitive Psychol. 12, 97–136 (1980).

36. Wolfe, J. M., Cave, K. R. & Franzel, S. L. Guided search: an alternative to the feature integration model for visual search. J. Exp. Psychol. Human 15, 419–433 (1989).

37. Wolfe, J. M. in Oxford Handbook of Attention (eds Nobre, A. C & Kastner, S.) 11–55 (Oxford Univ. Press, 2014).

38. Wolfe, J. M. & Horowitz, T. S. What attributes guide the deployment of visual attention and how do they do it? Nat. Rev. Neurosci. 5, 495–501 (2004).

39. Alexander, R. G., Schmidt, J. & Zelinsky, G. J. Are summary statistics enough? Evidence for the importance of shape in guiding visual search. Vis. Cogn. 22, 595–609 (2014).

40. Yamins, D. L. K. & DiCarlo, J. J. Using goal-driven deep learning models to understand sensory cortex. Nat. Neurosci. 19, 356–365 (2016).

41. Reijnen, E., Wolfe, J. M. & Krummenacher, J. Coarse guidance by numerosity in visual search. Atten. Percept. Psychophys. 75, 16–28 (2013).

42. Godwin, H. J., Hout, M. C. & Menneer, T. Visual similarity is stronger than semantic similarity in guiding visual search for numbers. Psychon. Bull. Rev. 21, 689–695 (2014).

43. Gao, T., Newman, G. E. & Scholl, B. J. The psychophysics of chasing: a case study in the perception of animacy. Cogn. Psychol. 59, 154–179 (2009).

44. Meyerhoff, H. S., Schwan, S. & Huff, M. Perceptual animacy: visual search for chasing objects among distractors. J. Exp Psychol. Human 40, 702–717 (2014).

45. Notebaert, L., Crombez, G., Van Damme, S., De Houwer, J. & Theeuwes, J. Signals of threat do not capture, but prioritize, attention: a conditioning approach. Emotion 11, 81–89 (2011).

46. Wolfe, J. M. & Franzel, S. L. Binocularity and visual search. Percept. Psychophys. 44, 81–93 (1988).

47. Paffen, C., Hooge, I., Benjamins, J. & Hogendoorn, H. A search asymmetry for interocular conflict. Atten. Percept. Psychophys. 73, 1042–1053 (2011).

48. Paffen, C. L., Hessels, R. S. & Van der Stigchel, S. Interocular conflict attracts attention. Atten. Percept. Psychophys. 74, 251–256 (2012).

49. Zou, B., Utochkin, I. S., Liu, Y. & Wolfe, J. M. Binocularity and visual search— revisited. Atten. Percept. Psychophys. 79, 473–483 (2016).

50. Hershler, O. & Hochstein, S. At first sight: a high-level pop out effect for faces. Vision Res. 45, 1707–1724 (2005).

51. Golan, T., Bentin, S., DeGutis, J. M., Robertson, L. C. & Harel, A. Association and dissociation between detection and discrimination of objects of expertise: evidence from visual search. Atten. Percept. Psychophys. 76, 391–406 (2014).

52. VanRullen, R. On second glance: still no high-level pop-out effect for faces. Vision Res. 46, 3017–3027 (2006).

53. Hershler, O. & Hochstein, S. With a careful look: still no low-level confound to face pop-out. Vision Res. 46, 3028–3035 (2006).

54. Frischen, A., Eastwood, J. D. & Smilek, D. Visual search for faces with emotional expressions. Psychol. Bull. 134, 662–676 (2008).

55. Dugué, L., McLelland, D., Lajous, M. & VanRullen, R. Attention searches nonuniformly in space and in time. Proc. Natl Acad. Sci. USA 112, 15214–15219 (2015).

56. Gerritsen, C., Frischen, A., Blake, A., Smilek, D. & Eastwood, J. D. Visual search is not blind to emotion. Percept. Psychophys. 70, 1047–1059 (2008).

57. Aks, D. J. & Enns, J. T. Visual search for size is influenced by a background texture gradient. J. Exp. Psychol. Human 22, 1467–1481 (1996).

58. Richards, W. & Kaufman, L. 'Centre-of-gravity' tendencies for fixations and flow patterns. Percept. Psychophys 5, 81–84 (1969).

59. Kuhn, G. & Kingstone, A. Look away! Eyes and arrows engage oculomotor responses automatically. Atten. Percept. Psychophys. 71, 314–327 (2009).

60. Rensink, R. A. in Human Attention in Digital Environments (ed. Roda, C.) Ch 3, 63–92 (Cambridge Univ. Press, 2011).

61. Enns, J. T. & Rensink, R. A. Influence of scene-based properties on visual search. Science 247, 721–723 (1990).

62. Zhang, X., Huang, J., Yigit-Elliott, S. & Rosenholtz, R. Cube search, revisited. J. Vis. 15, 9 (2015).

63. Wolfe, J. M. & Myers, L. Fur in the midst of the waters: visual search for material type is inefficient. J. Vis. 10, 8 (2010).

64. Kunar, M. A. & Watson, D. G. Visual search in a multi-element asynchronous dynamic (MAD) world. J. Exp. Psychol. Human 37, 1017–1031 (2011).

65. Ehinger, K. A. & Wolfe, J. M. How is visual search guided by shape? Using features from deep learning to understand preattentive "shape space". In Vision Sciences Society 16th Annual Meeting (2016); http://go.nature.com/2l1azoy

66. Vickery, T. J., King, L. W. & Jiang, Y. Setting up the target template in visual search. J. Vis. 5, 81–92 (2005).

67. Biederman, I., Mezzanotte, R. J. & Rabinowitz, J. C. Scene perception: detecting and judging objects undergoing relational violations. Cognitive Psychol. 14, 143–177 (1982).

68. Henderson, J. M. Object identification in context: the visual processing of natural scenes. Can. J. Psychol. 46, 319–341 (1992).

69. Henderson, J. M. & Hollingworth, A. High-level scene perception. Annu. Rev. Psychol. 50, 243–271 (1999).

70. Vo, M. L. & Wolfe, J. M. Differential ERP signatures elicited by semantic and syntactic processing in scenes. Psychol. Sci. 24, 1816–1823 (2013).

71. 't Hart, B. M., Schmidt, H. C. E. F., Klein-Harmeyer, I. & Einhäuser, W. Attention in natural scenes: contrast affects rapid visual processing and fixations alike. Philos. T. Roy. Soc. B 368, http://dx.doi.org/10.1098/rstb.2013.0067 (2013).

72. Henderson, J. M., Brockmole, J. R., Castelhano, M. S. & Mack, M. L. in Eye Movement Research: Insights into Mind and Brain (eds van Gompel, R., Fischer, M., Murray, W., & Hill, R.) 537–562 (Elsevier, 2007).

73. Rensink, R. A. Seeing, sensing, and scrutinizing. Vision Res. 40, 1469–1487 (2000).

74. Castelhano, M. S. & Henderson, J. M. Initial scene representations facilitate eye movement guidance in visual search. J. Exp. Psychol. Human 33, 753–763 (2007).

75. Vo, M. L.-H. & Henderson, J. M. The time course of initial scene processing for eye movement guidance in natural scene search. J. Vis. 10, 14 (2010).

76. Hollingworth, A. Two forms of scene memory guide visual search: memory for scene context and memory for the binding of target object to scene location. Vis. Cogn. 17, 273–291 (2009).

77. Oliva, A. in Neurobiology of Attention (eds Itti, L., Rees, G., & Tsotsos, J.) 251–257 (Academic Press, 2005).

78. Greene, M. R. & Oliva, A. The briefest of glances: the time course of natural scene understanding. Psychol. Sci. 20, 464–472 (2009).

79. Castelhano, M. & Heaven, C. Scene context influences without scene gist: eye movements guided by spatial associations in visual search. Psychon. B. Rev. 18, 890–896 (2011).

80. Malcolm, G. L. & Henderson, J. M. Combining top-down processes to guide eye movements during real-world scene search. J. Vis. 10, 1–11 (2010).

81. Torralba, A., Oliva, A., Castelhano, M. S. & Henderson, J. M. Contextual guidance of eye movements and attention in real-world scenes: the role of global features on object search. Psychol. Rev. 113, 766–786 (2006).

82. Vo, M. L. & Wolfe, J. M. When does repeated search in scenes involve memory? Looking at versus looking for objects in scenes. J. Exp. Psychol. Human 38, 23–41 (2012).

83. Vo, M. L.-H. & Wolfe, J. M. The role of memory for visual search in scenes. Ann. NY Acad. Sci. 1339, 72–81 (2015).

84. Hillstrom, A. P., Scholey, H., Liversedge, S. P. & Benson, V. The effect of the first glimpse at a scene on eye movements during search. Psychon. B. Rev. 19, 204–210 (2012).

85. Hwang, A. D., Wang, H.-C. & Pomplun, M. Semantic guidance of eye movements in real-world scenes. Vision Res. 51, 1192–1205 (2011).

86. Watson, D. G. & Humphreys, G. W. Visual marking: prioritizing selection for new objects by top-down attentional inhibition of old objects. Psychol. Rev. 104, 90–122 (1997).

87. Donk, M. & Theeuwes, J. Prioritizing selection of new elements: bottom-up versus top-down control. Percept. Psychophys. 65, 1231–1242 (2003).

88. Maljkovic, V. & Nakayama, K. Priming of popout: I. Role of features. Mem. Cognition 22, 657–672 (1994).

89. Lamy, D., Zivony, A. & Yashar, A. The role of search difficulty in intertrial feature priming. Vision Res. 51, 2099–2109 (2011).

90. Wolfe, J., Horowitz, T., Kenner, N. M., Hyle, M. & Vasan, N. How fast can you change your mind? The speed of top-down guidance in visual search. Vision Res. 44, 1411–1426 (2004).

91. Wolfe, J. M., Butcher, S. J., Lee, C. & Hyle, M. Changing your mind: on the contributions of top-down and bottom-up guidance in visual search for feature singletons. J. Exp. Psychol. Human 29, 483–502 (2003).

92. Kristjansson, A. Simultaneous priming along multiple feature dimensions in a visual search task. Vision Res. 46, 2554–2570 (2006).

93. Kristjansson, A. & Driver, J. Priming in visual search: separating the effects of target repetition, distractor repetition and role-reversal. Vision Res. 48, 1217–1232 (2008).

94. Sigurdardottir, H. M., Kristjansson, A. & Driver, J. Repetition streaks increase perceptual sensitivity in visual search of brief displays. Vis. Cogn. 16, 643–658 (2008).

95. Kruijne, W. & Meeter, M. Long-term priming of visual search prevails against the passage of time and counteracting instructions. J. Exp. Psychol. Learn. 42, 1293–1303 (2016).

96. Chun, M. & Jiang, Y. Contextual cuing: implicit learning and memory of visual context guides spatial attention. Cogn. Psychol. 36, 28–71 (1998).

97. Chun, M. M. & Jiang, Y. Top-down attentional guidance based on implicit learning of visual covariation. Psychol. Sci. 10, 360–365 (1999)

98. Kunar, M. A., Flusberg, S. J., Horowitz, T. S. & Wolfe, J. M. Does contextual cueing guide the deployment of attention? J. Exp. Psychol. Human 33, 816–828 (2007).

99. Geyer, T., Zehetleitner, M. & Muller, H. J. Contextual cueing of pop-out visual search: when context guides the deployment of attention. J. Vis. 10, 20 (2010).

100. Schankin, A. & Schubo, A. Contextual cueing effects despite spatially cued target locations. Psychophysiology 47, 717–727 (2010).

101. Schankin, A., Hagemann, D. & Schubo, A. Is contextual cueing more than theguidance of visual-spatial attention? Biol. Psychol. 87, 58–65 (2011).

102. Peterson, M. S. & Kramer, A. F. Attentional guidance of the eyes by contextual information and abrupt onsets. Percept. Psychophys. 63, 1239–1249 (2001).

103. Tseng, Y. C. & Li, C. S. Oculomotor correlates of context-guided learning in visual search. Percept. Psychophys. 66, 1363–1378 (2004).

104. Wolfe, J. M., Klempen, N. & Dahlen, K. Post-attentive vision. J. Exp. Psychol. Human 26, 693–716 (2000).

105. Brockmole, J. R. & Henderson, J. M. Using real-world scenes as contextual cues for search. Vis. Cogn. 13, 99–108 (2006).

106. Hollingworth, A. & Henderson, J. M. Accurate visual memory for previously attended objects in natural scenes. J. Exp. Psychol. Human 28, 113–136 (2002).

107. Flowers, J. H. & Lohr, D. J. How does familiarity affect visual search for letter strings? Percept. Psychophys. 37, 557–567 (1985).

108. Krueger, L. E. The category effect in visual search depends on physical rather than conceptual differences. Percept. Psychophys. 35, 558–564 (1984).

109. Frith, U. A curious effect with reversed letters explained by a theory of schema. Percept. Psychophys. 16,

113–116 (1974).

110. Wang, Q., Cavanagh, P. & Green, M. Familiarity and pop-out in visual search. Percept. Psychophy. 56, 495–500 (1994).

111. Qin, X. A., Koutstaal, W. & Engel, S. The hard-won benefits of familiarity on visual search — familiarity training on brand logos has little effect on search speed and efficiency. Atten. Percept. Psychophys. 76, 914–930 (2014).

112. Fan, J. E. & Turk-Browne, N. B. Incidental biasing of attention from visual long-term memory. J. Exp. Psychol. Learn. 42, 970–977 (2015).

113. Huang, L. Familiarity does not aid access to features. Psychon. B. Rev. 18, 278–286 (2011).

114. Wolfe, J. M., Boettcher, S. E. P., Josephs, E. L., Cunningham, C. A. & Drew, T. You look familiar, but I don't care: lure rejection in hybrid visual and memory search is not based on familiarity. J. Exp. Psychol. Human 41, 1576–1587 (2015).

115. Anderson, B. A., Laurent, P. A. & Yantis, S. Value-driven attentional capture. Proc. Natl Acad. Sci. USA 108, 10367–10371 (2011).

116. MacLean, M. & Giesbrecht, B. Irrelevant reward and selection histories have different influences on task-relevant attentional selection. Atten. Percept. Psychophys. 77, 1515–1528 (2015).

117. Anderson, B. A. & Yantis, S. Persistence of value-driven attentional capture. J. Exp. Psychol. Human 39, 6–9 (2013).

118. Moran, R., Zehetleitner, M. H., Mueller, H. J. & Usher, M. Competitive guided search: meeting the challenge of benchmark RT distributions. J. Vis. 13, 24 (2013).

119. Wolfe, J. M. in Integrated Models of Cognitive Systems (ed. Gray, W.) 99–119 (Oxford Univ. Press, 2007).

120. Proulx, M. J. & Green, M. Does apparent size capture attention in visual search? Evidence from the Müller–Lyer illusion. J. Vis. 11, 21 (2011).

121. Kunar, M. A. & Watson, D. G. When are abrupt onsets found efficiently in complex visual search? Evidence from multielement asynchronous dynamic search. J. Exp. Psychol. Human 40, 232–252 (2014).

122. Shirama, A. Stare in the crowd: frontal face guides overt attention independently of its gaze direction. Perception 41, 447–459 (2012).

123. von Grunau, M. & Anston, C. The detection of gaze direction: a stare-in-thecrowd effect. Perception 24, 1297–1313 (1995).

124. Enns, J. T. & MacDonald, S. C. The role of clarity and blur in guiding visual attention in photographs. J. Exp. Psychol. Human 39, 568–578 (2013).

125. Li, H., Bao, Y., Poppel, E. & Su, Y. H. A unique visual rhythm does not pop out. Cogn. Process. 15, 93–97 (2014).

PERSONAL VIEW

CROSS-CULTURAL DIFFERENCES IN VISUAL PERCEPTION OF COLOR, ILLUSIONS, DEPTH, AND PICTURES

Bermond, B., & Van Heerden, J. (1996). The Müller-Lyer illusion explained and its theoreti- cal importance reconsidered. Biology and Philosophy, 11, 321–338. https://doi. org/10.1007/BF00128785

Bonte, M. (1962). The reaction of two African societies to the Müller-Lyer illusion. The Journal of Social Psychology, 58, 265–268. https://doi.org/10.1080/002 24545.1962.9712375

Bovet, D., & Vauclair, J. (2000). Picture recognition in animals and humans. Behavioural Brain Research, 109, 143–165. https://doi.org/10.1016/ S0166-4328(00)00146-7

Brislin, R. W. (1974). The Ponzo illusion: Additional cues, age orientation and culture. Journal of Cross-Cultural Psychology, 5, 139–161. https://doi. org/10.1177/ 002202217400500201

Brislin, R. W., & Keating, C. F. (1976). Cultural differences in the perception of a three-dimensional Ponzo illusion. Journal of Cross-Cultural Psychology, 7, 397–412. https://doi.org/10.1177/002202217674002

Davies, I. R. L., & Corbett, G. G. (1997). A cross-cultural study of colour-grouping: Evidence for weak linguistic relativity. British Journal of Psychology (London, England,1953), 88, 493–517. https://doi. org/10.1111/j.2044-8295.1997.tb02653.x

Dawson, J. L., Young, B. M., & Choi, P. P. (1973). Developmental influences on geometric illusion susceptibility among Hong Kong Chinese children. Journal of Cross-Cultural Psychology, 4, 49–74. https://doi. org/10.1177/002202217300400105

Deregowski, J. B. (1972). Pictorial perception and culture. Scientific American, 227(5), 82–88. https://doi. org/10.1038/scientificamerican1172-82

Deregowski, J. B. (1998). W. H. R. Rivers (1864–1922): The founder of research in cross- cultural perception. Perception, 27, 1393–1406. https://doi.org/10.1068/ p271393

Halverson, J. (1992). The first pictures: Perceptual foundations of Paleolithic art. Perception, 21, 389–404. https://doi. org/10.1068/p210389

Hudson, W. (1960). Pictorial depth perception in sub-cultural groups in Africa. Journal of Social Psychology, 52, 183–208. https://doi.org/10.1080/002245 45.1960.9922077 Jahoda, G., & McGurk, H. (1974a). Pictorial depth perception: A developmental study. British Journal of Psychology, 65, 141–149. https://doi. org/10.1111/j.2044-8295.1974. tb02780.x

Jahoda, G., & McGurk, H. (1974b). Development of pictorial depth perception: Cross-cultural replications. Child Development, 45, 1042–1047. https://doi.org/10.2307/1128092 Kidd, D. (1904). The essential Kafir. London, UK: Adam and Charles Black. Retrieved from https://archive.org/ detailsessentialkafir00kidduoft (accessed December 20, 2018).

Kilbride,P.L.,&Robbins,M.C.https://doi. org/10.1525/aa. 1969.71.2.02a00090

Kitayama, S., Duffy, S., Kawamura, T., & Larsen, J. T. (2003). Perceiving an object and its context in different cultures: A cultural look at new look. Psychological Science, 14, 201–206. https://doi. org/10.1111/1467-9280.02432

Livingstone, D. (1857). Missionary travels and researches in South Africa. London, UK: Royal Geographic Society. Retrieved from http://www.gutenberg.org/ files/1039/ 1039-h/1039-h.htm (accessed December 20, 2018).

Masuda, T., Gonzalez, R., Kwan, L., & Nisbett, R. E. (2008). Culture and aesthetic preference: Comparing the attention to context of East Asians and Americans. Personality and Social Psychology Bulletin, 34, 1260–1275. https://doi.org/10.1177/ 0146167208320555

Matsumoto, D. (2006). Are cultural differences in emotion regulation mediated by personality traits? Journal of Cross-Cultural Psychology, 37, 421–437. https://doi.org/ 10.1177/0022022106288478

Nakagawa, E. (2002). Rats respond to configurations of stimuli. The Psychological Record, 52, 531–558. https://doi.org/10.1007/BF03395202

Nisbett, R. E., & Miyamoto, Y. (2005). The influence of culture: Holistic versus analytic perception. Trends in Cognitive Sciences, 9, 467–473. https://doi. org/10.1016/ j.tics.2005.08.004

Norenzayan, A., Smith, E. E., Kim, B. J., & Nisbett, R. E. (2002). Cultural preferences for formal versus intuitive reasoning. Cognitive Science, 26, 653–684. https://doi.org/ 10.1016/ S0364-0213(02)00082-4

Pedersen, D. M., & Wheeler, J. (1983). The Müller-Lyer illusion among Navajos. The Journal of Social Psychology, 121, 3–6. https://doi.org/10.1080/00224545.1 983.9924459

Phillips, W. L, Gharib, A., Cabral, I., Mendizabal, I. P., Ladines, N. A. & Garcia, E. (May, 2017) Asian-Americans prefer more background scenes in photographs than European-Americans. Poster presented at the 29th Annual Meeting of the Association for Psychological Science, Boston, MA.

Rosch, E. H. (1973). Natural categories. Cognitive Psychology, 4, 328–350. https://doi.org/ 10.1016/0010-0285(73)90017-0

Segall, M. H., Campbell, D. T., & Herskovits, M. J. (1966). The influence of culture on visual perception. Indianapolis, IN: Bobbs-Merril Co. Retrieved from https://archive.org/ details/ influenceofcultu00sega (accessed December 20, 2018).

Slobodin, R. (1978). W. H. R. Rivers. New York, NY: Columbia University Press. https:// doi.org/10.1037/10522-041

Smith, T. (1973). The susceptibility of Xhosa groups to a perspective illusion. Journal of Social Psychology, 90, 331–332. https://doi.org/10.1080/002245 45.1973.9712579

Tardif, T., Shatz, M., & Naigles, L. (1997). Caregiver speech and children's use of nouns versus verbs: A comparison of English, Italian, and Mandarin. Journal of Child Language, 24, 535–565. https:// doi.org/10.1017/S030500099700319X

Turnbull, C. M. (1961). Some observations regarding the experiences and behavior of the BaMbuti Pygmies. American Journal of Psychology, 74, 304–308. https://doi.org/10.2307/1419421

Wagner, D. A. (1977). Ontogeny of the Ponzo illusion: Effects of age, schooling, and envi- ronment. International Journal of Psychology, 12, 161–176. https://doi. org/ 10.1080/00207597708247386

Whiting, B. B. (1976). The problem of the packaged variable. In K. Riegel, & J. Meacham (Eds.), The developing individual in a changing world (Vol. 1) (pp. 303–309). Chicago, IL: Aldine.

EMOTION AND PERCEPTION: THE ROLE
OF AFFECTIVE INFORMATION

1. Proffitt DR, Bhalla M, Gossweiler R, Midgett J. Perceiving geographical slant. Psychon Bull Rev 1995, 2(4):409–428.

2. Bhalla M, Proffitt DR. Visual-motor recalibration in geographical slant perception. J Exp Psychol Hum Percept Perform 1999, 25(4):1076–1096.

3. Riener CR, Stefanucci JK, Proffitt DR, Clore GL. An effect of mood on the perception of geographical slant. Cogn Emotion 2011, 25:174–182.

4. Bruner JS, Postman L. Emotional selectivity in perception and reaction. J Pers 1947, 16:69–78.

5. Veltkamp M, Aarts H, Custers R. Perception in the service of goal pursuit: motivation to attain goals enhances the perceived size of goal-instrumental objects. Soc Cogn 2008, 26:720–736.

6. Schwarz N, Clore GL.Mood, misattribution, and judgments of well-being: Informative and directive functions of affective states. J Pers Soc Psychol 1983, 45:513–523.

7. Schwarz N, Clore GL. Feelings and phenomenal experiences. In: Social Psychology: A Handbook of Basic Principles. 2nd ed. New York: Guilford Press; 2007, 385–407.

8. Clore GL, Ortony A. Appraisal theories: how cognition shapes affect into emotion. In: Handbook of Emotions. 3rd ed. New York: Guilford Press; 2008, 628–642.

9. Simon H. Motivational and emotional controls of cognition. Psychol Rev 1967, 74(1):29–39.

10. Phelps EA, Ling S, Carrasco M. Emotion facilitates perception and potentiates the perceptual benefits of attention. Psychol Sci 2006, 17(4):292–299.

11. Cunningham WA, Van Bavel JJ, Johnsen IR. Affective flexibility: evaluative processing goals shape amygdala activity. Psychol Sci 2008, 19:152–160.

12. Frith U. Autism: explaining the enigma. Oxford: Blackwell Scientific Publications; 1989.

13. Davidoff J, Fonteneau E, Fagot J. Local and global processing: observations from a remote culture. Cognition 2008, 108(3):702–709.

14. Easterbrook J. This week's citation classic. Curr Contents 1982, 12:20.

15. Easterbrook J. The effect of emotion on cue utilization and the organization of behavior. Psychol Rev 1959, 66(3):183–201.

16. Derryberry D, Tucker DM. Motivating the focus of attention. In: Niedenthal PM, Kitayama S, eds. The Heart's Eye: Emotional Influences in Perception and Attention. San Diego, CA: Academic Press; 1994, 167–196.

17. Fredrickson B. The role of positive emotions in positive psychology: the broaden-and-build theory of positive emotions. Am Psychol 2001, 56(3):218–226.

18. Kimchi R, Palmer SE. Form and texture in hierarchically constructed patterns. J Exp Psychol: Hum Percept Perform 1982, 8:521–535.

19. Gasper K, Clore GL. Mood and global versus local processing of visual information. Psychol Sci 2002, 13:34–40.

20. Navon D. Forest before trees: the precedence of global features in visual perception. Cognit Psychol 1977, 9(3):353–383.

21. Gable PA, Harmon-Jones E. Approach-motivated positive affect reduces breadth of attention. Psychol Sci 2008, 19:476–482.

22. Huntsinger JR, Clore GL, Bar-Anan Y. Mood and global-local focus: priming a local focus reverses the link between mood and global-local processing. Emotion 2010, 10:722–726.

23. Aramova YR, Stapel DA, Lerouge D. Positive mood increases and negative mood decreases the effect of context on perception. J Pers Soc Psychol 2010, 99(2):203–214.

24. Storbeck J, Clore GL. The affective regulation of cognitive priming. Emotion (Washington, DC) 2008, 8:208–215.

25. Bless H, Schwarz N, Kemmelmeier M. Mood and stereotyping: affective states and the use of general knowledge structures. In: European Review of Social Psychology. 7th ed. Chichester: John Wiley & Sons; 1996, 63–93.

26. Bodenhausen GV. Emotions, arousal, and stereotypic judgments: aheuristic model of affect and stereotyping. Affect, Cognition, and Stereotyping. San Diego: Academic Press; 1993, 13–37.

27. Isbell L. Not all happy people are lazy or stupid: Evidence of systematic processing in happy moods. J Exp Soc Psychol 2004, 40:341–349.

28. Posner MI. Chronometric explorations of mind. Hillsdale, NJ: Erlbaum; 1978.

29. Treisman A. Strategies and models of selective attention. Psychol Rev 1969, 76(3):282–299.

30. Clore G, Huntsinger J. How emotions inform judgment and regulate thought. Trends Cogn Sci 2007, 11(9):393–399.

31. Kitayama S, Niedenthal PM. Introduction. In: Niedenthal PM, Kitayama S, eds. The Heart's Eye: Emotional Influences in Perception and Attention. San Diego, CA: Academic Press; 1994, 1–14.

32. Navon D, Margalit B. Allocation of attention according to informativeness in visual recognition. Q J Exp Psychol A 1983, 35(3):497–512.

33. Roskos-Ewoldsen D, Fazio R. On the orienting value of attitudes: attitude accessibility as a determinant of an object's attraction of visual attention. J Pers Soc Psychol 1992, 63(2):198–211.

34. MacLeod C, Mathews A. Anxiety and the allocation of attention to threat.QJ Exp Psychol 1988, 38:659–670.

35. Williams J, Watts F, MacLeod C, Mathews A. Cognitive psychology and the emotional disorders. 2nd ed Chichester, England: John Wiley & Sons; 1997.

36. MacLeod C, Rutherford E, Campbell L, Ebsworthy G, Holker L. Selective attention and emotional vulnerability: assessing the causal basis of their association through the experimental manipulation of attentional bias. J Abnorm Psychol 2002, 111(1):107–123.

37. Tamir M, Robinson M. The happy spotlight: positive mood and selective attention to rewarding information. Pers Soc Psychol Bull 2007, 33(8):1124.

38. Anderson E, Bliss-Moreau E, Barrett LF. The visual impact of affective information. Psychol Sci. in press.

DIFFERENT WAY OF SEEING

WAYFINDING SIGNAGE FOR PEOPLE WITH COLOR BLINDNESS

Ananto, B. S., Sari, R. F., & Harwahyu, R. (2011). Color transformation for color blind compensation on augmented reality system. Proceedings of 2011 International Conference on User Science and Engineering (i-USEr) (pp. 129–134). IEEE. https:// doi.org/10.1109/ iUSEr.2011.6150551.

Brettel, H., Vi not, F., & Mollon, J. D. (1997). Computerized simulation of color appearance for dichromats. Journal of the Optical Society of America A, 14(10), 2647–2655. https://doi.org/ 10.1364/ JOSAA.14.002647

Calori, C., & Vanden-Eynden, D. (2015). Signage and wayfinding design: A complete guide to creating environmental graphic design systems. Hoboken, New Jersey: John Wiley & Sons. https://doi. org/10.1002/9781119174615

Capilla, P., Dıez-Ajenjo, M. A., Luque, M. J., & Malo, J. (2004). Corresponding-pair procedure: A new approach to simulation of dichromatic color perception. Journal of the Optical Society of America A, 21(2), 176–186. https://doi.org/ 10.1364/ JOSAA.21.000176

Chevreul, M. E. (1839). The principles of harmony and contrast of colors. New York, NY: Van Nostrand Reinhold.

Choudhury, F. M., Ali, M. E., Masud, S., Nath, S., & Rabban, I. E. (2014). Scalable visibility color map construction in spatial databases. Information Systems, 42, 89–106. https://doi.org/10. 1016/j. is.2013.12.002

Cole, B. L., & Lian, K. Y. (2006). Search for coloured objects in natural surroundings by people with abnormal colour vision. Clinical and Experimental Optometry, 89(3), 144–149.

Color Blindness. (n.d.). In the free medical dictionary online. Retrieved from https://medicaldictionary. thefreedictionary.com/color +blindness.

Decker, K. (2017). The fundamentals of understanding color theory. Retrieved from https:// 99designs.com/blog/tips/ the-7-step-guide-tounderstanding- color-theory/.

DIC Corporation. (n.d.). Color universal design gains increased acceptance. Retrieved from: http:// www.dic-global. com/en/110th/universal/.

Dwight, E. (2008). Signs of the times. American School & University, 80(12), 38–40.

EIZO Corporation. (2006). Color universal design handbook. Retrieved from https:// webcube-general.s3.amazonaws.com/ eizo/ media/contentassets/2015/10/09/ handbook.pdf.

Flück, D. (2006). Color blind essentials. Retrieved from http://www.color- blindness com/2010/ 02/23/color-blind- essentials/.

Harwahyu, R., Manaf, A. S., Ananto, B. S.,
Wicaksana, B. A., & Sari, R. F. (2013). Implementation of color-blind aid system. Journal of Computer Science, 9(6), 794–810. https://doi. org/10.3844/ jcssp.2013.794.810

Itten, J. (1970). The elements of color. Ravensburg: John Wiley & Sons.

THE EFFECT OF PRINT SIZE ON READING SPEED IN DYSLEXIA

Adams, M.J. (1979). Models of word recognition. Cognitive Psychology, 11(2), 133–176.

Ans, B., Carbonnel, S. & Valdois, S. (1998). A connectionist multi-trace memory model of polysyllabic word reading. Psychological Review, 105, 678–723.

Atkinson, J. (1993). Vision in dyslexics: Letter recognition, acuity, visual crowding, contrast sensitivity, accommodation, convergence and sight reading music. In S.F. Wright & R. Groner (Eds.), Facets of dyslexia and its remediation. Amsterdam: Elsevier Science.

Carver, R.P. (1990). Reading rate: A review of research and theory. San Diego: Academic Press.

Chin, C.E., Ledesma, H.M.L., Cirino, P.T., Sevcik, R.A., Morris, R.D., Frijters, J.C. & Lovett, M.W. (2001).Relation between Kaufman Brief Intelligence Test and WISC-III scores of children with RD. Journal of Learning Disabilities, 34(1),2–8.

Cornelissen, P., Bradley, L., Fowler, S. & Stein, J. (1991). What children see affects how they read. Developmental Medicine and Child Neurology, 33, 755–762.

Cornelissen, P.L., Richardson, A.L., Mason, A., Fowler, M.S. & Stein, J.F. (1994). Contrast sensitivity and coherent motion detection measured at photopic luminance levels in dyslexics and controls. Vision Research, 35, 1483–1494.

Cornelissen, P.L., Hansen, P., Gilchrist, I., Cormack, F., Essex, J. & Frankish, C. (1998a). Coherent motion detection and letter position encoding. Vision Research, 38, 2181–2191.

Cornelissen, P.L., Hansen, P., Hutton, J., Evangelinou, V. & Stein, J. (1998b). Magnocellular visual function and children's single word reading. Vision Research, 38, 471–482.

Cornelissen, P.L. & Hansen, P.C. (1998). Motion detection, letter position encoding, and single word reading. Annals of Dyslexia, 48, 155–188.

Demb, J.B., Boynton, G.M. & Heeger, D.J. (1997). Brain activation in visual cortex predicts individual differences in reading performance. Proceedings of the New York Academy of Sciences, 94, 13363–13366.

Demb, J.B., Boynton, G.M., Best, M. & Heeger, D. (1998). Psychophysical evidence for a magnocellular deficit in dyslexics. Vision Research, 38, 1555–1559.

Eden, G.F., van Meter, J.W., Rumsey, J.W., Maisog, J. & Zeffiro, T.A. (1996). Functional MRI reveals differences in visual motion processing in individuals with dyslexia. Nature, 382, 66–69.

Estes, W.K. & Brunn, J.L. (1987). Discriminability and bias in the word-superiority effect. Perception and Psychophysics, 42(5), 411–422.

Everatt, J., Bradshaw, M.F. & Hibbard, P.B. (1999). Visual processing and dyslexia. Perception, 28(2), 243–254.

Galaburda, A.M. & Livingstone, M.S. (1993). Evidence for a magnocellular defect in developmental dyslexia. In P. Tallal, A.M. Galaburda, R.R. Llinas & C. von Euler (Eds.), Temporal information processing in the nervous system. Annals of the New York Academy of Sciences, 682, 70–82.