Part I
Introduction

1 Introduction and overview

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Color. Psychology. Each of these terms represents a concept that is rich in content and broad in applicability. Each term is commonly used in a colloquial sense in everyday language, but is surprisingly difficult to define in the realm of academic study. Each term has been the focal point of a scientific discipline that has generated a voluminous literature in and of itself (i.e., color science and psychological science). It is the combination of these two terms – *color* and *psychology* – that represents the conceptual space covered by the present *Handbook*.

Color has been defined in myriad ways, and it is fair to state that a definitive definition has yet to emerge (Kuehni, 2012). In defining color, it is important to distinguish between (1) the physical nature of the stimulus that is being encountered, and (2) the response of the individual encountering the color (Hunt, 1978). From early attempts to scientifically define color (for a historical overview, see Committee on Colorimetry, 1953) to the present day, the central focus has been on the subjective sensation or perception of the individual, rather than any objective characteristic of the environment (for philosophical debate on this subjective-objective issue, see Dedrick, Chapter 6, in this volume). Thus, the definition of color that may be considered the most popular at present is the most recent offering provided by the CIE (International Commission on Illumination) (CIE, 2011, p. 28): "color (perceived): Characteristic of a visual perception that can be described by attributes of hue, brightness (or lightness), and colorfulness (or saturation or chroma)." This definition is accompanied by the following note that highlights the complexity involved in defining color: "When necessary, to avoid confusion between other meanings of the word, the term perceived color may be used" (CIE, 2011, p. 28). Here and throughout the *Handbook*, we do not think it is necessary to include the qualifier "perceived"; unless otherwise specified, "color" will be used to connote perceived color.

Also highlighting the inherent complexity of defining color is the fact that several additional notes are appended to the CIE (2011) definition of color. One of these notes indicates that the way that color is perceived depends on numerous factors such as "the spectral distribution of the color stimulus," "the size, shape, structure, and surround of the stimulus area," and the state of the observer's visual system and broader experience (p. 28). Another of these notes indicates that color is viewed in a variety of different modes, such as on an object, on a particular surface, via direct light, etc. Color is also viewed in a number of different circumstances or contexts, such as in daylight or cool white fluorescent light, alone or next to another color, before or after viewing another color or colors, etc. (Fairchild, 2011; Nassau, 1998). The mode and circumstances in which a color is observed greatly influences the way that color is perceived. There are essentially an infinite variety of ever-changing modes and circumstances, such that each instance in which color is observed is a unique event that cannot be completely duplicated (Committee on Colorimetry, 1953). In short, color is a highly complex perceptual experience that is an integrative product of

numerous characteristics of the physical stimulus, the observer, and the environmental surround.

Like *color, psychology* has been defined in myriad ways, and a definitive definition is elusive (Reber, 1995). Most definitions that have emerged over the years have focused on behavior and/or the mind. Thus, psychology has been declared the scientific study of the mind (James, 1890), the scientific study of behavior (Watson, 1919), or, most commonly in the present day, the scientific study of the mind and behavior (American Psychological Association (www.apa.org); Schacter, Gilbert, and Wegner, 2010). An intriguing variant of this latter definition is provided by Myers (2013), who, in his popular and influential introductory textbook, characterizes the purview of psychology as "describing and explaining behavior and the mind underlying it" (p. 10).

Both "mind" and "behavior" are vague terms that can carry diverse meanings. Throughout the history of scientific psychology, the dominant meta-theoretical orientation of the day has not only determined whether psychology was defined in terms of mind, behavior, or both, but has also determined the precise meaning of mind and/or behavior. The current meta-theoretical orientation is inclusive and integrative (Cacioppo, 2007), leading to broad definitions of mind and behavior that include affect, cognition, and action in their multitude of instantiations and levels of analysis. As both a natural and a social science, psychology encompasses physiological and biological, as well as intrapersonal and interpersonal, foci. These foci are studied under labels such as biology and brain, sensation and perception, consciousness, learning, memory, language and thought, intelligence, development, social-personality, stress and well-being, motivation, emotion, and pathology and disorder. Given its breadth of scope, it is no surprise that psychological science connects to many different disciplines of knowledge (Henriques, 2011). In fact, psychology has recently been identified as a "hub discipline" along with six other sciences (e.g., chemistry, mathematics, physics); a hub discipline is one that profoundly influences work being done in other scientific fields (Boyack, Klavans, and Börner, 2005; Cacioppo, 2007).

Color psychology sits at the intersection of color science and psychological science, and it is interesting to consider how color psychology is construed by (i.e., fits within) each of these disciplines. Within *color science*, color vision is usually conceptualized as a series of stages of processing, beginning with a light stimulus, moving through various transformative mechanisms and systems (e.g., the retina, the lateral geniculate nucleus, the subcortical structures, the visual cortex) until the final outcome, a color image, is produced (for details, see Stockman and Brainard, Chapter 3, and Gegenfurtner and Ennis, Chapter 4, in this volume). Color scientists commonly group these stages of processing into various categories, using labels such as "physical," "physiological," "psychophysical," and "psychological." The descriptions of these various categories of processing differ by theorist, such that the label "psychological," especially, is sometimes implicated relatively early in the processing sequence and is sometimes implicated quite late, even to the point of relegating it to conscious perceptual experience and beyond (e.g., Kuehni, 2012). With regard to "beyond," color science has focused on a broad spectrum of psychologically relevant topics and issues, albeit with a disproportionate emphasis on a rather narrow subset, such as color categorization, color symbolism and association, and color preferences.

We believe that color science would do well to integrate psychology more deeply and pervasively into the discipline. Three points may be offered in this regard. First, the domain of psychology includes rudimentary physiological and biological responses of the organism to encountered stimuli; thus, it seems prudent to implicate psychology quite early in the color-vision processing sequence. For example, it seems reasonable to consider the response of the cone photoreceptors

to the image formed on the retina as a psychological process, if not the formation of the retinal image itself. Second, although describing color vision as a sequential transformative path in which a light stimulus is passed from one discrete stage to the next (akin to passing a baton in a relay race) is helpful for didactic purposes, it is important to remember that this model is heuristic and simplistic, and is not meant to be technically accurate (Conway, 2012). Color processing takes place across multiple stages simultaneously, undoubtedly crossing, and therefore blurring, the boundaries of physical, physiological, and psychological (no matter where these categories have been placed in the processing sequence). Third, processing at any and all stages of the sequence is influenced by higher-order psychological processes based on gender, culture, development, and even the viewer's expectations and experience (Conway, 2012). Thus, not only can color perception influence affect, cognition, and action, but also the psychological state of the observer can influence the way in which the basic mechanisms of the eye process light stimuli (Bubl, Kern, Ebert, Bach, and Tebartz van Elst, 2010; Hyett and Parker, 2013).

From the standpoint of *psychological science*, it is rather easy to discern where color fits: color is a core aspect of visual perception; therefore, it fits nicely within the "sensation and perception" category of psychological study (as may be seen in any introductory psychology textbook). As such, nearly all aspects of color-vision processing (including the rudimentary transformation of retinal images by cone photoreceptors), and its implications for affect, cognition, and action would clearly and unequivocally fall under the purview of color psychology. This stated, much like color science, psychological science has tended to focus disproportionately on a subset of topics and issues (including the same set listed above regarding color science), although there has been a recent expansion of interest in the effects of color perception on psychological functioning in achievement, mating, marketing, and food and beverage consumption contexts (Elliot and Maier, 2014). Psychological effects on color perception have received only a modicum of attention to date, but this is clearly an area that warrants extensive conceptual and empirical attention. Indeed, it is here, perhaps more than anywhere else, that the benefits of fully and deeply integrating knowledge from the color science and psychological science disciplines become most plainly evident.

A reading of the table of contents for this *Handbook* reinforces our statement that color psychology is a broad and rich area of inquiry. Part II covers the basic foundations of color science, including color models and systems, the fundamentals of color-vision processing, the evolution of color vision, and core ontological and epistemological questions about the concept of color. Part III covers the development of and differences in color vision, focusing on the early development of color vision, aging and color vision, individual differences in color vision, and deficiencies in color vision. Part IV covers color categorization – namely, the universality and cultural specificity of color categorization, the development of color categorization, and the semantics of color terminology in language. Part V covers color symbolism and association, focusing on early color symbolism; color in tradition and folklore; the use of color in camouflage, mimicry, and warning signals; emotional associations with color; and the use of color in metaphor. Part VI covers color preferences, specifically, learned and inherent sources of color preferences. Part VII covers the influence of color on psychological and biological functioning, addressing links between color and selective attention, color and mating (in humans and other animals), color and performance (in humans and other animals), color and face perception, color and flavor, and non-visual effects of colored light. Part VIII covers the influence of psychological functioning on color perception – namely, memory and emotion

effects on color perception. Finally, Part IX covers various color phenomena, including visual illusions and color-based synesthesia.

In creating this *Handbook*, we have worked diligently to acquire chapters from the very best theorists and researchers currently working within the area of color psychology. These scholars have, without exception, contributed stellar, state-of-the-art overviews of their focal topic for inclusion in the *Handbook*. We envision the *Handbook* occupying a prominent, ready-to-reach location on our bookshelves. We sincerely hope that our readers also find it an important and inspiring source of information and ideas on this most fascinating of topics – *color psychology*.

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Part II
Foundations: basics of color science

2 Color models and systems

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Introduction / overview

Color is one of the most ubiquitous, and often least-well-understood, phenomena in human experience. While, at its root, color is a deeply personal and profound experience, humans have long had the desire, perhaps obsessive, to define it, reproduce it, fabricate it, and control it. This chapter attempts to slightly clarify the mysteries of color by reviewing the technical definitions of color attributes necessary for consistent scientific discourse, and the main classes of color specification that are commonly used in color science and engineering. These definitions and specifications are the foundation of all color science. Fundamentally, though, we must all remember that color is a perception.

Color appearance terminology

It is often helpful to start with a picture, even if it only approximates to the phenomenon in question. Figure 2.1 is just such a picture. It shows a single physical stimulus presented on a gray background at different relative luminance levels. When darker than the background, that stimulus appears as a deep brown, but when lighter than the background, it appears as a vivid orange. Given greater dynamic range to vary the background or the patch, the same stimulus can be made to appear a brilliant orange or a very dark brown (even black if the background becomes bright enough).

The demonstration represented by Figure 2.1 illustrates many aspects of color stimuli and color appearance that require clear, consistent definition. Simply put, the color "brown" is orange in hue and low in lightness and chroma while the color "orange" has the same hue with high lightness and chroma. Another way to put it is that the same physical stimulus can appear "orange" or "brown," and this illustrates that color is a perception (not a physical attribute of a stimulus) and requires careful definition. The definitions below come from the CIE (International Commission on Illumination) *International Lighting Vocabulary* (CIE, 2011) and are reviewed in more detail in Fairchild (2013). The CIE is the international standardizing body responsible for all technical and scientific standards and recommendations related to light and color.

Color, related, unrelated

The definition of the word *color* itself provides some interesting challenges such as trying to write a definition of the word that does not contain an example of the perception. The current standard is as follows:

> *Color*: characteristic of a visual perception that can be described by attributes of hue, brightness (or lightness), and colorfulness (or saturation or chroma).

The authors of this definition were well aware that the perception of color is not a simple matter and added notes that capture this by saying, among other things, that "perceived color depends on the spectral distribution of the color stimulus, on the size, shape, structure, and surround of the stimulus area, on the state of adaptation of the observer's visual system, and

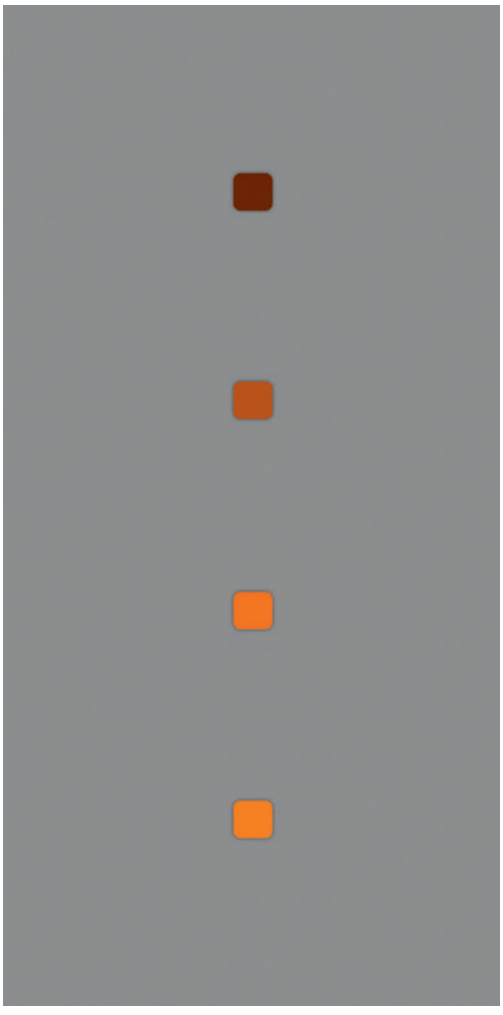

Figure 2.1 Illustration that the same physical stimulus (defined by spectral curve shape or chromaticity) can appear orange or brown depending on its viewing environment and luminance relative to the background.

on the observer's experience of the prevailing and similar situations of observation." Despite the difficulty in defining color, the various attributes of color can be defined much more precisely, and those are the terms that are of utmost importance in color science.

An important distinction in color stimuli that is often forgotten, but critical for understanding appearance is that between unrelated and related colors:

Unrelated color: color perceived to belong to an area seen in isolation from other colors.

Related color: color perceived to belong to an area seen in relation to other colors.

Almost every color-appearance application of interest deals with the perception of related colors. However, it is noteworthy that many visual experiments that provide the foundations for understanding color vision were performed with isolated stimuli. Sometimes, related colors are thought of as object colors and unrelated colors are thought of as self-luminous colors. There is no correlation between the two concepts. An object color can be seen in isolation, and self-luminous stimuli can be seen in relation to one another.

There are various phenomena that only manifest themselves for related or unrelated colors. One interesting example is the perception of colors described by certain color names such as gray and brown (e.g., Figure 2.1). It is not possible to see unrelated colors that appear either gray or brown. Gray is an achromatic color with lightness significantly lower than white. Brown is an orange color with low lightness. Both of these color name definitions require specific lightness levels. Since lightness and chroma require judgments relative to other stimuli that are similarly illuminated, they cannot possibly be perceived as unrelated stimuli. The perceptual color terms defined below are applied differently to related and unrelated colors. Unrelated colors exhibit only the perceptual attributes of hue, brightness, colorfulness, and saturation. On the other hand, related colors exhibit all of the perceptual attributes of hue, brightness, lightness, colorfulness, chroma, and saturation.

Six attributes of appearance

Six attributes of color appearance are required to fully specify the color of a stimulus. These are hue, brightness, lightness, colorfulness, saturation, and