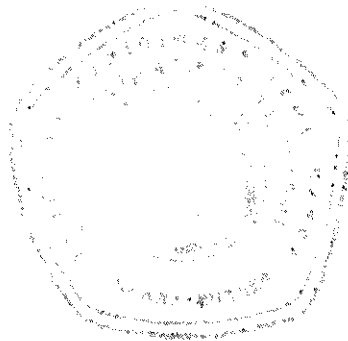


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**COLOR PERCEPTION OF COLORBLIND MONKEYS**

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## ABSTRACT

PUTI S. ANGELIKA. Color Perception of Colorblind Monkeys. Under the guidance of BAMBANG SURYOBROTO and AKICHIKA MIKAMI.

Old World primates possess three types of retinal cone photoreceptors with different spectral sensitivity to long (L), middle (M) and short (S) wavelengths of light. Genes that encode L and M are located in X chromosome, whereas that for S is in chromosome No. 7. The loss of the gene that encodes either L or M photopigment in human will cause dichromatic color vision, generally known as colorblind.

Molecular genetic analysis of more than 3000 macaque monkeys showed the existence of dichromatic genotype. The defect gene is located in the X chromosome. Males carrying this defect gene on their X chromosome would have protanope characteristic. Females carrying this defect gene on one of their X chromosomes would be heterozygous. Electroretinogram (ERG) measurement shows that the sensitivity to red light was extremely low in protanopic male monkeys compared to the normal genotype. Heterozygous carrier female has sensitivity that is intermediate between the genetic protanopes and normal monkeys.

Operant conditioning technique was used to see the color perception of crab eating monkey. Two dichromatic and two normal male monkeys were trained to do a color discrimination task with food as a reward. The task is finding a circle containing red color. Result shows that both dichromatic monkeys were unable to see red color.

## ABSTRAK

PUTI S. ANGELIKA. Color Perception of Colorblind Monkeys. Dibimbing oleh BAMBANG SURYOBROTO dan AKICHIKA MIKAMI.

Primata dunia lama memiliki tiga tipe *cone photoreceptors* di retina dengan sensitivitas spektrum yang berbeda terhadap panjang gelombang panjang (L), panjang gelombang menengah (M), dan panjang gelombang pendek (S). Gen yang menyandikan L dan M terletak di kromosom X, sedangkan yang menyandikan S di kromosom 7. Hilangnya salah satu gen yang menentukan pigmen itu pada manusia akan menyebabkan penglihatan dua warna (*dichromatic color vision*) yang dikenal sebagai buta warna.

Analisis genetika molekular terhadap lebih dari 3000 ekor monyet dari genus *Macaca* menunjukkan adanya genotipe *dichromat*. Genotipe *dichromat* itu disebabkan karena gen penyandi L dan M bersatu membentuk gen hibrid R4G5. Monyet jantan yang mempunyai gen hibrid pada kromosom X-nya bersifat *protanope* (tidak sensitif terhadap warna merah). Monyet betina yang mempunyai gen hibrid pada salah satu kromosom X-nya bersifat *heterozygous*. Pengukuran elektroretinogram (ERG) menunjukkan bahwa sensitivitas terhadap cahaya merah sangat rendah pada jantan *protanope* dibanding dengan jantan normal. Sensitifitas betina *heterozygous* terhadap warna merah berada di antara sensitifitas jantan normal dan jantan *protanope*.

Teknik *operant conditioning* digunakan untuk mengetahui persepsi warna dari monyet. Dua monyet jantan butawarna dan dua monyet jantan normal dilatih melakukan tugas membedakan warna dengan makanan sebagai hadiah. Tugasnya adalah menemukan lingkaran yang mengandung warna merah. Hasilnya menunjukkan bahwa kedua monyet butawarna itu tidak dapat melihat warna merah.

**COLOR PERCEPTION OF COLORBLIND MONKEYS**

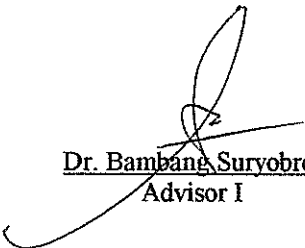
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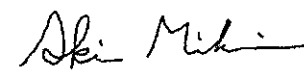
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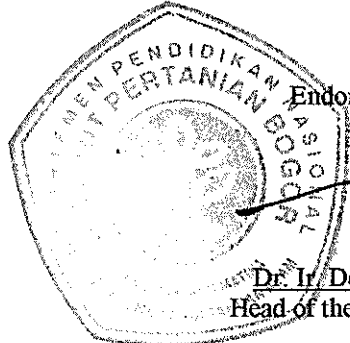
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## **CURRICULUM VITAE**

Writer was born in Semarang on 20<sup>th</sup> of February 1979 as the second child of three from the parent, the late Medhy Chumaidi and Indah Yudhawati.

On 1997, writer graduated from SMU N 1 Semarang and entered the Department of Biology, Faculty of Mathematics and Science, Bogor Agricultural University.

## FOREWORD

Writer made this minithesis titled: Color Perception of Colorblind Monkeys, after doing the experiment since February 2001. This experiment took place in the Laboratory of Zoology Department of Biology Faculty of Mathematic and Science Bogor Agricultural University, Bogor.

Writer's acknowledgments are send to Dr. Bambang Suryobroto and Prof. Dr. Akichika Mikami, MD as writer's counselors; to all the laboratory assistant that has helped the writer during her work at the laboratory; to Eka, Ine, Adi, Ani, and all writer's friends for their helping hands; and also to whoever that has help writer during her whole experiment. Writer's gratitudes are for Mama, whole families, and especially for Mas Wan sayang, for all their prayers and supports so writer can finish her minithesis.

Bogor, October 2001

*Puti S. Angelika*

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## INTRODUCTION

In Old World primates, trichromatic color vision originates from three types of retinal cone photoreceptors possessing different spectral sensitivity. Those photoreceptors are sensitive to long (L), middle (M) and short (S) wavelength of light. The gene for the S cones is located on chromosome number 7, whereas the genes for the M and L cones are located on the long arm of the X chromosome (Fox, 2002). Most defects in color vision in humans arise from the loss of the gene that encodes either L or M photopigment and causing dichromatic color vision (Onishi *et al.*, 1999). People with dichromatic color vision are known as colorblind people.

Molecular genetic analysis of more than 3000 macaque monkeys showed the existence of dichromatic genotype. The defect gene is a hybrid gene constructed by genes encoding L and M photopigment and called R4G5. This hybrid gene consist of exons 1 to 4 from gene that encode L and exons 5 and 6 from gene that encode M. R4G5 gene encode a photopigment that is insensitive to red (Onishi *et al.*, 1999). Consequently, males carrying the R4G5 gene on their X chromosome would have protanope characteristic. Females carrying the R4G5 gene on one of their X chromosomes would be heterozygous. Electroretinogram (ERG) measurement shows that the sensitivity to red light was extremely low in protanopic male monkeys compared to the normal genotype. In heterozygous female, sensitivity to red light was intermediate between the genetic protanopes and normal monkeys. Decreased sensitivity to long wavelengths was thus consistent with genetic loss of L photopigment (Hanazawa *et al.*, 2001).

Although molecular genetic and physiological analysis shows the existence of dichromatism in macaque monkeys, it is still not known what is the color perception of dichromatic monkeys.

The objective of this behavioral experiment is to know the color perception of colorblind monkeys.

This experiment took place from February to August 2001, in the Laboratory of Zoology Department of Biology Faculty of Mathematic and Science Bogor Agricultural University, Bogor.

## METHODS

This experiment was using an operant conditioning technique which refers to a process in which the frequency of occurrence of a bit of behavior is modified by the consequences of the behavior (Reynolds, 1975). Two dichromatic male monkeys (#5 and #39) and two normal male monkeys (#30 and #63) were trained to do a visual discrimination task. In the task, monkeys learned to find a circle to get a piece of food as a reward. In this basic task, different colorings and brightness formed the circle. All monkeys are able to identify the circle on that condition. After they learn the basic task, they were then tested using different colorings only.

The stimulus is a color card composed by six colors, which are 1) light brown, 2) dark brown, 3) light green, 4) middle green, 5) dark green, 6) dark yellow, in decreasing order of red. Dots of brown and yellow form a circle on green dots background. The color composition of the card is shown in table 1. Each card has a control card which consist of the background color without the circle. The stimuli used were training pattern (P100) and test patterns with different levels of difficulty. The difficulty levels can be seen in table 2. The most difficult pattern is 0E which contains red color only and the easiest pattern is 50E.

After monkeys were adapted to the new environment (the experimental cage, the tools, the experimenter, etc.), monkeys were taught to pick up food from the experimental box. The experimental box has 2 little boxes in it. The color card and its control card were placed on top of those little boxes. The little box with circled color card was filled with food, such as peanut or biscuit. The little box with control card was not filled with food. When the monkey picked the little box with circled color card in his attempt to get food, he will receive one point. When the monkey picked the little box with control card, he will receive zero point and did not get food. In all sessions, pseudorandom number was used to determine the place of the color card and 40 repetition were done for each monkey for each day.

In first training session, monkeys were taught the relationship between food as a reward with the training pattern seen on top of the box. The circle of training pattern is made of dark yellow color which will be seen by both normal and

dichromatic monkeys. After monkeys succeeded in picking training pattern for more than 90% for three successive days, it is concluded that the monkey knows the relationship between the colored circle and the food as reward.

The second training session was designed to introduce monkeys to the test session that will use cards with different coloring. Firstly, training pattern was mixed with 50E pattern with composition of 90% of training pattern and 10% of 50E pattern. Then, after monkeys can pick 50E pattern for more than about 90% for three

successive days, the proportion of 50E pattern was raised in stages (20, 30, 40, 50, 60, 70, 80, 90, 100%). The experiment continued to test session after monkeys can pick 50E pattern in 100% condition for more than 90% for three successive days. Correction method was used in all training session when miss was repeated up to five times for the same experiment.

In test session, 50E pattern was mixed with 25E, 12E, and 0E pattern with the composition of each pattern are 85%, 5%, 5%, and 5%.

Table 1. Color composition of pattern (Komposisi warna pattern)

Pattern		Colors					
		1	2	3	4	5	6
Training pattern (P100)	Circle						✓
	Background			✓			
Test pattern (0E)	Circle	✓	✓				
	Background			✓	✓	✓	

Chart 2. Difficulty level of pattern (Tingkat kesukaran pattern)

Difficulty level	Colors composition	
	Training pattern (P100)	Test pattern (0E)
50E	50%	50%
25E	25%	75%
12E	12%	88%
0E	0%	100%

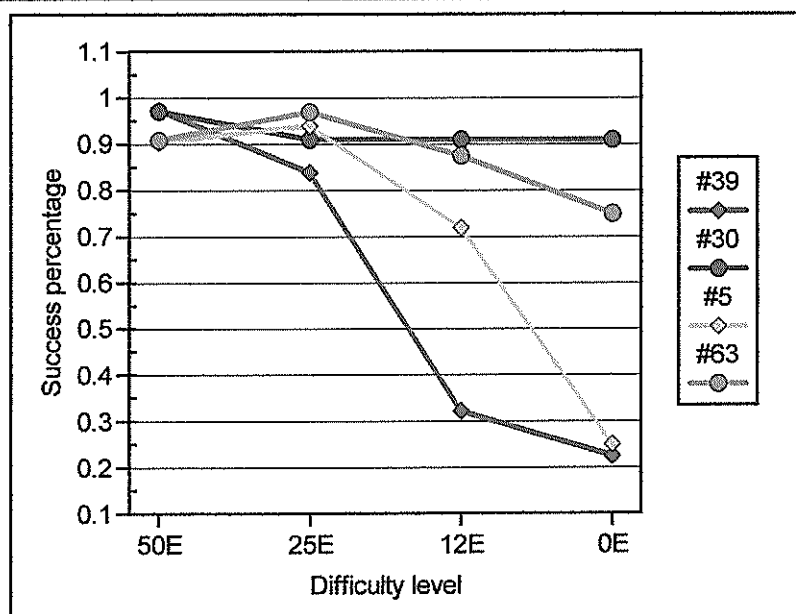


Fig 1. The monkey's success percentage in picking up pattern and get food as reward in test session  
Persentase keberhasilan monyet dalam memilih pattern dan mendapatkan makanan

## RESULTS

Fig. 1 shows the monkey's success percentage in picking up the circle pattern and get food as reward in test session. Both dichromatic monkeys show significant decrease from the lowest difficulty level, which is 50E pattern, to the highest difficulty level, which is 0E pattern. They show very low marks on the highest difficulty level with each mark are 22.6% and 25.0%. Meanwhile, both normal monkeys show higher marks on the same difficulty level with each mark are 90.9% and 75.0%.

The circle as pattern test contains red color that increases from the lowest difficulty level to the highest difficulty level.

Marks in the test session shows that both dichromatic monkeys indeed facing difficulty in seeing red due to their low sensitivity to long-wavelength-light.

## DISCUSSION

This behavioral experiment was conducted with male macaque monkeys identified as normals and dichromats genetically (Onishi *et al.*, 1999) and physiologically (Hanazawa *et al.*, 2001). Molecular genetic analysis predicts the complete absence of L cones in male dichromatic monkeys. This event would be expected to lead to severe and moderate decreases in retinal sensitivity to long wavelength. Physiological experiment using ERG is consistent with those predicted by the genotypes of the monkeys and provide electrophysiological evidence for the existence of dichromatism in macaque monkeys (Hanazawa *et al.*, 2001). Although ERG analysis showed the reduction of sensitivity to red, these monkeys still have chance to see red color after cortical processing. The behavioral experiment was conducted to confirm their color vision. The results confirmed that these monkeys have the similar vision as human protanopia and could be a good model to understand the brain functions of the human protanopia.

Present color discrimination experiment adapted similar pattern test used on human dichromats. The difference lies on the pattern of color that was used. Color test for human has a pattern in shape of number or letter or picture. This pattern will not be seen by colorblind man or

will be seen as different number or letter. We can always ask the human subject what pattern they have seen. Animals, in this case monkeys, cannot read letters or numbers used for pattern. They also cannot speak so that we cannot ask them what pattern they have seen. Therefore, the method used on human must be adjusted and simplified for monkeys.

The adjustment came in the form of circle as pattern test. The operant conditioning technique is used to obtain the answer from the monkeys of what they have seen.

The operant conditioning technique reflects the principle of learning formulated by Thorndike in 1898-1911 called Law of Effect (Mazur, 1994). It says that responses made accompanied or closely followed by satisfaction to the animal will, will be more likely to recur. The animal in this experiment was satisfied by giving them food as reward. They will receive the reward when they successfully picked the right pattern. In return, they will show their satisfaction with their willingness to continuously try to find the food promised. Their success in getting food, which means choosing the right pattern, will be noted and its frequencies counted. Modified pattern test used in this experiment is the first time ever conducted to know the color perception of colorblind monkeys behaviorally.

Fruit test was conducted to support the results obtained in test session. Fruit with different color and taste is chosen. The food used in this test was buni fruits (*Antidesma bunius*). Buni has sweet taste when the color is black, but not sweet when the color is green or red. Black buni was mixed with red buni and also with green buni to see the color sensitivity of the monkeys.

Table 3. The monkey's success percentage in picking up black buni out of green and red buni in fruit test  
Persentase keberhasilan monyet memilih buah buni hitam dari buah buni hijau dan merah

	Green v. black	Red v. black
#39	100.0%	68.8%
#30	100.0%	100.0%
#5	91.1%	57.8%
#63	93.3%	100.0%

Table 3 shows the monkey's success percentage in picking up black buni out of green and red buni

in fruit test. Both dichromatic monkeys picked black buni out of red buni only 68.8% and 57.8% of the cases. On the other hand, both normal monkeys successfully picked black buni out of red buni by 100% for each monkey.

This shows that both dichromatic monkeys indeed facing difficulty in seeing red due to their low sensitivity to long-wavelength-light.

This experiment has described the behavior of colorblind monkeys due to its color perception. Apart from that, this experiment also supported the previous results that dichromatic monkeys have low sensitivity to red light because of the loss of L photopigment. Further behavioral study in heterozygous monkeys in their natural habitat or in the laboratory will complete the data obtained in dichromatic monkeys.

## CONCLUSION

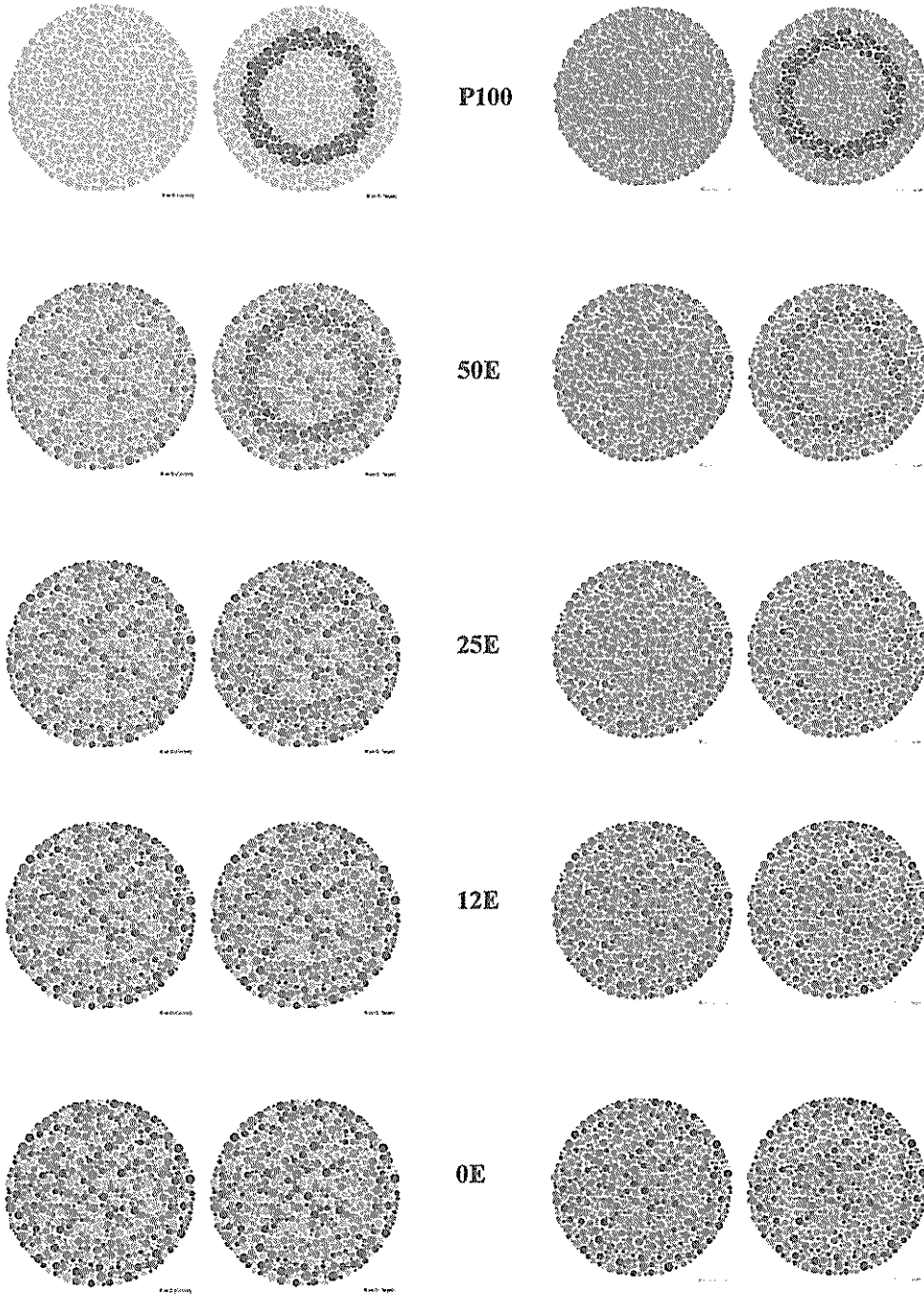
Dichromatic macaque monkey shows difficulty in seeing red color. It is seen in the very low successful percentage when choosing the most difficult pattern which composed of red color only. They also failed to pick up black buni out of red buni fruits.

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## **APPENDIX**

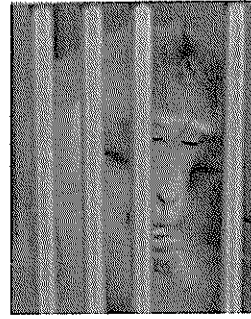
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Appendix 2. Two normal male monkeys (#63 and #30) and two dichromatic male monkeys (#5 and #39), buni fruits, and how the experiment was done.



#63



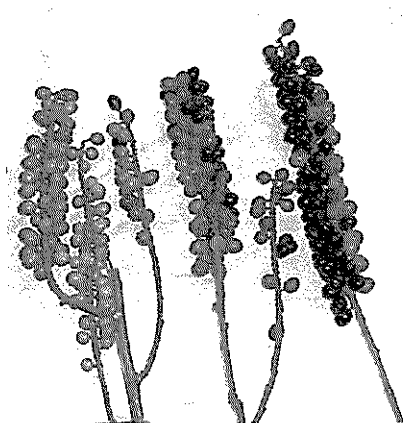
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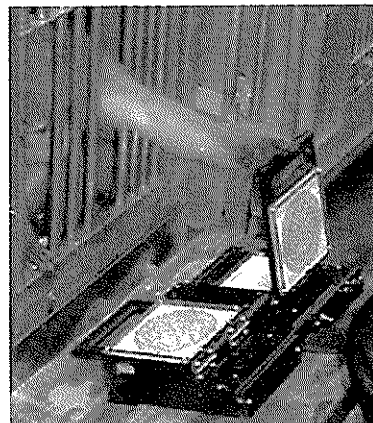
#5



#39



Buni fruits



The experiment

