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COLOR PERCEPTION IN THE CAPUCHIN MONKEY, *CEBUS APELLA*: A STUDY USING THE ISHIHARA TEST

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Introduction

The biological advantages of color vision in the natural world have motivated comparative studies in different species of monkeys. Color can be used for the perceptual segregation of targets and is certainly one of the cues that monkeys use to identify conspecifics and species of particular plants (Mollon, 1989). In the case of obligate frugivorous monkeys, such as cebids (Rosenberger, 1992), one of the most important functions of color vision is expected to be to judge the ripeness of fruit from the external appearance (Mollon, 1989; Osorio and Vorobyev, 1996).

Recent studies on marmosets (*Callithrix*) and tamarins (*Saguinus*) have shown a sex-linked color vision polymorphism, characterized by the presence of three types of trichromacy and three types of dichromacy; males expressing only dichromatic phenotypes (Tovée *et al.*, 1992). However, there are some inconsistencies. While the saddle-backed tamarin (*S. fuscicollis*) follows the trend and shows a sex-linked polymorphism (Jacobs *et al.*, 1987), the cotton-top tamarin (*S. oedipus oedipus*) makes accurate discriminations across the visible spectrum (Savage *et al.*, 1987). Interspecific and/or methodological differences may, however, account for such differences.

Regarding the family Cebidae, studies of color vision in squirrel monkeys (*Saimiri sciureus*), which report a sex-linked polymorphism (for example, Bowmaker *et al.*, 1987) are in contrast with a fragmentary knowledge of color vision in capuchin monkeys (*Cebus apella*). In this last species, studies have suggested both the presence of dichromacy in male *C. apella* (see Jacobs and Neitz, 1987) and its absence (see Gunter *et al.*, 1965; Ptito *et al.*, 1973).

As suggested by Jacobs (1993), ideally, a survey of color vision should include direct behavioral evidence for color vision. In order to increase our understanding of this question, we recently presented evidence of behavioral trichromaticity in the capuchin monkey (Pessoa *et al.*, 1997a; Pessoa *et al.*, 1997b). In these studies, the ability of two males and a female *Cebus* in discriminating chromatic and achromatic stimuli was tested with Munsell color chips. However, the chips require a broad range of brightness values at each discriminable hue to eliminate the possibility of subjects using brightness cues rather than hue to make the discrimination. One speedy, simple, and effective method used with humans to distinguish between normal and deficient red-green color perception is provided by Ishihara pseudoisochromatic plates (Birch, 1997). Its popularity abides, partially, in the imperviousness of the test to changes in experimental viewing conditions (Long *et al.*, 1985). In such plates, the perceptual segregation of a figure is done by color cues, while the environment and figure vary randomly in lightness. Besides the keen technique for masking luminance edges, the plates offer conditions which are common in the complex scene of the natural world (Mollon, 1989).

Taking this into account, the purpose of this study was to investigate the possibility of color perception in *Cebus* through Ishihara pseudoisochromatic plates. As far as we know there has been no previous work using Ishihara plates with non-human primates.

Methods

Subjects

Three young adult capuchins, *Cebus apella* - two males and one female - served as subjects (Ss) for this study. They were housed in cages (4 m length, 2.9 m width, 2 m height), at the Primate Center of the University of Brasília. The animals were tested in their own home cages and they were not food deprived. Prior to an experimental session food was removed and was again available only after the test. They had free access to water. All the Ss had previous experience with two-choice color discrimination training, using Munsell color chips.

Equipment

A modified version of the Wisconsin General Test Apparatus was used. The apparatus was mounted on a portable table in front of the animal's home cage. A tray carried the stimuli and a wooden screen was used to permit the experimenter to set up problems and prevent animals observing stimuli between trials. This set up was manually operated.

Procedures

The experimental sessions were conducted three times a week, between 13.00 and 15.30 h under daylight diffuse illumination according to viewing conditions as prescribed by the Ishihara test. Training was begun with the presentation of one pair of stimuli at a time. On any given trial, the subject was faced with a choice between two discriminating stimuli. A food reward (SD+, a grape) was placed under one of these stimuli (a wooden cube) and was accessed by the monkey only if its choice was correct. The left or right position of the reinforcer was determined according to the Gellerman table of random numbers. Nine correct responses on ten given trials was used

as a learning criterion for the Ss. Thereafter, they were tested in a reversal learning procedure until reaching 90% of correct responses. In this phase, the SD+ was changed to SD- and *vice-versa*. A delay of 10 s was used as an intertrial interval.

Stimuli

The stimuli consisted of 75% reduced photocopies of Ishihara plates on the upper surface of wooden cubes (size = 3cm; weight = 10g) covered by a white paper. For the purpose of this study, three different designs from a 24-plate edition (Ishihara, 1980) were used: (a) an introductory plate, (b) vanishing plates and (c) hidden digit plates. The numeral in the introductory plate (plate 1) can be detected both by the trichromat as well as by the various color vision deficient. The vanishing format (plates 8, 10 and 11) discriminate between color-normal and color-abnormal subjects. The hidden digit group (plates 14 and 15) contained figures discernible only to individuals with red-green deficiencies, although many human subjects with normal color discrimination can detect them. To assess color perception in *Cebus* with Ishihara plates, each pair of stimuli presented to the animals consisted of copies from the same plate to be discriminated, that is, both contained the same elements or figures, but one stimulus was rotated 180°, being inverted with respect to the subject.

Results

All of the monkeys tested reached criterion within 251 trials on every discrimination problem presented during the original learning. Table 1 presents a summary of individual test performances.

Table 1. Performance summary: *Cebus* color vision test using Ishihara plates.

Plates	N°	N° of trials to criterion		
		Original learning - Reversal learning		
Design		Lola O-R	Túlio O-R	Edmundo O-R
Introductory	1	71-169	75-63	45-85
Vanishing	8	25-67	53-212	21-46
	10	148-57	95-10	91-80
	11	29-16	48-169	251-43
Hidden	14	125-84	24-10	106-160
	15	75-221	20-97	27-402

Number of trials in all sessions to reach the criterion (nine out of ten correct responses) for three different subjects (one female "Lola", and two males - "Túlio" and "Edmundo") using a discrimination learning procedure during original (O) and a subsequent reversal learning (R). The introductory, vanishing and hidden designs are meant to be seen, respectively, by trichromats and color vision deficient, by trichromats only and by dichromats only.

Discussion

All capuchin monkeys tested in the present experiments were able to discriminate the Ishihara plates designed to be perceived by normal trichromats as well as the hidden digit plates meant to be detected by dichromats. These findings are puzzling, at first glance. If *Cebus* are trichromats, as suggested in our previous study using a similar behavioral paradigm (Pessoa *et al.*, 1997a, 1997b), how did the monkeys discriminate the protan-deutan plates? In spite of the robustness of Ishihara plates to experimental manipulation, there is the possibility that the reproduction produced enough

changes in luminance and chromaticities to extinguish the diagnostic value of the original plates. This possibility is being currently investigated.

Our evidence of trichromaticity in *Cebus* contrasts with microspectrophotometrical and electrophysiological measurements in receptors of *Cebus apella*. These experiments show a single class of middle wavelength cone (Jacobs and Neitz, 1987) suggesting that male *Cebus* are obligatory dichromats. However, the correlation between number of retina cone types (photopigment types) and the dimensionality of resultant color vision must be considered with caution. Spectral positioning of photopigment alone fails to capture everything required to understand color vision. Differences in pigment optical density provide a possible account for red/green chromatic discriminations in some color-deficient observers with only a single opsin gene (Sanocki *et al.*, 1997). The fact that color perception is a result of active operations carried out in the nervous system as a whole has been stressed by Zeki (1993). Despite these arguments, it would be also interesting to assess the color vision of our putative trichromat monkeys through molecular biology approaches.

Regarding the uses of color vision in the natural environment, the presence of an exclusive trichromacy in *Cebus* monkeys is a plausible hypothesis. Selective pressures favor accurate color vision, thereby helping primates to discern the presence of ripe fruits (Osorio and Vorobyev, 1996). Furthermore, it has been suggested that a subset of neotropical trees depend upon primates for their dissemination and typically have fruits that are yellow or orange when ripe (Regan *et al.*, 1996).

Concerning *Cebus apella*, its diet during the fruiting season, is composed mainly of fruits which are in the long wavelength region of the spectrum when ripe (Terborgh, 1983). This is an inadequate foraging situation for dichromatic color vision (Regan *et al.*, 1996), unless the dichromats search for fruits cooperatively in groups, enjoying the advantage of female trichromacy (Mollon, 1989). However, differences in the nutritional costs and requirements of reproduction may influence the feeding patterns of male and female primates (Garber, 1987). For example, *C. olivaceus* males spend more time eating fruits, whereas females devote more of their foraging to the acquisition of higher protein resources such as leaves and insects. Polymorphism of color vision in *Cebus* may not, therefore, be advantageous. In addition, *Cebus-Saimiri* associations may involve cooperation in food searching, in which the squirrel monkeys, which have a color polymorphism, take advantage of the capuchin's detailed knowledge of the fruiting trees (Terborgh, 1983).

Cebus apella does not seem to be the only exception to the color vision polymorphism amongst the New World monkeys. A recent electrophysiological study shows that howler monkeys, *Alouatta*, have trichromat color vision (Jacobs *et al.*, 1996). Further studies in other species of monkeys and a knowledge of their foraging strategies and dietary preferences will help to clarify the question of the evolution of color vision in the New World monkeys.

Acknowledgments: This research was funded in part by the Fundação de Amparo à Pesquisa do Distrito Federal, Brazil, and a grant from the Brazilian Higher Education Authority (CAPES/DAAD/PROBAL - 058/98). We thank Raimundo Oliveira and Washington Luiz Vargas for their technical assistance. We are especially grateful to Dr. Cristina M. Curto for providing the Ishihara book.

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PRIMATES OF THE ITUBERÁ FOREST COMPLEX, BAHIA, BRAZIL

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Introduction

The near complete destruction of the Atlantic forest biome through deforestation and hunting has resulted in the precipitous decline of its endemic primates (Rylands *et al.*, 1997; Myers, 1987; Fonseca, 1985). Santos *et al.* (1987) pointed out the particular importance of preserving the remnant forests of southern Bahia where all six of the Atlantic forest primate genera historically occurred. The forests between the Rio de Contas and the Recôncavo of the Bahia have received only cursory scientific attention, and with the exception of surveys carried out by the WWF Primate Program (Mittermeier *et al.*, 1981, 1982; Santos *et al.*, 1987), by Alonso *et al.* (1987; *Callithrix* hybridization in the Recôncavo da Bahia), and by Oliver and Santos (1991), little information has been collected on the primates of this region. Here I report the results of a primate census from the forests near the town of Ituberá. Fundação BioBrasil (an NGO based in Salvador) initiated this study as part of an effort to determine the conservation value of these forests.

The Area

Ituberá is located on the southern Bahian coast (13°50'S, 39°15'W) in a hilly region dominated by plantation agriculture with rubber, cacao, oil palm, pupunha palm, guaraná, piaçava palm, heliconias, manioc and bananas, as the main crops, along with cattle ranching. The rich biological heritage of the area results from a diversity of distinct habitats including Atlantic