Color Perception

Physiology, Processes and Analysis

Darius Skusevich
Petras Matikas
Editors

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COLOR PERCEPTION: PHYSIOLOGY, PROCESSES AND ANALYSIS

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COLOR PERCEPTION: PHYSIOLOGY, PROCESSES AND ANALYSIS

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AND

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CONTENTS

PREFACE

There is no color without light, nor is there color perception without a sensory organ and brain to process visual input. This book discusses the complex impact of color action on the organism. It is shown that the perception of color depends on the action of irritants on other sensor systems and, vice versa, the action of color may exert exciting or inhibiting influence on the perception of sounds or smells. The mechanism of increasing realism of colored images is also discussed, as well as the epistemic role of color. Furthermore, this book examines whether there exist very large individual differences in the perception of color, and if so how these differences manifest themselves. Other chapters in this book discuss the role of visual processing in the regulation of adaptive behaviors, a review of image denoising, and the role of color in psychological functioning (i.e., the unconscious associations people have with color that could act as possible confounds).

Chapter 1 - In order to investigate a possible role of visual processing in regulation of adaptive behaviors, two behavioral experiments using color stimulus were performed. In the first experiment, hemispheric asymmetry of color processing was investigated by measuring reaction time to a stimulus presented either in the left or the right visual field responded by ipsilateral hand. The simple reaction time was shorter to a color stimulus presented in the right hemisphere in the right-handed participants, while no hemispheric asymmetry was found in color discrimination reaction time without verbal cues. In the second experiment, a modulatory effect of color on sensory-motor interaction was investigated using a prepulse modulation task. Amplitude of a startle eyeblink response elicited by an air-puff to the cornea was significantly inhibited by a shortly (100 ms) preceding color prepulse. A different amount of the inhibition was induced by different color prepulses. Yellow was more effective as compared to a blue prepulse. Although the exact neuronal pathways underlying the prepulse inhibition of the corneal blink response is not determined, a top-down pathway from the cortex to the brainstem nuclei via the amygdala seems to be involved in the sensory-motor interaction. The descending pathway seems to play a role in modulation of the startle responses. From these findings combined with other studies, a dual processing hypothesis of visual inputs will be proposed, where physical features of the stimulus are processed in the cerebral cortex with consciousness, while the psychological and biological meanings are processed mainly in the limbic system without consciousness. Traditionally, it was thought that these two processes are in series, while in the present model these processes are in parallel, in addition to the serial processing. Visual inputs are conveyed to the limbic system via the indirect cortical and the direct subcortical pathways. The cortical pathway further divided into two routs; one is from the inferotemporal cortex and the other is from the posterior parietal association cortex through the pulvinar nucleus of the thalamus.

Chapter 2 - There are two basic approaches to studying color: one of them considers the issue of the physical reasons of color, the other investigates color perception. According to the first, color is not an objective physical entity; the second approach has many experimental evidences of color influence on human organism, for example, changes of the emotional condition, blood pressure, accuracy of perception, etc. The considered question can be formulated as follows: how color, being a sign without a referent, can make a real impact on the organism? A working hypothesis is that color is a non-conventional objective sign. This hypothesis will be subjected to critical analysis from the point of view of psychology of development in order to ascertain whether the sign properties of color are innate or are formed by the influence of culture. Another topic is a role of color in the world cognition. This question was usually considered from the point of view of direct influence on the increase of the visual recognition accuracy. We will investigate a question of indirect influence of color by means of pre-setting of the nervous system to perception; this is possible thanks to the system character of perception.

Chapter 3 - There is no colour without light, nor is there colour perception without a sensory organ and a brain to process visual input. This chapter first reviews how the colour of objects is produced. Most commonly, this depends on so-called pigments, the molecular nature of which provokes strong absorption of part of the incident light falling on an object. Colour can also be produced by optical phenomena such as refraction, dispersion, interference or diffraction from ordered structures within objects. A wide variety of photonic microstructures are known in the living world and specific examples will be described in mammals, birds, fish and insects. Some of these structures reflect light in the near ultraviolet spectral region, particularly pertinent for certain birds, insects and fish which are sensitive to these wavelengths. A detailed account of a particularly elaborate structure present in the king penguin beak will be given to illustrate the extent to which evolutionary pressure leads to the elaboration of such structures to satisfy specific needs of birds or animals. Subsequently, the perception of colour in man and animals and its biological significance is dealt with. For man, this will include a discussion of the symbolic meaning of different colours. In many species, especially birds, the colours of plumage and parts of the skin have an important survival function. Such biological colourations may fulfil the role of ornaments that determine mate choice and reproduction of the species, or signal good health, allowing individuals to secure and maintain territorial dominance. Colour perception may also have an underlying survival function in man, but more complex explanations are needed to relate perception to such a function. The colour of an object in the visual field is known to determine the way in which humans perceive relations between objects and their background, particularly which objects appear nearer. This suggests that colour perception is important in processing information about the physical structure of the world. The colour red plays an important role in this process, since it drives mechanisms of visual selection which attract attention to, or away from, objects in the visual field. Psychophysical studies of colour perception in both animals and man help to understand these complex processes. Finally, colour perception in man may contribute either to rewarding psychological sensations of warmth, comfort and safety or to aversive sensations of coldness and discomfort, sensations which can strongly influence individuals in their daily social interactions.

Chapter 4 - Since the formulation of the Young-Helmholtz chromatic theory in the 19th century, it has generally been accepted that human colour vision is trivariant, i.e., it is possible to match any colour stimulus by mixing three primary stimuli in appropriate proportions. This resulted in the definition by the International Commission on Illumination in 1931 of the standard colorimetric observer for fields of 2° only three years after the definition of the standard photometric observer known as the V_{λ} luminous efficiency curve.Much progress has been made in the knowledge of colour vision since then, in such fields as physics, physiology, genetics, biochemistry, neuroscience, and psychology. That is why it is perhaps the time to raise our level of exigency a step when it comes to characterizing a chromatic observer. The question we should ask ourselves is not whether that figure of the standard colorimetric observer represents the average of the population, because this can indeed be done with successive corrections. Rather it is whether there exist very large individual differences in the perception of colour, and if so how these differences manifest themselves. This is of course apart from observers characterized as defective.In this chapter, we review the state-of-the-art in this field, and present our own latest research results concerning this question.

Chapter 5 - Classically, different physical attributes of the visual stimulus were thought to be solved in parallel by interdependent neuronal populations conveying information from the retina to the parietal and temporal cortical areas. According to this assumption, while neurons in the dorsal areas of the visual system were mainly related to the analysis of motion and spatial information, those located at the more ventral positions were mostly associated to shape and color processing. However, although this functional segregation between visual areas has been supported for several decades, there is also strong experimental evidence suggesting an alternative task-driven view of the visual system. According to this more recent perspective, neuronal responses in cortical visual areas can be simultaneously dependent on more than one single visual attribute. As far as color perception plays a central role in visual recognition, it could be assumed that color-sensitive neurons would be also involved in the analysis of some other critical visual attributes. In agreement with this idea, it has been shown that V1 double opponent cells respond to edges defined not only by chromatic and luminance differences, but also by the orientation of their receptive fields. Furthermore, results from many electrophysiological and neuroimaging studies have also demonstrated that color-sensitive neurons in V2 and V3, modulate their responses depending on diverse physical attributes of the stimulus such as the stimulus direction, orientation, luminance and shape, revealing the simultaneous contribution of magno- and parvocellular inputs from the Lateral Geniculate Nucleus (LGN) at different levels of the visual system. At higher visual areas, several authors have reported the existence of multi-sensitive neurons. Middle Temporal (MT) neurons, in the dorsal stream, are sensitive to motion spots defined by single or combined changes in texture and color. In the ventral stream, responses to both, color and orientation have been described in V4 and the inferotemporal cortex. Additionally, results from several studies blocking the magno- and parvocellular projections from the LGN to V4 have shown that these two channels can simultaneously contribute to neuronal responses at this level of processing. All these data evidence that even sharply-color-tuned neurons can show color-related responses modulated by many other visual attributes.

Chapter 6 – Colour composition divides colours into two types: unitary and binary colours. Colours which are not composed are said to be “unique” or “unitary” colours, whereas composed colours are always binary. Colour composition and the distinction between unitary and binary colours have played a major role in colour science and in the philosophy of colours. They have for example been invoked to introduce opponent-processes in the mechanisms underlying colour vision and have been used to criticize philosophers who defend a physicalist view on the nature of colours. Most philosophical or scientific theories suppose that colour composition judgments refer to the way colours appear to us. The dominant view is therefore *phenomenalist* in the sense that colour composition is *phenomenally* given to perceivers. This paper argues that there is no evidence for a phenomenalist view of colour composition and that a conventionalist approach should be favoured.

Chapter 7 – Image restoration has been a classical and significant topic of image processing, which refers to the techniques to reconstruct or recover an image from distortion (e.g. motion blur and noise) in different applications, such as satellite imaging, medical imaging, astronomical imaging, and family portraits. For motion blur, *image deblurring* techniques are used to estimate the actual blurring function and "undo" the blur to restore the original image. In cases where the image is corrupted by noise, *image denoising* methods are employed to compensate for the degradation the noise caused. In the past two decades, image denoising has been a fundamental and active research topic and widely used as a key step in a variety of image processing and computer vision applications, such as image segmentation, compression, object recognition, and tracking. This chapter focuses on image denoising, specifically for color image denoising and the application to color photo denoising.

Chapter 8 – Psychology is a discipline that prides itself on being an empirical science. As such, rigorous statistical and methodological controls must be used to ensure the validity of every result. Ostensibly, each submission for publication is peer reviewed, and needs to be replicated by other scientists in other locations to confirm or disconfirm the results. This is how a scientific discipline must operate if it wishes to produce meaningful, accurate results. When a discipline strays from these procedures, it leaves itself open to criticism and more importantly, to the possibility of inaccurate or misleading conclusions. All research needs to ascribe to these standards, regardless of how time consuming, inefficient, or difficult they may be.

One area of research that has failed to live up to these standards is the study of color and psychological functioning. The aesthetic property of color may at first consideration make it seem like a trivial topic for study, but recent research indicates exactly the opposite. Color has been shown to influence affect, cognition, and behavior. The degree and type of influence has varied from study to study, some more psychologically consequential (e.g. color and performance) than others (e.g. shoe color preference). None of these results, however, can be considered valid if they fail to live up the methodological rigors of science.

An in depth examination of the color research of the past and present makes it clear that most of the work fails to meet scientific standards. Too many studies have failed to take into account the three basic properties of color. Others have failed to consider the unconscious associations people have with color that could act as possible confounds. Stated differently, color used in an experiment may affect the experiment's dependent variable in unwanted and unaccounted for ways. In either case, it is impossible to draw meaningful conclusions from these studies, as their results could be due to any number of variables. This is the primary argument that will be made throughout this chapter. The aim is not to criticize or demean the existing research or researchers. Rather, it is hoped that this analysis will lead to more systematic, scientifically valid empirical work on color psychology. By learning about and avoiding the mistakes documented in this chapter, researchers will be able to meaningfully add to the growing body of work in on color psychology.

Chapter 9 - Carotenoids are widely used in aquaculture to achieve natural coloring of salmon flesh, improvement of trade quality (color) of sea urchin roe and in aquaculture of Crustaceans.For salmon, it has been found, that the relationship between pigment content and color parameters is complex and nonlinear. Nevertheless, there is an evident correlation between the total concentration of carotenoids (mainly astaxanthin) and the red, most valued by consumers, color of a muscular tissue of salmon (i.e. the higher the pigment content the better). Assimilation of carotenoids in salmon usually does not exceed 10-15 per cent, and cost of astaxanthin makes up about 6-8 % from the cost of filleted fish. Thus, researches in this field are directed on improvement of feed composition increasing of carotenoid assimilation and search of new sources of these pigments; optimization of processing and storage conditions of production, allowing keeping natural color. Ability to reach desirable color of roe is crucial condition for commercial echinoculture. A number of studies were devoted to developing of composition of artificial feed giving desirable color characteristics. Considering macroalgae, the best results have been reached with species of Laminaria, Alaria, Palmaria, and Ulva. It has been proved great significance of carotenoids as essential micronutrients for sea urchin aquaculture. A promising source of carotenoids in aquaculture may be microalga Duneliella salina. Carotenoid content correlates with redness of the gonads, but unlike salmon, for sea urchins there is a certain optimum of the pigment concentrations in gonads, excess or, on the contrary, lack of the pigments lead to falling into less desirable for customers color grades.

Chapter 10 - A common problem among social scientists who group all members of a race/ethnicity together is that they assume that all of the life experiences of those individuals are the same, and thereby, overlook the prevalence of heterogeneity within ethnicities. One such example is a global phenomenon present in all cultures where there is skin tone variation—colorism. This longstanding ideology which suggests preference within ethnic groups is closely linked with skin color is often ignored. Recent research, however, has found that among Blacks, lighter skin has major implications in the job selection process—where one is better off if he/she is lighter-skinned. Due to issues of attractiveness and general levels of comfort, individuals tend to feel a lighter-skinned black is more competent or less threatening, respectively. Though many companies are now concentrating efforts on enhancing diversity—with race being one of the primary focuses—one has to wonder if these "advancements" in diversity are resulting in more lighter-skinned Blacks being hired over their equally-qualified darker-skinned counterparts. This research commentary intends to look broadly at the executive boards of corporate America to investigate if this "lopsidedness" is indeed present. It is expected that greater numbers of light-skinned Blacks will be found in these positions, which will support prior research and illustrate the need for greater discussion and future research regarding this very issue.

Short Communication 1 - In outer space habitats, where the weightlessness and isolation deeply influence human life**,** color perception, processing and reaction to color are subjects for analysis in Human Factors investigation. The "µgOrienting" project aims to improve the life quality in outer space by research on colors and other visual stimuli.

Short Communication 2 - In microgravity under weightlessness conditions, where 'Up' and 'Down' have no meaning, orientation is of primary importance. Instinctual reactions to color and symbols are investigated in the WIUD experiment to help implement Up and Down orientation in Outer Space Habitats.

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Chapter 1

CORTICAL AND SUBCORTICAL PROCESSING OF COLOR: A DUAL PROCESSING MODEL OF VISUAL INPUTS

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ABSTRACT

In order to investigate a possible role of visual processing in regulation of adaptive behaviors, two behavioral experiments using color stimulus were performed. In the first experiment, hemispheric asymmetry of color processing was investigated by measuring reaction time to a stimulus presented either in the left or the right visual field responded by ipsilateral hand. The simple reaction time was shorter to a color stimulus presented in the right hemisphere in the right-handed participants, while no hemispheric asymmetry was found in color discrimination reaction time without verbal cues. In the second experiment, a modulatory effect of color on sensory-motor interaction was investigated using a prepulse modulation task. Amplitude of a startle eyeblink response elicited by an air-puff to the cornea was significantly inhibited by a shortly (100 ms) preceding color prepulse. A different amount of the inhibition was induced by different color prepulses. Yellow was more effective as compared to a blue prepulse. Although the exact neuronal pathways underlying the prepulse inhibition of the corneal blink response is not determined, a top-down pathway from the cortex to the brainstem nuclei via the amygdala seems to be involved in the sensory-motor interaction. The descending pathway seems to play a role in modulation of the startle responses. From these findings combined with other studies, a dual processing hypothesis of visual inputs will be proposed, where physical features of the stimulus are processed in the cerebral cortex with consciousness, while the psychological and biological meanings are processed mainly in the limbic system without consciousness. Traditionally, it was thought that these two processes are in series, while in the present model these processes are in parallel, in addition to the serial processing. Visual inputs are conveyed to the limbic system via the indirect cortical and the direct subcortical pathways. The cortical pathway further divided into two routs; one is from the inferotemporal cortex and the other is from the posterior parietal association cortex through the pulvinar nucleus of the thalamus.

1. INTRODUCTION

Color is one of attributes of an object. However, color does not belong to the object itself, but is produced in the organism that receives it. Indeed, sight of mono- or dichromatic observers is so different from normal trichromatic sight. It is well known that a black and white stimulus can produce color sensation if it is presented in a certain spatio-temporal arrangement. Benham top is a famous example showing that color does not belong to the physical object itself, but depends on physiological and psychological events, which are produced in the visual system (Newton, 1672).

Color processing is a function of the visual cortex (Zeki, 1991; Corbetta et al., 1991; De Valois and De Valois, 1993; Ungerleider and Haxby, 1994). However, little is known about the hemispheric difference of the color processing. Moreover, there are few studies that examined functional meanings of color information. In the present study, two experiments were undertaken to answer these questions; one examined the hemispheric dominance of color processing, and the other examined the effect of color on modulating a startle reflex in normal human subjects.

Results of these experiments will clearly demonstrate that the right hemisphere has superiority in color detection in right-handed participants, and that color information modulates a startle reflex by a subcortical pathway to the brain stem, presumably via the limbic system. From these results and related findings, I propose a new hypothesis that the sensory inputs, in general, are analyzed and processed in two evolutionary different systems (limbic and neocortex) to elicit adaptive behaviors to maintain homeostasis of the organism. A visual stimulus, including color, is processed in two systems in parallel; one is a modality specific visual system and the other is a non-specific limbic system. In detail, local physical features of the stimulus are processed in the former system with consciousness, while the global psychological and biological meanings are processed mainly in the latter system without consciousness.

These two systems are in parallel in nature, with some interactions, and the outputs of the former system are transferred to the latter system.

2. EXPERIMENT 1: HEMISPHERIC ASYMMETRY IN COLOR PROCESSING

2.1. Background

2.1.1. Anatomical Asymmetry of Brain

Bilateral asymmetries have been found in the human brain—larger right than left prefrontal and larger left than right occipital lobe volume (Foundas et al., 2003). Asymmetry has been also reported in several subcortical structures. Amygdalar and hippocampal volume measurements indicate a right-greater-than-left asymmetry for right-handed normal participants (Jack et al., 1989; Szabo et al., 2001). These structural asymmetries suggest functional lateralization of various cerebral functions.

2.1.2. Hemispheric Lateralization of Cerebral Functions

It has been suggested that the left hemisphere plays an important role in linguistic and higher order cognitive processes, such as self recognition (McFie et al., 1950; Conway et al., 1999; Turk et al., 2002), whereas the right hemisphere is responsible for visuospatical perception and facial recognition (Kimura, 1969; Gazzaniga and LeDoux, 1978; Sergent et al., 1992; Haxby et al., 1994; Kanwisher et al., 1997; Barton et al., 2002; Corballis, 2003).

Several researchers have postulated lateralized function to each hemisphere. The right-hemisphere functions were referred to as "visuospatial," or "constructional" (Sperry, 1982). It has also suggested that the right hemisphere is specialized for the analysis of global-level information, and serves as an anomaly detector, while the left hemisphere tends to create a "story" to make sense of the incongruities (Ramachandran, 1998; Smith et al, 2002). Levy (1969) studied an organizational differentiation of the hemispheres for perceptual and cognitive functions and supposed that the left hemisphere is specialized for analytic and the right hemisphere is specialized for integrative processing. In addition, the left hemisphere is specific in logical processing, while the right one has superiority in emotion, music and holistic processing (Levy, 1969; Ladavas et al., 1984; Magnani et al., 1984; Patel et al., 1998). Little is known, however, about hemispheric asymmetry in color processing. In the first experiment we examined the hemispheric lateralization of color processing.

2.1.3. Hemispheric Asymmetry Using Reaction Time

Lateralized function in the cerebral hemisphere has been studied by using several methods, such as a same-different comparison task (Hannay, 1979), a list-learning procedure (Berry, 1990), tachistoscopic presentation (Malone and Hannay, 1978) and reaction time (Davidoff, 1976). These different methods reveal the different features of the cerebral function. However, the input information presented to either one of the hemispheres immediately transfers to the other hemisphere via the commisure fibers. The interhemispheric transfer time is estimated from 2 to 6 ms (Poffenberger, 1912; Berlucchi et al., 1971; Brizzolara et al., 1994; Brysbaert, 1994). Therefore, in order to detect a difference in the processing time between two hemispheres, a method with high time resolution should be used. The reaction time task has an advantage that it is sensitive to analyze the difference in time for information processing in the hemispheres.

2.1.4. Reaction Time Task Based Upon Double Crossed Projections

The optic nerve fibers originating from the nasal retina project to the contralateral visual cortex, while the others from the temporal retina project to the ipsilateral visual cortex, and the right motor cortex innervates the left hand and the left one innervates the right hand. Hemispheric dominance in color processing can be evaluated by using a reaction time task based upon these double crossed projections of the visual and pyramidal pathways features in human participants (Poffenberger, 1912; Berlucchi et al., 1971).

2.2. Experiment 1-1: Reaction Time Difference by Dominant and Non-Dominant Hands

2.2.1. Purpose

Hemispheric asymmetry can be evaluated based on the difference in reaction times to lateralized stimuli presented either in the left or the right visual field, and responded by the ipsilateral hand (Fig.1). The first experiment was designed to evaluate a difference of reaction times between the dominant and non-dominant hands using achromatic targets presented at the center of the visual field. The results of this experiment will serve as a control for difference of reaction time by different hand.

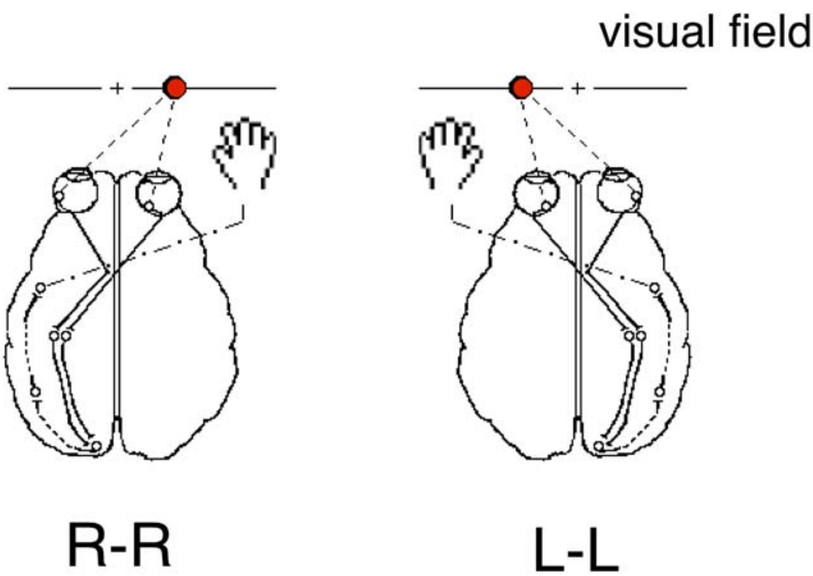

Figure 1. Schematic representation of experimental conditions used in Experiment 1. Reaction time was measured to a target presented in the right visual field by the right hand (R-R, left hemisphere) or the left visual field by the left hand (L-L, right hemisphere).

2.2.2. Methods

2.2.2.1. Participants

Ten right-handed undergraduate students (3 males and 7 females) with normal or corrected normal vision (mean age 19.5 years, SD 2.7) participated in the first experiment. Most of the participants were selected from ten groups of eight subjects each in a preliminary experiment, because they showed the smallest variability and the shortest reaction time in each group. In the preliminary experiment, thirteen simple reaction times to color stimuli (either red, green, blue or yellow) presented at the center of a cathode ray tube (CRT) display were recorded. No 'ready' signal was used in the preliminary experiment. All the participants were naive to this kind of behavioral experiment and the experiments were performed with the consent of each participant.

2.2.2.2. Apparatus

An achromatic solid circle with a diameter of 2 deg (x = 0.283, y = 0.320, CIE) was presented on a CRT display (Panasonic TX-D7P35-J, Japan, with a resolution of 800 x 600 dots at 60 Hz, 9300K). The luminous intensity of the target was 12, 14, or 18 cd/m^2 with a uniform gray background of 10 cd/m^2. The CRT display was placed at a distance of 57 cm from the participant's eye. All the visual stimuli were generated using a graphic generator (VSG Series Three, Cambridge Research Systems Ltd., England).

Reaction time was measured using a programmable logic controller (Keyence KV24AT, Japan). The experiments were automatically controlled by a computer (Power Macintosh 7300/180, Apple), using a hand-made program (HyperCard, Apple) and a serial/parallel interface.

Electro-oculogram (EOG) was recorded from two small electrodes with a diameter of 5 mm placed 2 cm above or below the lateral edges of right and left eyes. The signal was amplified with a time constant of 1.5 sec and with a high-cut filter at 60 Hz (Nihon Kohden, EEG-4316, Japan) and was recorded on a computer (Power Macintosh 7100/80AV, Apple) after being digitized at 400 Hz (MacLab, AD Instruments, Australia). If the amplitude of EOG exceeded 50 μV, which corresponded to an eye-movement of 3 deg in the visual angle, or if an eye blink occurred at the time of stimulus presentation, the trial was omitted from later analysis. In addition, trials with reaction times longer than 400 ms were omitted from later analysis. Thus about 10 % of the trials were omitted as error trials.

2.2.2.3. Procedures

Participants were seated in a sound-attenuated chamber, facing the CRT display. The participant's head was loosely restrained by using a chin rest, and the participant was asked to fixate at a small cross (0.5 deg, 0.5 deg) at the center of the CRT. An auditory 'ready' signal preceded the onset of the target stimulus by 1-4 sec (mean 2.5 sec), and the delays were delivered in a quasi-random order (Fig. 2).

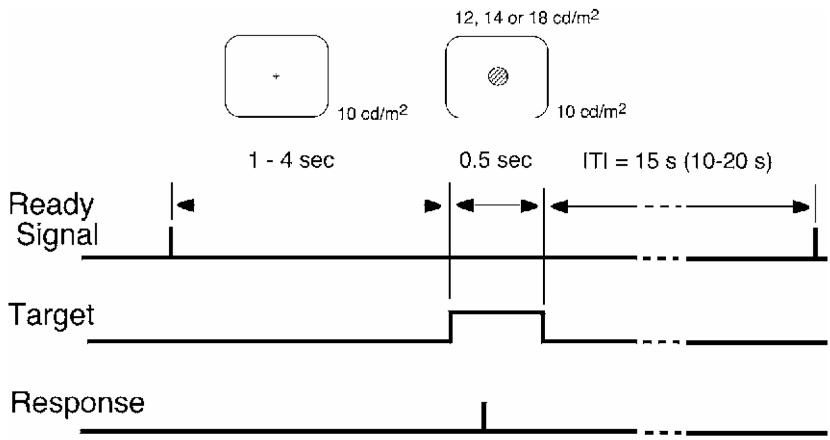

Figure 2. Schematic illustration of the time schedule for Experiment 1-1. A trial started with an auditory ready signal preceding 1-4 sec with a mean of 2.5 sec. A target was presented for 0.5 sec at the center of the CRT, where a small cross was presented as a fixation point. A total of 15 trials were performed with an intertrial interval of 10-20 sec with a mean of 15 sec. The target was a gray circle with a diameter of 2 deg at either12, 14 or 18 cd/m^2 with a gray background of 10 cd/m^2.

Two blocks of experiments were performed with an inter-block interval of about 5 min. In each block, participants were required to press the key as quickly as possible to each stimulus presented at the center of visual field (Fig. 3). Before starting each block, participants were instructed which hand to use and the order of hands used were randomized among the participants. Each block consisted of 15 trials with a randomized intertrial interval of 15 sec ranging from 10 sec to 20 sec. The median reaction time was calculated for each block for each participant. The mean value was then obtained for each condition (right or left hand).

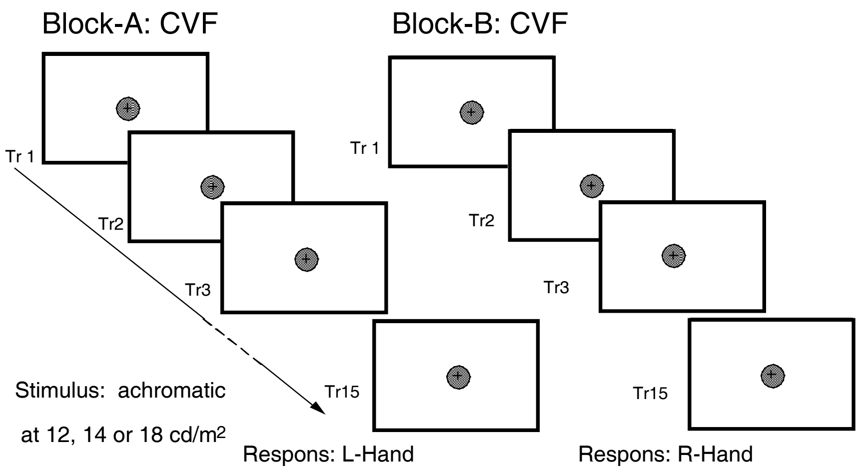

Figure 3. Schematic drawing of the procedure for Experiment 1-1. Two blocks, each consisting of 15 trials, were performed, using three different luminance stimuli (12, 14 or 18 cd/m^2) each for 5 trials. For both block-A and block-B, target was presented at the center of visual field (CVF). Response was made by the left hand (L-Hand) for block-A, and by the right hand (R-Hand) for block-B, respectively. Order of the blocks was randomized for each individual. Which block was performed had been informed before starting each block.

2.2.3. Results

There was no significant difference between the reaction times by the dominant (right) and non-dominant (left) hands (Fig. 4). Figure 5 shows reaction times by the dominant and non-dominant hands to three target luminance (12, 14 and 18 cd/m^2). Reaction time decreased gradually as a function of stimulus intensity. For both dominant and non-dominant hands, however, there was no significant difference between the reaction times of the right and left hands in any luminance condition. Similar results were obtained for the mean of these three luminance conditions, shown at the extreme right column in Fig. 2 (12-18 cd/m^2). Statistical analysis using analysis of variance (ANOVA) showed that only the effect of luminance was significant ($F(2,18) = 5.854$, $p < 0.01$), and both the effect of hands and the interaction between these two factors were not significant ($F(1,9) = 0.019$, N.S., $F(2,18) = 0.550$, N.S., respectively).

2.2.4.Discussion

The results of Experiment 1-1 show that the dominant hand has no advantage over the non-dominant hand for the simple reaction time task, in which triggering simple hand-movement-initiation is required. This finding is well consistent with previous studies (Hayes