幼童的色彩知覺及其認知發展的關係探討

The Relationships Between Young Children's Color Perception and Their Cognitive Development

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摘要

許多研究成果指出幼童對色彩資訊的感知及處理方式和他們自身的認知發展有很強烈的關聯性。在本篇文章中，作者旨在調查並闡述有關幼童色彩知覺的研究以說明幼童如何感知及處理色彩資訊。其他相關的研究項目，如幼童的色彩視覺、色彩命名的困難性、視覺區域和性別差異的關係、色彩知覺與認知發展的關聯性、視覺感知的研究技巧等亦在此篇文章中有所論述，以幫助讀者對此方面之研究有更深入的了解。最後，作者強調如何應用有關幼童色彩知覺研究成果的重要性，因為如此作才能促進幼童的認知發展，尤其對具不同學習障礙的幼童們更有助益。

Abstract

Research findings demonstrate that the way how a young child perceives and processes color information is strongly associated with their cognitive development. In this paper, studies on young children's color perception are reviewed and discussed to help shed some light on how young children perceive and process color information. Other research issues, such as young children's color vision, color-naming difficulty, visual field and gender difference, color perception and cognitive development, and research techniques in visual perception are also introduced to ensure that readers have a more in-depth understanding. Finally, the application of research findings on young children's color perception is emphasized because by so doing we may be able to facilitate young children's cognitive development, especially those who suffer from various types of learning deficits.

關鍵字詞

幼童Young child　　色彩知覺Color perception
認知發展Cognitive development　　性別差異Gender difference
色彩命名Color naming　　色彩配對Color matching
研究技巧Research technique

I 、Introduction

Color is one of the most essential visual features encountered by humans in the daily life. Research evidence suggests that all humans, despite of their age differences, prefer to perceive colorful visual stimuli rather than black and white information. For example, Adams (1987) demonstrates that newborns, 3-month-olds, and adults all prefer to look at the chromatic visual stimuli over the achromatic ones. Furthermore, color also plays an important role in young children's cognitive development. As a matter of fact, research evidence has shown that young children's color perception and their cognitive development are strongly interrelated and that we may be able to assess young children's cognitive development by investigating how they process color information. In other word, young children's abilities to perceive color information can be used as an index of their cognitive development (Bernasek & Haude, 1993). Many research studies uncover that children are able to perceive and discriminate different colors in their early infancy. For example, infants as young as four months old are capable of discriminating one color from another and recognizing when two colors are the same (Bornstein, Kessen, & Weiskopf, 1976; Catherwood, Crassini, & Freiberg, 1989). Research findings also reveal that infants possess perceptual color categories that seem to be exactly the same as adults' color categories (Bornstein et al., 1976; Teller, Peeples, & Sekel, 1978; Bjorklund, 1995).

Each human eye contains approximately 8 million cones and 120 million rods. Rods are sensitive to the full spectrum of visible light, but are not sensitive to colors. Even under a dim light environment, rods can respond to brightness but not to color. On the other hand, cones which have three different pigment types are only selectively sensitive to a certain range of wavelengths. The first type of cone pigment can respond maximally to the light of 440nm (1nm=10-9m) which is perceived as violet, the second type answers best to the light of 530nm which looks green, and the third type has its peak response to the light of 560nm which appears as yellow. Cones are responsible for detailed vision and color perception. In human eyes, the majority of cones are located in the central area of the retina close to the fovea, and most of the rods exist in the peripheral regions of the retina. There is primarily one type of rod in human eyes, and it offers its best response when stimulated with approximately 500nm of light. Providing shorter or longer wavelengths will cause a degraded response.

Newton (1704, 1952) argues that an object does not possess color itself, nor is the light reflected from this object colored. The reason why humans can perceive color is because objects selectively absorb and reflect different wavelengths of light which stimulate the human visual sensory system. That is, various wavelengths reflected from an object's surface are perceived as color by one part of the visual cortex, called the prestriate cortex. The perceived visual information is encoded as neural impulses and transmitted from the eyes to the brain. According to Hilz, Huppman, and Cavonius (1974), under normal circumstances, adult humans with normal color vision are very sensitive to color and can discriminate similar colors whose wavelength difference can be as small as 0.2nm. In addition, the light source is another crucial factor in influencing the way humans perceive color. More specifically, humans perceive color under the presence of light sources, and color cannot exist without the light sources. An object's color appearance depends on the strength of illumination as well.

II、Research on Young Children's Color Vision and Color Perception

Color vision, defined as the ability to discriminate between different stimuli on the basis of their spectral composition (Brown, 1990), is also the basis of color perception. The studies of human adults' color vision and color perception have been conducted for several hundred years. Nonetheless, research on young children's color vision and color perception is still in its early stage. Before we try to understand how young children perceive colors, it is necessary for us to understand the current physiological and neurological research studies on young children's color vision. Current research studies on young children specify that many normal 2-month-olds and most normal 3-month-olds have demonstrated their capabilities in making chromatic discrimination; i.e., the distinction among different colors (Teller & Bornstein, 1983). Based on this finding, we may infer that 3-month-olds have possessed more than one type of photoreceptor (i.e., more than one type of cone cells) in their eyes' retina. It also implies that their color signals are carried by more than one postreceptoral neural mechanism (see Brown & Teller (1989) for a more detailed study on chromatic opponency in 3-month-old human infants).

Because infants cannot orally express their perception of color, it is more difficult for us to understand exactly how they perceive colors. Various direct and indirect measuring techniques have been developed to assist the generation of valid data. Why is the study of young children's color vision so important? This is because the study of color vision deficiency in adults has been used to diagnose possible diseases of the visual system. Therefore, it will be more accurate for the researchers to apply color vision in diagnostic testing in young children if the researchers know the course of their normal color vision development.

The research methods used in analyzing color vision and color perception of adults and young children are different. Generally speaking, color-matching experiments are conducted for adults because they can orally express their perception of different colors; e.g., which pair of colors being discriminated is different, and/or which color is brighter. On the other hand, the experiment to investigate young children's color vision is often conducted by a task called single-looking time method that measures their eye fixation duration on a particular visual stimulus. Color researchers infer that an young child who shows reliably different looking time to the stimuli of different spectral composition (i.e., different colors), but identical luminance, must possess color vision. This method can also be utilized in conjunction with a habituation task, in which the young child who is habituated to particularly chosen stimuli of one color can show dishabituation to stimuli of a different color only if s/he possess color vision (Brown, 1990). By using the habituation and dishabituation technique, color researchers are able to generate a more reliable conclusion regarding young children's color vision and color perception. For instance, research evidence shows that young children prefer to look at novel objects more than at familiar events (Banks & Ginsburg, 1985). However, many research studies also point out that the color discrimination of 3- and 4-week old human infants is very deficient (Harmer, Alexander, & Teller, 1982; Packer, Hartmann, & Teller, 1984; Varner, Cook, Schneck, MacDonald, & Teller, 1985). Moreover, Adams, Maurer, and Davis (1986) demonstrate color vision in newborn infants by utilizing the single-stimulus looking method, both with and without habituation. Their findings also suggested that newborn infants possess the color vision only good for long-wavelength stimuli, and that they lack color vision for short wavelengths. Based on these research findings, we may infer that newborn infants do possess color vision, but they cannot perceive colors as well as adults do. In order to generate more accurate research findings on young children's color perception, other different types of visual stimuli, such as contour, pattern, and texture, are often utilized in combination with color to investigate young children's visual perception, categorization skills, and cognitive development (see research conducted by Colombo, McCollam, Coldren, Mitchell, & Rash, 1990, and Younger & Cohen, 1986).

In addition to the single-stimulus looking method mentioned above, there exists another commonly used technique, forced-choice preferential looking method, which is also a type of eye fixation duration technique to be used to measure a young child's behavior and physiological responses after seeing some particular visual stimuli. Very often, an adult observer is required to participate in this type of experiment. Forced-choice preferential looking method incorporate the young child's looking behavior into a forced-choice experiment (Teller, 1979). The assumption is that if the adult observer can correctly guess the location of the stimulus more than 50% of the trials on the basis of the young child's behavior alone, we can infer that the young child can see the stimulus at least on some trials. The data generated from the forced-choice preferential looking method are a measure of the young child's visual preferences. However, there is a deficit in the forced-choice preferential looking method. Because it is possible that the young child did "see" the stimulus, but for some reason s/he failed to look at it, this method would fail to report that the young child saw the stimulus. Brown (1990) points out two crucial issues: one is about attentiveness; the other is the question of the young child's preferences; i.e., perhaps s/he demands a specifically salient or appealing stimulus to attract his/her gaze. This also suggests that the young child's perceptual threshold may be higher than adults'. Olson and

Sherman (1983) also claim that the reliability of a looking time difference can be enhanced by employing a (dis)habituation test. That is, looking time can be measured as similar habituating stimuli are repeatedly presented until the time for each presentation diminishes to half of its original duration. After that, a different test stimulus is presented. If the stimulus is novel to the young child, the dishabituation is supposed to occur and the looking time should increase. More specifically, from the young child's looking behavior if s/he demonstrates that a test stimulus is novel, s/he must have discriminated the difference between the habituation and the test stimuli.

Ⅲ 、The Color-Naming Difficulty Among Young Children

It is well known that young children experience tremendous difficulty in stating an appropriate color name when they are presented with a color stimulus, even though they may be effective in matching one color stimulus with another and may possess a good vocabulary of color terms (Davidoff & Mitchell, 1993). The young children's color-naming deficit is similar to the color agnosia neural deficits occurred among adults. Various research studies regarding young children's knowledge of color have been conducted to investigate this type of color-naming difficulty. For example, Au and Laframboise (1990) claim that young children's semantic domain of color names should have been well established by the end of preschool years. Similarly, Heider (1971) and Johnson (1977) also argue that the majority of 4-year-olds should possess the knowledge of a number of basic color names, such as red, green, yellow, blue, brown, orange, purple, pink, and gray. However, they may still encounter difficulties in learning non-basic color names, such as mauve and ecru (e.g., Andrick & Tager-Flusberg, 1986; Au & Markman, 1987). Bornstein (1985) also asserts that in average, 38% of 2.6-year-olds, 50% of 3-year-olds, and 56% of 3.3-year-olds know and can correctly apply four basic color names. Besides, these young children's color-naming abilities increase dramatically after 3.5 years; e.g., 71% of 3.6-year-olds, 72% of 4-year-olds, and 79% of 4.3-year-olds can name four colors. Research evidence also reveals that young children's color-naming difficulty is more obvious when they learn to state their first color term. Once they can overcome this barrier and successfully mention their first appropriate color name, it will then become easier for young children to state additional color names. Therefore, a young child's ability to name a color may increase as s/he grows older.

Exactly what causes this type of color-naming difficulty among young children is still under investigation. Soja (1994) proposes two possible explanations. The first explanation is that young children are equipped with only perceptual representation of color (i.e., being able to perceive color only), and they do not possess conceptual representation of color (e.g., being able to establish the associations between color and other objects) like most of the adults do. This possible explanation is called conceptual hypothesis. The second explanation is that young children do represent color conceptually but confine the kinds of allowable mappings between words and meanings. This implies that though young children cannot map color onto words, they still can map colors onto other objects. This explanation is called language acquisition hypothesis. So far, research findings are not sufficient enough to determine which hypothesis is more accurate. In fact, there exists evidence in favor of both hypotheses. For instance, Rice (1980) and Smith (1984) are in favor of the conceptual hypothesis, and Istomina (1963) and Cruse (1977) are in favor of the language acquisition hypothesis. However, an experiment conducted by Soja (1994) supports the language acquisition hypothesis. Soja claimed that young children who are not aware of color words do possess a conceptual representation of color. They can map objects (including words) onto color, and they can make inferences based on color as well. But young children are inhibited from making an inference about the meaning of a word on color. That is, young children can learn to understand that a word co-occurs with a color, but not that it refers to a color.

Ⅳ、Young Children's Color-Naming and Color-Matching Studies on Visual Field and Gender Difference

Research evidence shows that young children's color-naming and color-matching abilities are a function of their visual fields and gender differences, and studies on young children's color-naming and color-matching abilities can also serve as an index of their cognitive development (Bernasek & Haude, 1993). Neurological evidence indicates that the left and right hemispheres of the human brain are specialized for verbal and nonverbal (spatial) abilities respectively. Research conduced by Bryden (1990) demonstrated a very strong support in this aspect. Molfese, Freeman, and Palermo (1975) also claim that the normal human brain undergoes both structural and functional maturation throughout the infancy and early childhood, and that the onset of this lateralization may occur when children are two to three months old or possibly even earlier. After the lateralization process is complete, different hemispheres of the brain are responsible for different functions. Many research studies have been conducted to investigate the lateralization differences by means of color-naming and color-matching tasks. For example, Levy and Trevarthen (1981) conducted an experiment to test color-matching, color-naming, and color-memory in split-brain patients. In a color-naming task, they found that the accuracy measures were significantly higher when stimuli were presented in the patient's right visual field. This supports the theory that the left hemisphere considerably controls the verbal functions. They also reported that the left visual field is superior in color-matching task. This finding is consistent with the theory that the right hemisphere is associated with spatial functions. Furthermore, Tokar, Matheson, and Haude (1989) also report similar findings by studying lateralization differences for color-naming and color-matching tasks in normal males and females.

Another important issue about the lateralization differences is gender differences. Many research studies have demonstrated that there exist gender differences with respect to human verbal and spatial abilities as well as differences in the extent of lateralization. For instance, McGlone (1980) stresses that females surpass males in the area of language functions, such as speed of articulation, fluency, and grammar. In addition, Kimura and Harshman (1984) contend that females' mechanisms for speech appear to be more focally organized in the left hemisphere. McGee (1979) also argues that males tend to be superior on spatial tasks. Very often, the experiment conducted by utilizing color-naming and color-matching tasks are used to show the differences of verbal and spatial abilities between males and females. For example, Bernasek and Haude (1993) strongly argue that color is an adequate visual stimulus for the investigation of problems within the context of gender differences and thedifferences in lateralization among young children. In their

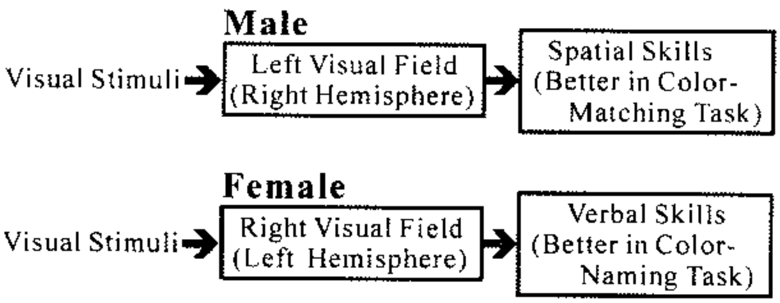

Figure 1. Gender differences in color-naming and color-matching tasks

experiment, they reported that boys matched more colors presented to the left visual field than girls, but fewer in the right visual field. These findings are consistent with Kraft's (1984) study which suggests that, in girls, spatial skills mediated by the right hemispheric function may develop more slowly than boys, and Levy's (1978) evolutionary-based theory which suggests that males are more lateralized and possess better visuospatial skills than females. Figure 1 summarizes these research findings in terms of visual fields and gender differences in color-naming and color-matching tasks (Chen, 1999).

V、Young Children's Color Perception and Cognitive Development

Research evidence indicates that young children's development of color sense is related to their ability to name colors, and their abilities to represent color information have also been found to increase with advancing age (Shukla & Misra, 1988). Based on this, it is clear that cognitive factors have a tremendous effect on young children's perception of color. That is, cognitive development is important in young children's abilities in color perception, identification, naming, and preference. For example, Gibson (1967) argues that young children's abilities to recognize similarity among a series of perceptually-related stimuli are thought to be quite relevant to their cognitive development. Research evidence also reveals that young children may encounter difficulty in naming a color, but they have less difficulty in categorizing colors. Therefore, we may infer that the development of young children's color categorization abilities is ahead of accurate color-naming abilities. Moreover, research evidence also suggest that young children's perception of color together with other cross-modal abilities are all related to brain functions, and these abilities reflect the degrees of their cognitive development as well. For example, Reardon and Bushnell (1988) argue that in addition to their demonstrated cross-modal abilities, young children are equipped to learn readily at least certain arbitrary bimodal correspondences, and these results in conjunction with other findings suggest the importance of motivational factors and potential biological significance in young children's cognitive development.

Other studies with respect to young children's cognitive development illustrated that they tend to focus more on concrete and observable objects than on abstract qualities (Adams, Maurer, & Davis, 1986). This may be due to the fact that concrete and observable objects are easier than abstract qualities to be represented in their perceptual knowledge. However, what is the relationship between young children's visual perception and their knowledge? Pillow (1989) conducted an experiment to investigate young children's visual perception as a source of knowledge. He found that 3- and 4-year-olds could correctly attribute knowledge or ignorance of a hidden object's color to themselves or another person on the basis of past perceptual experience. However, it is not clear whether 2-year-olds expect hiding and showing to influence another person's subsequent knowledge and behavior, but research evidence indicates that 2 and a half years old children appear to be competent at showing and hiding objects (Flavell, Shipstead, & Croft, 1978). In addition, Marschalek (1988) argues that the role of processing visual information in pictures is an important factor in tacit and implicit types of learning. In his experiment, he demonstrated that young children's memory about color increases in a linear fashion from grade 1 through grade 5. Therefore, the test of young children's memory (at least from grade 1 to grade 5) by using color perception can serve as an index to assess their cognitive development.

VI、Research Techniques Used in the Studies of Young Children's Visual Perception

Due to the fact that infants and very young children cannot orally or by any other means to express their perception of a particular object or a color stimulus, it is challenging for researchers to adequately measure the perceptual effects. Various direct and indirect research techniques have been developed to ensure that researchers can obtain the most accurate data when conducting the experiment on young children's color perception. Among these techniques, the eye fixation duration (indirect technique) and event-related potentials (ERPs) (direct technique) are two of the most important techniques to be employed in this type of study. Most researchers who examine young children's visual perception utilize eye fixation duration as a variable to assess their performance. The eye fixation duration technique is a kind of indirect measure. The major disadvantage of using eye fixation duration is that young children, especially infants, do not always focus on the target stimuli as the researchers plan; i.e., it is very likely that they can focus on anything within their visual fields instead of one particular visual stimulus. Therefore, the generated data may not be always reliable. In addition, the experiment using eye fixation duration technique is often measured by a third human observer. Though this indirect measuring technique has been proved with very high correction if the experiment was taped and validated by another person, it is still possible that the human error may occur and the measure of eye fixation duration may not be able to achieve the optimal validity and reliability from the experiment.

In addition to the traditional indirect measure of eye fixation duration to assess young children's visual perception, there also exist other neurological techniques which can facilitate the research on young children's visual perception and their cognitive development. More specifically, current neurological knowledge collaborated with specialized high-tech equipment can help the researcher obtain a more direct measure and provide a more in-depth understanding about young children's visual perception and cognitive development. Among these different neurological research techniques, the measure of event-related potentials (ERPs) can be utilized to examine the effects of young children's visual perception based on their brain activities. ERPs are transient voltage oscillations that occur in a young child's brain when responding to a discrete event. In addition to the easiness and quickness that ERPs can be recorded during an experiment, the ERPs can also provide multiple pieces of information about young children's information processing (Nelson & Collins, 1991). For instance, because ERPs are utilized to reflect the activity of a pool of neurons that are synchronously activated when responding to a particular visual stimulus (Donchin & Isreal, 1980), we can often infer that a greater ERP response is caused by involvement of a larger group of neurons. By measuring a young child's different brain areas, researchers are able to perceive which area is more sensitive to a particular type of visual stimulus, such as color, contour, pattern, and texture. In addition, cross-modal research can also be conducted by employing the ERPstechnique. Nelson and Collins (1991) emphasize two advantages of using the ERPs to provide an index of young children's perceptual processing. The first advantage is that ERPs can provide a better temporal resolution; i.e., ERPs assess the stream of perceptual processing as it actually occurs. The second advantage is that ERPs will not be contaminated by response selection and execution; i.e., ERPs will not confound the mechanisms controlling the ability to respond with what that response conveys about perceptual processing. ERPs can also be employed to examine young children's competence in dealing with different colors. For example, Shukla and Misra's (1988) study shows that young children encounter more difficulty in identifying green, orange, and brown colors than red, yellow and blue colors. By measuring the young children's ERPs, researchers are able to validate that young children's brain activities are more active when seeing red, yellow, and blue colors than green, orange, and brown colors.

Ⅶ、Applications and Conclusions

So far, most of the young children's visual perception studies on color are primarily concerned with constructing perceptual theories. Nonetheless, the application of these research findings is even more important. That is, the utilization of these useful research findings to facilitate normal young children's cognitive development, and to benefit those who suffer from different types of deficits, such as perceptual and learning deficits, should also be emphasized. For instance, dyslexic children encounter difficulty in recognizing letters. However, research studies suggest that color stimuli may facilitate their perceptual ability by improving their eyes' peripheral sensitivity. Holowinsky and Farrelly (1988) also conducted an experiment by comparing two groups of young children's visual memory: one group is educable mentally retarded, and the other group includes young children with average ability. They found that both groups performed better with a color than black-white card. Based on this finding, we know that color stimuli can enhance young children's visual memory even if the young children are mentally retarded. Therefore, colorful visual aids should be designed and utilized to facilitate the mentally retarded children's learning process.

In addition, Cameron, Brown, Carson, Meyer, and Bittner (1993) claim that there is a strong association between young children's creative thinking and color discrimination.

That is, color discrimination may be an important aspect of young children's cognitive development, of which the evolution of creative thinking is an integral part. Evidence shows that direct assessments of young children's creative thinking may yield stronger correlation between creativity and color discrimination than teachers' ratings of children's creative thinking ability. Though further studies need to be conducted to validate this argument, it may be very helpful to assess young children's creative thinking ability by using color discrimination task if this argument is true. Furthermore, Fleming, Holmes, Barton, and Osbahr (1993) argue that a young child's cognitive skills influence his/her perception of color, and perceptual development is important in the young child's color identification, naming, and preference. They want to demonstrate that color preferences can be discerned among young children in varying states of health. The findings indicate that color preferences may be a means to distinguish normal children from those who are acutely or chronically ill, and those who are well but have adjustment problems. Based on the above findings, studies on the young children's color perception and preferences may provide us a vehicle to detect problem children in the early stage and offer them a suitable treatment. Moreover, by understanding the color perception and preferences among young children of different ages, researchers may be able to recommend employing applicable colors on the design of young children's toys, books, and other educational devices to facilitate their perceptual and cognitive development. That is, objects which exist in young children's living environment can be modified and improved in light of research findings on their color perception in order to assist young children's cognitive development.

In summary, many research findings mentioned in this paper suggest that there is a strong relationship between young children's color perception and their cognitive development. We need to keep in mind that conducting the research on young children's color perception is not merely to collect a set of good data. The applications of what we have learned from the research findings to facilitating young children's cognitive development are even more important. As mentioned before, research on young children's color perception is still in its early stage, and many unclear issues are waiting for further exploration. The utilization of suitable research techniques can definitely lead us to a more correct direction in understanding young children's color perception. The author hopes that, in the coming future, more advanced research techniques can be developed as the progress of modern technology. Then researchers will be able to obtain a more in-depth understanding about young children's color perception and their cognitive development. Hopefully, more of the normal children and the children with deficits can benefit from this kind of research.

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人類的色彩視覺-平行視覺通路之探討

Seeing the Color - From Pigment to Perception

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摘要

可見光光譜中波長資訊的收錄是人類色彩視覺的開端，並且已知是屬於視網膜錐細胞的功能。無論如何，色彩知覺的產生並不單獨來自視網膜的神經信號，而高階的大腦皮質可能扮演更重要的角色。生理上與心理物理上的平行視覺通路已被證實由視網膜到大腦皮質傳遞不同的視覺訊息。心理物理上的證據顯示在色彩空間中有兩類不同的色彩信號可被加以區辨出來，而解剖學上的研究亦指出人類的視覺系統中存在著這樣的平行視覺通路。

Abstract

The encoding of the wavelength information of visible light spectra is the beginning of human color vision. This has been known to be a function of the retinal cones. However, the emergence of color perception is beyond retinal signals, and higher cortical areas play even more important roles. Parallel physiological and psychophysical visual pathways have been suggested to carry different visual signals from retina to cortex. Psychophysical evidences show that there are two kinds of color signals which can be specified in the color space, and recent anatomical studies also suggest these parallel pathways in human color vision.

關鍵字詞

色彩知覺color perception　　平行視覺通路parallel pathways
視錐刺激cone excitation　　色彩外觀color appearance

壹、引言

雖然視覺是大多數動物都具備的感官，色彩視覺卻是只有少部分動物才有的天賦特殊能力，而在哺乳類動物中也只有包括人類在內的部分靈長類動物具有看到色彩的能力。所謂色彩視覺所指的是視覺系統分辨可見光光譜中不同波長光線的能力；「彩虹七色」的現象便是可見光中不同波長光線產生色彩視覺經驗的直接例子。這種分辨不同波長光線的能力，在人類的視覺系統中是由視網膜上的視錐細胞(cones)加以收錄的。三類不同的視錐，分別對可見光中短波長域(SWS 視錐)，中波

長域(MWS 視錐),以及長波長域(LWS 視錐)的光線有較高的敏感度，而具有不同波長成份的光線會在這三類視錐系統上產生不同強度的訊號，從而使得視覺系統可以分辨不同波長的光線，進而產生色彩視覺。由SWS, MWS,以及 LWS 三種視錐構成的色彩視覺機制，提供了色彩學中的三色論之視覺生理基礎，可以圓滿解釋混色的現象與色彩配對(Color Matching)的實驗結果，為色彩美學與視覺生理學間搭起溝通的橋樑。

以視網膜上 SWS, MWS,與 LWS 視錐的機制為基礎的三原色論雖能解釋混色的現象，但仍未能給予色彩知覺現象完整的解釋。色彩知覺是指人類對色彩的主觀視覺感受，雖屬個人意識所覺知的一種現象，但仍可在其中歸納出許多人類普遍共同具有的穩定知覺經驗。獨特色調(Unique Hues)的現象指出在人類的色彩視覺中，對「紅」、「綠」、「黃」、「藍」等四個色調具有一種特殊的經驗。透過適當的色彩混合程序，人類可看到，知覺到具有這些色調的純粹色彩，不攙雜有任何其他顏色的知覺。例如獨特的紅色(unique red)，不帶黃色也不帶藍色的成份，無法用其他色調的形容詞來加以修飾。獨特色調的知覺現象與另一稱為「拮抗色彩」(Opponent Color)的知覺現象密切相關。人類知覺的色彩中，大部分的色彩均可用該四種具有獨特色調經驗的色彩來加以形容表達。比如說「帶有黃色的紅色」便可做為「橙色」(Orange)的另一種表示方法，但只要仔細觀察，便可發現「紅色」與「綠色」的知覺是無法並存的，也就是說，人類的視覺中不具有「既紅又綠」的色彩知覺經驗。同樣的現象也存在於人類所經驗到的「黃色」與「藍色」這一對色彩之間。這些現象說明了紅與綠，黃與藍構成了色彩知覺中兩對獨特的(unique)拮抗色彩(Pokorny, Shevell, & Smith, 1991)。

獨特色調的色彩經驗以及「紅綠」、「黃藍」色彩的拮抗現象，說明了人類的色彩視覺中存有兩個「平行的」視覺通路。平行視覺通路的概念認為視覺消息的處理是經由並存在視覺系統中的不同機制加以分析，同時分別分離出不同類別的視覺消息加以處理，最後形成人類所知覺到的視覺經驗。平行視覺通路不僅出現在色彩視覺消息的處理上，也存在於明度與色彩消息的處理上。在對人類視覺所進行的研究中，已有許多證據支持平行視覺通路的概念。而這樣的概念，不僅增進我們對視覺的了解，甚至可進一步提供我們發展表色、演色的工具，甚或選配色方法的基礎。

貳、平行視覺通路的生理與心理

在對人類視覺所進行的探索中，心理物理的研究指出視覺系統中存有明度與色彩的平行視覺通路，分別對由明度與色彩構成的視覺刺激反應。在實驗的測量中，明度調變的閃爍光(flicker)與色彩調變的閃爍光具有不同的反應曲線(Pokorny, Smith, Martin, & Valberg, 1990)，而明度差異構成的光柵圖形與由色彩差異構成的光柵圖形

也具有不同形狀的反差敏感涵數(Contrast Sensitivity Function)，說明了這樣的平行視覺通路之存在。

明度與色彩的平行視覺通路說明了明度與色彩的訊息似乎是由不同的機制加以分別處理。這樣的概念不單是由視覺心理物理的實驗中可以得到証實，也在視覺解剖與生理的研究中可以找到相對應支持平行視覺通路的構造。在人類視網膜上收集(pool)視覺細胞信號的節細胞(ganglion cells)，可由其細胞本體及樹突分佈範圍的大小與形狀加以區分成兩個系統，稱為大細胞系統(MC)與小細胞系統(PC)。大細胞與小細胞系統對各類視覺刺激的生理反應，與由心理物理所量測發現的視覺系統對明度與色彩刺激的反應分別具有相當程度的吻合，因此使得大細胞系統被視為是明度系統的生理機制，而小細胞系統則被視為是色彩系統的生理機制。

色彩與明度的視覺訊息已有許多研究說明是經由心理物理上的明度/色彩或是解剖生理上的大細胞/小細胞平行視覺通路來加以獨立的處理，但其實色彩視覺訊息處理的本身，也有類似且具備解剖生理基礎的平行視覺通路。負責收錄色彩的三種視錐中，SWS視錐所代表的是一個在演化上較古老的色彩視覺系統，功能上使得視覺系統得以區辨可見光光譜中由短波長到中波長的色彩(Casagrande, 1994. Dacey & Lee, 1994)。而MWS與LWS視錐則屬另一個在演化上較新發生的色彩系統，功能特別在區辨波長較550 nm長的波域之可見光色彩(Mollon, 1995)。色彩視覺的這兩個「次系統」(Subsystems)，也可稱為另一組平行視覺的通路，不僅是在解剖生理有存在的證據，也可在人類的色彩視覺表現中找到關聯的行為特徵。

參、平行色彩視覺通路的表現

SWS視錐系統與MWS/LWS視錐系統之間的關聯，可以在人類視覺的心理物理實驗測量中發現。當一個人類受試者注視著一個色彩調變的刺激一段時間後，視覺系統會因「適應」(adaptation)而使得隨後測量的色彩外觀產生變化。一系列的研究發現，當造成適應的色彩調變刺激是在SWS視錐敏感的方向上變化時，所測得的色彩外觀改變也只限於與SWS視錐刺激量相關的方向上的色彩。而同樣的結果也可在MWS/LWS視錐刺激量變化的軸上獲得(Mollon, 1995)。另一系列的研究，測量色度區辨(chromatic discrimination)的閾值，也發現SWS與MWS/LWS視錐閾值的變化是互相獨立的(Miyahara, Smith, & Pokorny, 1993)。這些結果都顯示了在色彩視覺中SWS視錐系統與MWS/LWS視錐系統是一對平行的視覺通路。

肆、平行視覺通路的效果

應用色彩視覺的平行視覺通路互相獨立的概念，科學家已據以建立了色彩座標

體系。在這樣的座標系統中，SWS視錐的刺激與MWS/LWS視錐的刺激被用以做為兩個獨立的軸，加以呈現此兩個獨立且平行的色彩系統所受的刺激量，稱為「視錐刺激空間」(Cone Excitation Space)(Smith & Pokorny, 1996)。

「視錐刺激空間」這個色彩空間上所標示的色彩之位置，與 CIE 的 (x, y) 色彩座標系統是完全可以直接進行數學轉換的。與一般通用的CIE 色彩座標系統相比較，「視錐刺激空間」具有視覺心理與生理上的重要性及理論根據，更能清楚表現具有重要理論意義的彩度變化。

SWS視錐系統與MWS/LWS視錐系統的差異特徵也可能在在色彩知覺的層次找到。S視錐系統所相關的知覺將可見光光譜中的光線分成冷-暖的色系。通常短波長為主要成分的光線對SWS視錐系統的刺激量較大，而其具有的色彩外觀也偏藍、綠的所謂冷色調。而以長波長為主要成分的光線則會呈現偏黃、等的暖色調、而MWS/LWS視錐系統則可區分光譜中呈現由綠到黃、紅等較長波長區域的色調，對於視覺系統在「紅花綠葉」之類的視覺環境中辨認物體扮演關鍵的角色。

伍、研究展望

色彩視覺中的SWS視錐與MWS/LWS視錐這兩個可稱為「平行視覺通路」的次系統，雖已在解剖生理上以及心理物理學的研究上得到證實，但其對於我們所知覺到的彩色世界，究竟有什麼樣的關聯，仍有許多未知的地方。在SWS視錐方向上變化的色彩，以及在MWS/LWS視錐方向上變化的色彩，在選配色方法的設計使用上，是否會產生不一樣的效果，仍是值得探究的地方。

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