

# Cognitive Aspects of Color

*Gunilla Derefeldt, Jean-Pierre Menu,\* and Tiina Swartling  
National Defence Research Establishment, Linköping, Sweden  
CERMA,\* Bretigny-Sur-Orge, France*

## 1. Abstract

This report surveys cognitive aspects of color in terms of behavioral, neuropsychological, and neurophysiological data. Color is usually defined as psychophysical color or as perceived color. Behavioral data on categorical color perception, absolute judgement of colors, color coding, visual search, and visual awareness refer to the more cognitive aspects of color. These are of major importance in visual synthesis and spatial organization, as already shown by the Gestalt psychologists. Neuropsychological and neurophysiological findings provide evidence for an interrelation between cognitive color and spatial organization. Color also enhances planning strategies, as has been shown by studies on color and eye movements. Memory colors and the color-language connections in the brain also belong among the cognitive aspects of color.

Keywords: color, color cognition, spatial awareness, eye movements, color coding

## 2. Definitions of Color: Psychophysical, Perceived

The CIE,<sup>1,p.67</sup> defines *psychophysical color* as “a specification of a color stimulus in terms of operationally defined values, such as three tristimulus values.” *Perceived color*, as an “attribute of visual perception consisting of any combination of chromatic and achromatic content,” can be “described by chromatic colour names such as yellow, orange, brown, red, pink, green, blue, purple, etc., or by achromatic colour names such as white, grey, black, etc., and qualified by bright, dim, light, dark, etc., or by combinations of such names.”<sup>1,p.47</sup> To these definitions, CIE gives notes considering the relations between perceived color and size, shape, structure and surround of the stimulus area, the state of adaptation of the observer’s visual system, and the observer’s experience; and the modes of color appearance.

The cognitive aspects of color are not mentioned in these definitions of color, although some hints are given in the notes. In the psychological literature, the distinction between perception and cognition is not clear and has been the subject of much debate. A common distinction is that while perception is said to refer to real perception of objects or events in the real world, cognition refers to mental imagery or an internal representation of the same objects or events. According to Schupp, Lutzenberger, Birnbauer, Miltner, and Braun,<sup>2,p.77</sup> “mental imagery is conceptualized as behavior guided by internal representation only.” Behavior guided by mental imagery is also said to be more hypothetical and anticipatory than behavior guided by perception.

Early in color science, psychological studies on color naming and color memory recognized the cognitive aspects of color. Neuropsychological disorders and recent neurophysiological findings have later given evidence for the distinction between the perceptual and cognitive aspects of color.

## 3. Cognitive Color

The cognitive aspects of color have been discussed by many authors.<sup>3-5</sup> In his book *Cognition Through Color*, Davidoff<sup>6</sup> discusses the cognitive aspects of color within a theoretical framework in which he puts forward a model of color cognition from a perspective of object recognition. “Understanding of objects is linked to the knowledge concerning their color.”<sup>6,p.xiii</sup> However, the rapid increase in physiological and neurophysiological findings showing the abundance of projections of visual pathways in the cortex from visual primary cortex to other parts of the brain including the temporal, the parietal, and the frontal areas,<sup>6-12</sup> have given new content to the term “cognitive color.”

Zeki,<sup>12</sup> states: “The study of colour vision has thus been instrumental in modifying our views on the cerebral processes involved in vision. Indeed, it has provided us with powerful insights into brain function. Understanding the role of the cortex in colour vision has therefore philosophical and epistemological implications which go far beyond understanding the detailed physiological mechanisms underlying the perception of colours. In short, the study of colour gives us a vision of how the visual cortex works. The study of the visual cortex in turns gives us a vision of how the brain works.”

The cognitive aspects of color were perhaps first realized by some neuropsychological disorders illustrating the dissociations between perceptual and cognitive color.<sup>6,11-14</sup>

Such disorders are:

cerebral	
achromatopsia	loss of color vision, an entirely central defect and “a condition in which the signals relayed to the brain are normal but the mechanism used to construct colours is defective.” <sup>12,p.268</sup>
chromatopsia	resulting from carbon monoxide poisoning characterized by accurate color vision but impaired form perception
color agnosia	inability to use colors in object recognition
color anomia	disorders of color naming; ability to experience color normally, ability to discriminate and recognize colors but without being able to name them.

Studies on the neural basis of language<sup>15</sup> have suggested that there may be separate neural structures for the perceptual, categorical, and semantic aspects of color. Concepts for color depend on one system, the words for color on another system, and the connections between words and concepts on a third.

In this paper we will address the representational and anticipatory aspects of color. Color in categorical color perception, in spatial organization, and in visual search tasks will be discussed in terms of behavioral, neuropsychological, and neurophysiological data.

#### 4. Cognitive Color Spaces

From the distinctions between perception and cognition, a distinction between perceptual and cognitive color spaces may be made. A perceptual color space is defined from descriptions of attributes of perceptions of real colors in the real world. The maximum number of colors in a perceptual color space have been estimated to be about 6 million.<sup>16</sup>

There are several perceptually based color spaces in use today,<sup>17</sup> some illustrated by more than thousand color chips representing only a limited set of the total perceptual color space. A cognitive color space would refer to the internal representations of the colors and would also include semantic color representations, i.e. names representing the colors mentally. Such spaces have been discussed earlier by Berlin and Kay<sup>18</sup> and Hardin.<sup>5</sup> In dealing with color-naming data, internal consistency is usually good while between-subject differences are great.<sup>16,19</sup> This fact would make a cognitive color space more difficult to specify than a perceptual one. The maximum number of colors in a cognitive color space may be no more than 30.\*†

#### 5. Categorical Color Perception

From the literature on categorical color perception, we know that only a limited number of colors can be internally represented and absolutely identified across different cultures<sup>20-24</sup> and during different tasks.<sup>25</sup> The number varies between 3 and 30 depending on training<sup>26</sup> and how well the perceived color matches the inner semantic representation of the percept. The eleven colors that are almost never confused are well known.<sup>5,18-21</sup> Using free associations Derefeldt and Swartling<sup>27</sup> found that about 30 colours could be named and identified without training.

The cognitive and representational aspects of color in categorical color perception were studied by the Gestalt psychologists Gelb, Goldstein, and Scheerer.<sup>14,28-32</sup> They found that categorical color perception seems to be closely related to visual synthesis and spatial organization. Patients with brain damage to the occipito-parietal cortex lose capacity for categorical color perception, surface color perception, figure-ground perception and spatial synthesis or organization.

\* erratum shown in shaded box; revised sentence shown below.†

†The maximum number of colors in a cognitive color space is far below that of perceptual color space.

## 6. The Stroop Effect

The Stroop effect<sup>6,34-36</sup> is perhaps one of the most striking phenomena illustrating the cognitive aspects of color. This effect can be said to demonstrate a conflict between perceptual and semantic processing. While earlier theoretical explanations emphasized limited attentional capacity, recent theories invoke parallel processing of relevant and irrelevant dimensions.

Conflicting Stroop color stimuli are words for colors printed in incongruent colors (e.g., the word 'red' is printed in a green color). Subjects are asked either to pronounce the word ("red") or to name the color of the word ("green"). When subjects are asked to name colors, they experience a conflict between the cognitive meaning of the word (red) and the perceived color (green). Pronouncing the word does not produce the same conflict in the observer.

There is a difference in the Stroop interference between English and Chinese readers performing English versus Chinese versions of the test.<sup>37</sup> "Chinese readers showed markedly greater interference than did English readers. Biedermann and Tsao explain this finding as follows: Chinese characters permit more direct access to meaning than an English word. The direct accessing of meaning from a pattern's configuration is a function that has been assigned to the right cerebral hemisphere. Recent evidence also indicates a right hemisphere advantage for accessing information about color. Thus reading Chinese characters and the use of color information may be competing for the same perceptual capacities whereas reading English, a left hemisphere activity, and color naming could, by this account, be executed by different mechanisms. This interference in processing the color would be an additional, presumably perceptual, source of interference in the Chinese version of the Stroop test which would add to the semantic and response interference which has already been documented for the English version."<sup>37, p. 130</sup> In Western cultures, the Stroop interference appears to be most pronounced when words are presented to the left hemisphere. With Chinese characters<sup>38</sup> and with Japanese Kanji (individual Kanji recognition),<sup>39</sup> the Stroop interference is most pronounced when stimuli are presented to the right hemisphere. Hatta<sup>39, p. 91</sup> states: "Recent investigations indicate a right hemisphere advantage for processing color information and a right hemisphere advantage for processing individual Kanji. Therefore, perceptual capacities for color information and direct accessing of the meaning of individual Kanji seem to be competing and thus producing a greater amount of interference in processing the color of Kanji in the right hemisphere." The functional locus of the Stroop effect is not known. The systems that are involved still remain to be identified. When Japanese subjects responded to Kana Stroop stimuli, no hemispheric differences were found. Klein<sup>40</sup> found that the Stroop effect also applies to words and colors with strong associations like green and grass and blue and heaven, respectively.

## 7. Attention and Visual Search

In his 1890 textbook, *Principles of Psychology*, Williams James defined attention as follows: "It is the taking possession by the mind, in clear and vivid form, of one out of what





Case 1



Case 2

Case 3



Case 4



Case 5



Fig. 4 Cases 1 through 5 reproductions of "Fuji Girl" image.

seem several simultaneously possible objects or trains of thought... It implies withdrawal from some things in order to deal effectively with others.” More recent writers use a “filter” metaphor; “attention filters out unattended events.”<sup>41, p. 60</sup>

In visual search tasks, the attentive and anticipatory aspects of behavior are important. Mental concentration is on some anticipated sensory input. Colors have been found to improve human performance in searching for colored targets in unformatted displays. The literature on color coding and visual search shows that the use of color is almost always advantageous if used as a completely redundant code.<sup>25,42</sup> As summed up by Krebs and Wolf,<sup>43</sup> color is an effective code when used as (1) a cue or alerting signal, (2) a method of grouping similar items or separating items, or (3) a means-of-increasing symbol visibility.

The number of colors found to be useful for visual search tasks varies between 5 and 15. These facts indicate the involvement of a cognitive color space. The colors must be accurately perceived, absolutely judged, and correctly named. Color used as an alerting signal means that it is used for attention.

Studies on silent thinking using regional cerebral blood flow (rCBF) have shown that concentrated attention is effectively related to neural events in human observers.<sup>7</sup> Moran and Desimone<sup>44</sup> have shown from responses of single cells in areas V4 and inferior temporal cortex of two rhesus monkeys that selective attention gates visual processing. Responses of the cells in V4 or inferior temporal cortex were determined by the attended stimulus.

Differences between the parvocellular—and magnocellular systems have been taken to suggest parallel processing of separate aspects of visual attributes such as form, color, movement in V1, V2, V4 and V5. Recent findings<sup>12,45</sup> show that the magno- and parvosystems are not as separate as was earlier thought. Regarding the anatomical basis of interactions between the parvo- and the magnosystems, Zeki,<sup>12, p. 192-193</sup> states: “There are massive connections linking the cortex of the superior temporal sulcus to the parietal cortex that would suggest that the two systems are not isolated from each other.... Both V4 and V5 project to the parietal cortex, from which it follows that both P and M signals find their way to the parietal cortex. There is no suggestion that the input from V5 is stronger than that from V4. The projections are to contiguous regions of the intraparietal sulcus, with only partial overlap... the observation of a projection from V4 to the parietal cortex shows that the input to the parietal cortex cannot be conceived of as consisting of one system only. The same is true to a lesser extent of the anterior end of the superior temporal cortex, since area V5 has been consistently found to project there, though not nearly as massively as area V4.... The fact that both the parietal and temporal cortex receive inputs from the same specialized areas indicates that the latter perform functions which are of interest to both these widely separated zones of the cortex. In fact, the temporal cortex interconnects with the parietal cortex, thus giving the lie to the isolation of the two systems.”

The close interconnections between the parietal and temporal cortex give some neurophysiological support for the advantages of color in visual search tasks. Pathways for color have strong links to those involved in attention and eye movements. The prefrontal cortex including the frontal eye field have strong connections between cortical areas in

the occipital, parietal, and inferotemporal lobes<sup>12,46</sup> and between subcortical areas (thalamus, hippocampus, amygdala) to which V4 projects. The prefrontal cortex is important in voluntary saccadic eye movements that are involved in visual search. Eye movements behavior can be regarded as a global index of both perceptual and central processing aspects of cognitive workload.<sup>47</sup> By studying gaze duration and number of fixations, Manton and Hughes<sup>47</sup> found that more effort was required to search and acquire information from monochrome displays than from redundantly color coded displays. The advantage of the color coded displays was greater at high information levels.

Hippocampus plays a significant role in declarative memory and in working memory.<sup>45,46,48,49</sup> There are strong connections between hippocampus and V4, the infero-temporal and the parietal cortex which could account for the role of color in attention, visual search and in learning new tasks.

## 8. Spatial Organization

Maps are a form of complex forms of information display. “To provide spatial lucidity and overview color has been used within cartography for centuries.”<sup>33</sup> In cartography it is recognized that color has integrating and segregating properties which provide structure and organization and separability in addition to conveying meaning.<sup>33</sup> In accordance with principles from the school of Gestalt psychology, which asserts that perception of complex images is governed more by global characteristics rather than by local detail, a “top-down” approach is preferred since this facilitates the perception of a hierarchy of structures that corresponds to the functional and intellectual importance of the information. In cartography some form of rank ordering of information categories according to task priority is also recommended. Taylor<sup>33</sup> emphasizes that to enhance structure and organization it is of utmost importance to choose color codes with careful logic. Taylor<sup>50</sup> has studied the use of color as an organisational factor in complex pictorial aircraft displays. He found that relevant color facilitates figure-ground segregation.

According to Luria (1973), categorical color perception and spatial organization seem to be closely interrelated functions. Patients with damage to the parieto-occipital lobes have impaired capacity for ‘wide simultaneous synthesis’ which enable a whole situation to be perceived at the same time. Such patients are unable to perceive figure-ground relations, to combine individual impressions into complete patterns, to group objects or to grasp a complete situation such as a thematic picture. They also have impaired coordination of eye movements. Gelb and Goldstein<sup>29</sup> found that speech participates directly in the most complex forms of perception and that speech disturbances can lead to loss of the ability to perceive color categories.

## 9. Summary

The definitions of psychophysical and perceived colour do not cover cognitive aspects of color. In this paper we have reported on some phenomena where the term “cognitive color” would be more meaningful. “Cognitive color” has been discussed in relation to color spaces, categorical color perception, the Stroop effect, attention and visual search, and spatial organization.



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\* Celeste Howard is currently at Hughes Training, Inc., Armstrong Laboratory (Mesa, Arizona, USA)

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