

AN INVESTIGATION OF THE EFFECTS OF VISIBLE RADIATION
OF VARIOUS WAVELENGTHS ON THE ESTIMATION OF DISTANCE
AND TIME

by

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ABSTRACT

The present research was concerned with the effects of visible radiation of various wavelengths on the perception of distance and time. In particular, the effects of red and blue light were investigated. The selection of these two colours was made on the basis of their effect upon certain psychophysiological functions.

The present study consisted of three parts. The first dealt with the effects of colour on the estimation of distance. The results showed that objects under red light appeared to be nearer than under blue light. A further experiment with infra-red radiation showed that perceived hue and activation together might be responsible for the phenomenon of an apparent decrease of distance under red light.

The second part dealt with the effects of red and blue illumination on the estimation of time. The results showed that time seemed to pass more slowly under red illumination than under blue illumination.

The third part studied the effects of red and blue light on the estimation of time and the relationship between EEG activity and time estimation. The results showed that under red illumination alpha activity increased and time seemed to pass more slowly. Under blue illumination, on the other hand, alpha activity decreased comparatively and time seemed to pass comparatively less slowly.

The results of the second and third part of the present study were explained in terms of a hypothetical wavelength sensitive biological oscillator the rate of which may indicate the human time sense.

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TABLE OF CONTENTS

	Page
1. Introduction	1
2. The psycho-biological effects of visible radiation of various wavelengths	2
3. Affective and cultural factors in the perception of colour.	7
<u>The present investigations:</u>	
Part I: The perception of distance and the effects of light and colour	26
1. A review of the studies on the effects of colour on the perception of distance	27
2. The present investigation	40
(a) The hypothesis	40
(b) A preliminary investigation	40
(c) Method and procedure	41
(d) Results	48
(e) Discussion of the results	54
(f) A further investigation into the problem of distance perception as a function of colour	61
Part II: The perception of time and the effects of light and colour	67
1. A review of the studies of the phenomenon of time perception	68
2. The present investigation	78
(a) The problem	78
(b) Method and procedure	79
(c) The results	83
(d) Discussion of the results	87

	Page
Part III: EEG activity and the appreciation of the change of time under the influence of red and blue light	95
1. A review of the relevant literature	96
(a) EEG, its components, origin and activation pattern	96
(b) EEG activity and the perception of time	103
2. The present investigation	107
(a) The problem	107
(b) Experimental design and procedure	108
(c) The results	116
(d) Discussion of the results	122
Summary and conclusion	142
Bibliography	149

1. Introduction

In this introductory chapter we will discuss the aim and plan of the present study, define the concept of light and colour and review the literature on the psycho-biological effects of light and colour.

The present study consists of three parts. Part 1 will deal with the perception of distance and the effect of light of different colours; Part 2 with that of time and the effect of light of different colours; and Part 3 with the estimation of time and EEG activity under coloured illumination.

Light is defined here as "the aspects of radiant energy of which a human observer is aware through the visual sensations which arise from the stimulation of the retina of the eye" (Committee on Calorimetry, 1944). Light is characterized by its wave motion, its location in the radiation spectrum being defined by wavelength. Radiant energy consisting of cosmic rays encircles the whole universe. From the gamma ray, which is one ten-billionth of a centimeter long, the wavelengths of the electromagnetic radiation extend through an enormous range up to radio waves which are miles in length. The radiant energy visible to the human eye, with which we are concerned in this study, lies within the range of wavelengths 380-760 millimicrons. This range is that of photo-biology.

Our main aim in this study is to investigate how the variation of wavelength of light affects the human organism in his spatial

and temporally oriented behaviour. More specifically, we wish to study the effects of coloured light on the perception of distance and time.

2. Psycho-biological action of visible radiation

Evidence exists for the fact that visible light influences and affects living organisms. All plant life survives and prospers in visible light and will die under infra-red and ultra-violet radiation. Within the visible spectrum different colours act differently. An experiment of Flammarion's (quoted by Havelock, 1900) has shown clearly the different reactions of plants to red and violet rays. He had four rooms designed as follows: (1) covered by ordinary transparent glass; (2) covered by red glass; (3) covered by green glass; (4) covered by dark blue glass. Seeds were sown on the same soil in each room. After forty days there were notable differences in height of the plants under the different colours. After three months, it was found that while those under blue glass had made no progress, those under red had attained extraordinary development.

The physical effects of red light on animals seem to be opposite in character, but the results so far obtained are somewhat contradictory. Beclard (quoted by Havelock, 1900) found that the larvae of the flesh fly raised under violet glass were three-fourths larger than those raised under red glass. In order of effectiveness for stimulating growth the colours were violet, blue, red, yellow, white and green in descending order. • Young

(quoted by Havelock, 1900) found that violet or blue was more favourable to the growth of frogs. He also found that fish hatch most rapidly under violet light. Marti (quoted by Havelock, 1900); on the other hand, found red light, exclusive of violet, exerts beneficial effects on the haemoglobin of the blood and on general metabolism. Red rays, with the exclusion of violet, have healing effects on skin diseases. Finsen (quoted by Havelock, 1900) treated small-pox in red rooms. He also found beneficial effects from red rays in the treatment of measles.

To return to plants again, the phenomenon of photosynthesis, the process by which carbohydrates are formed, is directly related to visible light. Many experiments have been performed with light and the greatest effect has been obtained within the red and blue ends of the spectrum, the infra-red and ultra-violet regions contributing nothing to the process of carbohydrate metabolism (Wald, 1959; Rabinowitch, 1948). The development of time-lapse photography has led to a number of interesting observations on plant and animal growth responses to variations in light energy wavelengths. Ott (1964) has shown the effect of light on the growth of apples, pumpkin vines and on the responses of morning glories. He found that the use of red filters prevented the morning glories from opening normally, but the addition of dark blue cellophane filters resulted in the morning glory buds opening all the day. The apples inside a box under the ordinary window-glass sky-light remained green and kept on growing larger and were

approximately twice the size of those on the same tree but outside of the box. Ott also found that microscopic time-lapse pictures of the streaming of chloroplasts within the cells of *Elodea* grass showed that all the chloroplasts streamed actively to the full extremities of the cells under direct sun-light. When sun-light was filtered through ordinary glass, most of the chloroplasts continued streaming, but some moved to the centre of each cell and remained motionless. Exposure to blue light would cause abnormal pseudopodial activity in the pigment epithelial cells, while red light would cause the cell walls to rupture and allow the cytoplasm to run out.

A recent discovery by Albert Kelner (1949) was that visible light might stop or reverse the injurious effects of ultra-violet light. Subsequent investigations (Blum and Matthews, 1952; Rieck, 1954; Rieck and Carlson, 1955) have shown that the death rate of animals brought about by severe exposure to ultra-violet rays may be significantly reduced by re-exposing them to visible light. Rieck and Carlson (1955) first performed the experiment on mammals, albino mice. Each of the animals was exposed to ultra-violet radiation five days a week. One half of the animals were kept in darkness between each exposure, the other half were exposed to visible illumination between each radiation period. The result was a higher mortality rate in the dark group than in the light group. Secondly, those animals which remained in darkness between exposures to ultra-violet radiation exhibited a much greater damage to the ears than those

which were kept in light.

The experiments on the effect of colour upon emotion are few in number and the results often contradictory. It has been found by some observers that red rays are far more soothing and comfortable, less irritating than the total range of coloured lights. Garbini (1894), for example, found angry infants were soothed by the light through red glass only, slightly through green glass, and not at all by other coloured lights. Working with infants, Smith (quoted by Havelock, 1900), on the other hand, found that blue light tended to lessen activity and crying. In spite of this apparent contradiction, it has been shown quite clearly that red rays increase activity and muscular tension and blue and green lessen them. (Pancoast, 1877; Babbitt, 1925; Wood, 1929; Gerard, 1958).

Féré's (1900) result is interesting and convincing in this respect. Experimenting on normal as well as nervous subjects, with coloured lights, he found notable differences in muscular power as measured by a dynamometer and in the circulation as measured by plethysmographic tracings of the fore-arm. He found with one subject whose normal muscular power was represented by 23 kilograms, that blue light increased his power to 24, green to 28, yellow to 30, orange to 35 and red to 42. Féré's result was confirmed by recent studies in which a muscular tonus reaction was reported to occur with coloured lights (Blum, 1941). Blum relates that muscular tension rises with colours of long

wavelength and relaxes with those of short wavelength. Metzzer (1931) found that with lights directed on one eye a tonus condition could be produced in the corresponding half of the body of many animals and human beings. Metzzer also reported that his subjects, who had their two hands stretched out horizontally in front of their bodies, spread away their arms from each other in red light and brought them closer in green light. Goldstein (1942) made an extensive study of this effect of colour and found a muscular tonus reaction with colour and light.

It should be noted that colours need not be seen by the subjects to produce this effect. Féré (1900) reports that in one subject who was unable to see colours with one eye, the colour stimulus had, nevertheless, the same dynamogenic effect even when applied to the defective eye. Deutsch (1937) also found the same effect even when the eyes of his subjects were tightly sealed to exclude light. Some animals change the colour of their bodies with the corresponding change in the environmental colour to hide themselves from their enemies. For example, frogs change their body colour. Hollwich (1964) found that this change in body colour in frogs could be effected even if the eyes of the frogs were completely closed. All this shows that to some extent the reaction to colour and light may be spread over the whole body.

Of particular importance vis-à-vis its extra-visual function is the photo-endocrine effect of light. Various experiments have pointed out that visible radiations of longer wavelengths

(essentially the red ones) have effects upon gonadal development of ducks (Benoit, 1964; Hollwich, 1964). In one experiment (Benoit, 1964), ultra-violet, indigo, green, yellow, orange and red rays were used. It was found that the testes of ducks only responded to orange and red radiations (light being thrown on the duck's eyes). It was also found that light had considerable effect on ducks in reaching sexual maturity and presenting sexual cycles though light was not absolutely necessary for the development of sexual activity, as total absence of light did not prevent ducks from attaining such activity. The influence of light on the endocrine system has been thoroughly investigated by Hollwich (1964).

Thus we see the effects of visible light on the living organism. Plants depend directly on visible light. Animals live on plants for their food. So animals also depend on visible light directly or indirectly. Animals depend on visible light, grow with it, see with it and become delighted with it. Rightly has this range of the effects of visible light been described as the range of photo-biology.

3. Affective and cultural factors in the perception of colour

Experimental evidence exists for the fact that when two stimuli are perfectly matched in all aspects other than colour, a measurable difference occurs in their perception (Drechsler, 1960). Chromatic stimuli tend to arouse responses accompanied by affective phenomena, such as associative blocking, strong emotional reactions, and symptoms

of conceptual and behavioural disorganization. Thus, colour is said to be affect-laden.

But the question arises: Does the mere presence of colour in an object endow it automatically with affect-arousing property? Siipola (1950) answers this question with an emphatic 'no.' She offers an explanation according to which these symptoms of affective involvement are regarded as an indirect effect of the presence of colour rather than a direct effect of hue as such. The addition of hue to an object (inkblot in her case) is likely to introduce a new difficulty, a hue-form incongruity, for the subject which causes conceptual conflict and emotionally toned behaviour.

This is a probable explanation. Siipola found that only certain coloured blots, mainly those characterized by hue-form incongruity, showed striking effects upon perception. This hue-form incongruity variable, however, can be experimentally controlled. And if even after that the effects are evident, we can definitely attribute them to the presence of colour.

Ten years after Siipola, Drechsler (1960) overcame some of the methodological difficulties inherent in using Rorschach cards as crucial materials in such experiments. In his experiment, he used homogeneous rectangles of either red, green or grey projected on a screen during the presentation of word-association test. The results supported the hypothesis that coloured stimuli elicit more emotional responses than do grey stimuli. These

results challenge Siipola's hypothesis that colour itself has no emotional impact. Drechsler offered an "intrusion" hypothesis as a possible explanation for the role of colours as affect-stimulating agents. By "intrusion" he means that bright colours intrude on the perceiving person in such a way that his on-going thought processes are interrupted or disrupted until the intrusive stimulus is removed or otherwise assimilated.

Notwithstanding these explanations, the question still remains as to why different colours should produce different results. Thus red is said to arouse more emotionally toned responses than either green or blue. How could these differential characteristics of colours be explained? An "intrusive" or a "hue-form incongruity" hypothesis is not sufficient to explain this phenomenon. We shall discuss below this problem in terms of a learning hypothesis.

Colour perception is associated with feelings of pleasure or displeasure. According to a learning explanation the two occur by differential conditioning. Thus, a child does not at first distinguish red flowers or other red objects from red flames or blood. Later, however, through injury associated with blood or fire, he learns a differential response to red. Later still, when he observed that red is used as a signal for danger, his differential response to the colour is further reinforced.

Next comes the question of colour preference. Most people have preferences for certain colours rather than for others.

This order of preference seems to be fairly constant within a culture. According to Eysenck (1941), among Western peoples it is as follows: blue, red, green, purple, orange and yellow. To Eastern peoples, though there is not much uniformity, the order is quite different and green, yellow and white will be preferred. The distribution of colour preferences in Eastern countries, mainly Asian, will be discussed later on. Again, particular colours may give rise to particular emotional reactions: red to excitement or anger, green to freshness and vigour, blue to calm and pleasure, white to modesty, and black and grey to sadness or depression (Havelock, 1900, 1906; Gerard, 1958). It is difficult to measure as to what extent these emotional reactions are spontaneous, or whether they are symbolically associated through cultural traditions. These intra-species differences would appear to support a learning hypothesis.

If we look at the development of cultural tradition we can see its effect on the perception of colour. Studies show that primitive people do not perceive colours as we do, since their languages do not include the colour names included in ours. In some cases the name used by such peoples may be that of an object which it characterizes. Thus the word green is often the same as or derived from the name for grass or other vegetables. In an experiment, Brown and Lenneberg (1941) found that recognition of colour was easier as colour becomes more codeable (consistency with which a name is applied to a stimulus). In the experiment

with European adults, eight colours with well-known names (red, pink, orange, yellow, green, blue, purple, and brown) were presented together with sixteen other colours. The subjects were asked to recognise them from among a set of 120 different colours. They recognised the eight colours more quickly and with greater consistency than the other sixteen. But Zuni Indians, who performed the same task, frequently confused orange and yellow when they tried to recognise them. These Zuni Indians use the same name for these two colours.

Experimental evidence also exists for the fact that past experience and social factors play a vital part in the perception of colour (Duncker, 1939; Bruner, Postman and Rodrigues, 1951; Harper, 1953; Baker and Mackintosh, 1955; Fisher, Hull and Holtz, 1956; Rosenblith, 1961). Children imitate their parents and other near ones in the choice of colour, even in a controlled experimental situation. By the same token, past associations influence the perception of colour. We do not perceive a colour alone. We perceive it generally with a form. Thus, the hue-form incongruity which Siipola refers to is a phenomenon of learning. Colour judgements are not only influenced by adaptation conditions of the eye or by other stimulus factors but also by experience factors. One convincing demonstration of such an influence is found in the experiment by Bruner, Postman and Rodrigues (1951). They have shown that colour matches for familiar forms or objects

(i.e. tomato, lemon, etc.) were in accordance with the usual colour attributes of the objects depicted even when the forms were presented as silhouettes of grey paper against a blue-green background. Baker and Mackintosh (1955) have shown that this influence is also evident even in a few colour-form exposures of unique nonsense forms, previously associated with colours.

Related to the perception of colour is the "Stroop phenomenon." This refers to the interference of words in naming colours when the word and the colour appear in incongruent combinations, e.g. the word "red" printed in the colour yellow, the word "yellow" in the colour blue, and so on. This phenomenon was first experimentally studied by Stroop (1935). Recently, Klein (1964) investigated the basis of this interference and found that the word's semantic structure, its meaning and relatedness to the colour-naming response, was responsible for this interference. Where the word and the colour name were semantically distant, the effect disappears.

Apart from the experimental studies reported above, there are sociological and anthropological studies which also show that cultural factors play a part in determining the emotional feeling attached to a particular colour. The following is a review of such studies in the perception of colour in different races of the world. We group the review of such studies into the following headings:

1. Perception of red
2. Colour vocabularies and colour perception

3. Perception of yellow, and
4. Perception of blue and green

Perception of red

Red, among all colours, is undoubtedly the most emotionally toned colour. Gerard (1958) found greater cortical and ^{autonomic} automatic arousal under red than under blue. Red is the colour that even idiots learn to recognize easily (Havelock, 1900). It is the colour that catches attention most readily and on primitive levels of perception, as shown by the fact that small children and some primitive tribes react, only or primarily, to red. This will be dealt with in greater detail below.

In many parts of the world red is the symbol of joyous emotion. Scarlet garments were at one time the exclusive privilege of the royal family in France and Madagascar (Havelock 1900). Among the aborigines in Australia red is a predominant colour. In times of joy and merry-making they paint themselves red. The same practice still exists among Indian Hindus (the ancient religious group) which is seen in their observance of "Holy" (a Hindu festival of rejoicing in which they paint themselves red). In paintings and rock carvings the native Australians mainly used red. Spencer and Gillen (cited by Havelock, 1900) in their works on the natives of central Australia, have described the significance and importance of red ochre in the lives of the natives who would coat their implements, weapons and sacred objects with red ochre.

Red was not, however, uniformly used as a symbol of joy. Havelock says "a great many different colours are symbolical of mourning in various parts of the world but so far^{as} I am aware, red never" (p. 365). But Dana (1900, p. 661) opposed this by quoting the following: "..... reed clothes ben layed upon deed men in remembrance of theyr hardness and boldness". "It apperenth in the time of Saxons the manner over their dead was a red cloth, as we now use black" This shows that red was also used as a symbol of mourning. But it is also clear that red was used in remembrance of valour, courage and hardship.

In years gone by, Europeans have followed exactly the same practice. German women, in the early ages, used red and yellow colours to adorn their faces and bodies (Havelock, 1900). With the advent of civilization this practice has gone except, perhaps, vestigially with the current use of lip-stick.

It seems that the distinct, affective value of colour is closely related to the capacity for an aesthetic experience of colour. This is a relatively late development of highly differentiated cultures. Rivers (1901, 1905, 1903), after his extensive studies of colour sense of different races, is of the opinion that as long as the colours presented have primarily aesthetic value and no practical significance, primitive peoples seem quite indifferent to them. On the other hand, the Maories have about 3000 separately designated colours all of which have practical significance for them (Reche Emil, 1926). In the same way, the Kaffir language has

more than twenty six terms to designate the different colours and markings of horned cattle (Magnus Hugo, 1880). The abundance of words for practically significant colours contrasts with the absence or scarcity of words for colours with no practical value. In the Niger there are only three words for colour, namely red, white and black. All that is not white or black is called red. So, one should not be surprised if in Rorschach records of some of the primitive tribes no colour responses are found. This was found to be so in the Pilaga Indians (Rorschach Analysis of Pilaga Indian children).

Colour vocabulary and colour responses

That colour response is, in part, influenced by cultural development is shown by the study of colour vocabulary and colour response. It is seen that in every country the words for the colours at the red end of the spectrum are of earlier appearance, more definite, and more numerous than for those at the violet end. The careful investigations, of Uralis and Sholagas, and of the natives of Egypt, by Rivers (1905, 1903), of the Cambridge Anthropological Expedition, have shown that in all these communities there are definite names for red, less definite for yellow, still less for green, while no definite name for blue could be found. Similar phenomena were found in Europe. The same precision and conspicuousness of the colour vocabulary at the long wave end of the spectrum are found among earlier Europeans as well as among

primitive people. This is shown by the fact that (1) Latin was especially rich in synonyms for red and very poor in synonyms for green and blue; Latin had to borrow a word for blue from Teutonic speech, "caeruleus" originally meant dark (Havelock, 1900) and (2) Greek colour vocabulary, especially at the violet end of the spectrum, is vague.

In large measure, relying on the examination of 300 chukchis during the Nordenskiöld Expedition, Magnus Hugo (cited by Havelock, 1900) concluded that although the colour vision of uncivilized people has the same range from red to violet as that of the civilized, there is a certain dullness, a sort of haziness, as regards green and blue; while the colours at the other end of the spectrum are perceived with much greater vividness. The investigations of Rivers, as mentioned before, have confirmed the conclusions of Hugo. Rivers found that corresponding to the defect of colour terminology there appeared an actual defect of vision for colours of short wavelength.

It is a noteworthy fact in this connection that in normal persons a colour sense may be acquired. This has been experimentally demonstrated by Féré (quoted by Havelock, 1900), who by means of his chromoscopic boxes containing very dilute coloured solutions, found that by practice it was possible to recognise solutions which had previously seemed uncoloured.

The studies of colour sense in children show that the familiarity with the red end of the spectrum is earlier and more

perfectly acquired than with the violet end. Garbini has thrown much light on this matter. Garbini (1894), with 600 North Italian children, found that the order of perception is red, green, yellow, orange, blue and violet. Garbini's experiments are worth noting in detail. He found that for the first few days after birth the child avoids light, and at the 14th day, he ceases to be photophobic and starts enjoying light which is shown by the fact that the child becomes quiet when brought into light and cries when taken from it. It is not until after the 18th month that the child's chromatic perception begins, any preference for red or yellow objects at an earlier age being due merely to their greater luminosity. Between second and third years children are found to be most successful in recognizing red, then in green, but they very often confuse orange with red and mix up yellow, blue, violet and green. In the 5th and 6th years, red, green and yellow are always correctly chosen. In the 6th year children are perfecting their knowledge of orange, blue and violet and thereby completing their knowledge of colour designations.

From the above studies and discussion it may be concluded that primitive people and children primarily react to red. What about the normally developed civilized adult? Does he not still react emotionally more to red than to other colours? If the answer is 'yes', how might this be explained? The following points are relevant:

1. What are the chief coloured objects that are of most vital concern to human beings? Among many races, the colour of fruits

might be a powerful factor in developing a sensitivity for red and with such sensitivity was associated the emotional satisfaction derived from it. Those people who depend on the colour of fruits to determine their ripeness or edibility may develop a special sensitivity to that colour. Pickford points out that the frequency of red-green colour blindness has increased among the people with growing civilization. Whereas it is less frequent among some primitive peoples who must take right fruits (the selection being made by colour) to avoid food poisoning (Pickford, 1964).

The second factor is that red is the colour of fire. Fire is a source of massive physical satisfaction. Fire is associated with food; it is also a protection from the wild beast (to nomads or tribal people) and the accompaniment of festival (camp fire). Fire is also associated with pain and anxiety.

Another very powerful factor in its emotional influence is the the fact that red is the colour of blood. In many languages blood is a synonym for red. In Bengali, for example, the word "rakhtim," meaning red, comes from "rakhtho" (pronounced rakh-tho), meaning blood. Blood is also associated with accident, injury or murder.

Red is not only the colour of ripe fruits, of fire, and of blood, it is also the colour of love and sex. This is certainly an ancient and powerful factor in the emotional

attitude towards red. This association of red with love and sex might be the important factor in the emotional arousal in Drechsler's experiment (mentioned before) in which red and a picture of a nude aroused more emotional reaction than did the same picture when grey.

Perception of yellow

The emotional response to red is fairly uniform among all peoples at all levels of civilization. But the emotional tone of yellow is very difficult to define. It varies to a marked extent at different historical periods, in different regions of the world, even under the same civilized conditions, at different ages in the same individual. In one part of the globe it is highly honoured, while in the other it is highly disliked.

Children like yellow after red, sometimes they even prefer the former. But this preference changes with age. Loebson (1904), investigating the colour preferences of a large number of school children, found that children's love of yellow diminishes with age. Wissler (cited by Havelock, 1906), in comparing colour preferences of freshmen and seniors of both sexes, found that with age there is a shifting of preferences towards the violet end of the spectrum.

Investigations on students in various countries of Western civilization have shown that yellow is the least attractive and preferred colour. The most preferred colour is blue. Cohn

(*Philosophische studien*, vol. 10), in Germany, found among students, that yellow, even in any degree of saturation, was never the preferred colour. Blue was the most preferred colour. Major (1895), at Cornell University, in a series of carefully designed experiments, found that among all his subjects yellow was the least pleasant colour, while blue was the most preferred colour. In determining the colour preferences of 4500 men and women in Chicago, Jastrow (1897) found that yellow was the least preferred colour, though women seemed to like yellow more often than did men. Again, the most frequently chosen colour was blue.

According to Havelock (1906), in ancient Greece and Rome, yellow was especially worn by women at marriage and by the priests. In Homer's *Iliad*, a bed of saffron is prepared for lovers. Ancient Greeks liked saffron coloured frocks and dyed their hair yellow. But yellow today is the least preferred colour. Havelock explains this decline in the love of yellow by the advent of Christianity. In Christian ecclesiastical usage, yellow was regarded with disfavour and finally yellow garments were prohibited for the priests. Yellow became the colour of jealousy, cowardice and treachery. Jews, writes Havelock, in some countries were compelled to dress in yellow.

Why did Christianity view yellow with suspicion? Yellow had been the colour associated with wanton love. At the beginning it was associated with legitimate love. It has already been said that brides' garments were of yellow. But courtesans in different

countries, especially in Greece and Rome, began to exploit this association. Later on, a situation arose whereby chaste women were discouraged from wearing yellow garments. Thus yellow became symbolic of adultery. In modern English the word "golden" has replaced anything (meaning) yellow and the word has come to mean largely what is beautiful or brilliant without any reference to colour.

Another association which made yellow gradually a less desirable colour is that yellow is the colour of bile and of jaundiced skin. The degree to which mankind has been impressed by the yellowness of bile is sufficiently proved by the fact that bile has served to supply a name to yellow. Thus, according to Rivers (1901), among the Eskimo, the Chukchis, the Samoyeds, the Voguls and other sub-arctic races yellow is called by a word which means bile.

Thus, the attitudes initiated by early Christianity and the subsequent emphasis of all its unpleasant associations, may possibly account for the kind of emotional response to yellow among people on both sides of the Atlantic.

That the modern Western dislike for yellow is due to cultural and historical factors seems to be evident from the observation that children like yellow as much as red, as has been stated above, and only later in life is yellow disliked. Emery (1938) reports an experiment in which patients were asked to point out, without stopping to think, the most desirable colour from a box filled with large balls of wool in red, green, blue, violet

and yellow. The choice of patients who had regressed or failed to progress beyond infantile level was yellow. Another interesting finding, in this connection, has been reported by Latta (1904) in his careful investigation of a man operated on at the age of thirty for congenital cataract. After recovery, the colour he first saw was red, while green took him the longest time to recognise. But yellow had a remarkable effect upon him. Latta reports, "the first time he saw yellow he became so sick that he thought he would vomit" (p. 145). From the report we know that this man was exceptionally interested in the outside world. He even used to prepare garlands with different colours and as such he was aware of different colours by their names. So it was quite possible that this man had absorbed current ideas about yellow and that the appropriate emotional tone was associated with the colour before he had even seen it. There is no mention in Latta's report that the patient was shown yellow without being informed of its name. When he first saw the red carpet on the floor of his bed in the hospital, his fellow patient told him it was red. The same thing might happen when he first saw yellow. The moment he saw yellow and could identify the name "yellow" (probably suggested by somebody) the emotional tone already associated was aroused and he felt sick perhaps remembering that yellow is the colour of envy, of adultery, of jaundiced skin, and of bile.

So far we have discussed only one side of the picture. If we turn to the other side of the globe, from the Atlantic to the Pacific,

we find that yellow is the most respected colour. It is still the most sacred and supreme colour in India, Malaya, China, Ceylon and even in Persia. The geographical distribution of the love of yellow has been investigated by Arnold (quoted by Havelock, 1906). In India and Ceylon yellow is highly preferred and respected. There has been an interesting study of the sacred uses of yellow in India by Dymock (1890). The love and admiration for yellow in India is expressed in language, songs, music, rituals and ceremonies. Yellow, in Sanskrit, is described as "charu" fair, "saurabha" fragrant, and "mangalaya" propitious. Termeric is known as "haridra" in Sanskrit and has as many as forty-six synonyms.

In Hindu ceremonials termeric is essential. The most important occasions in which it is used are the marriage ceremony, the "puja" ceremony (worship of gods and goddesses) and in other day to day rituals. Yellow and plants having that colour have an erotic significance. That is why, we find them playing an important part in marriage ceremonies and in the relations between the sexes. Termeric in Ramayana (Hindu sacred book) is the loftiest colour as it is one of the eight ingredients of the "Arghaya," a respectful oblation to the gods. Krishna (sacred god and sun-god) is represented as clothed in yellow garments. The "Baishnabs" (the followers and admirers of Krishna) wear yellow garments.

The reason why Indian Hindus hold yellow in high esteem possibly follows from the fact that the Hindus are great worshippers

of the solar system. They hold in especial ^{esteem} ~~estimation~~ those plants which yield a golden yellow dye, remembering sun light. It is the sun's rays that quicken life, sustain it, and through them new life springs up. Through this they have formed the idea of the sun-god who is considered as the personification of youth and beauty.

Yellow is also the sacred colour of the Buddhists. In China yellow is regarded as the most fortunate colour. In Malaya, yellow, after white, is the most sacred colour. Yellow is a royal colour in Malaya and the ordinary people may not wear yellow garments in public while even the use of yellow handkerchiefs or curtains is prohibited.

While discussing the colour preferences above we have seen that in the whole of the Western hemisphere blue is the most preferred colour. But still in some other regions of the world the tendency to prefer green is found. This is found in countries now or formerly Mohammanadan and also in countries with an arid or desert climate.

In the scientific world, too, the position of yellow is uncertain. In the trichromatic theory of colour vision, for example, yellow is omitted from the list of fundamental colour. But some scientists regard yellow as the most fundamental colour in the whole colour spectrum. C.V. Raman (1965) says, "..... that hypothesis (trichromatic hypothesis) regards red, green and blue as the major visual sensations and relegates the

sensation of yellow to a minor and secondary or derivative position. Actually, it is yellow which is the major visual sensation, while red, green and blue though more colourful are only its subsidiaries. They are perceived as full colours only when the yellow is put out of the way." (page 16).

To summarize, it would seem that the individual builds up a cognitive structure or schema for the perception of colour on the basis of information received from various social sources both private and cultural.

P A R T 1

The effects of red and blue illumination on the estimation
of distance

PART 1The perception of distance and the effect of light and colour:(1) A review of the studies of the effect of colour on the perception of distance

The judgement of distance depends upon different factors, such as relative size, relative height, interposition, texture gradient, aerial perspective, accommodation and monocular parallax and, in binocular vision, retinal disparity and convergence. However, we know very little about colour as a cue. Experimental studies in this field are very few, some of the results are contradictory and the explanations of the results offered are diverse. We propose here to go through some of the available works and review their methodology, which may be helpful to our present study. In one of his observations, Helmholtz (1867) looked through a tube, painted black inside, at two vertical slits, one covered by red glass and the other by blue glass. After the two markings had been compared for a considerable length of time, the impression left was that the red mark was nearer than the blue one. In a similar observation, Katz (1935) reported the occurrence of the same phenomenon. He found that when he drove a series of broad-headed nails into a board and then covered alternative nails with red and blue papers, the red ones seemed, when viewed from a distance of 80 cm., to be strikingly nearer than the blue ones. Luckiesh (1918), in his experiment, presented two letters, X and Y, in a dark room in red and blue light respectively. The result

was that seven out of nine subjects perceived red as nearer than blue. One subject was inconsistent, and one perceived blue as nearer.

In a study by Taylor and Sumner (1945), Hering's coloured papers (red, yellow, green, blue, white, black and neutral grey) were made into tubes which fitted snugly over the vertical metal poles of the Howard and Dolman depth perception apparatus. The depth perception apparatus, illuminated by a 40-watt fluorescent lamp, consisted of a stationary pole and a movable pole. The stationary pole to the S's left was always covered with the neutral grey paper while the six coloured paper tubings were used in the movable pole in the course of the experiment. Their results showed that all colours appeared nearer in comparison with neutral grey, the order being white, yellow, green, red, blue and black.

Johns and Sumner (1948) repeated the study of Taylor and Sumner in identical conditions with the one important change in the methodology that the movable pole to S's right was constantly covered with neutral grey paper while the six coloured tubings were rotated on the stationary pole. Their results confirmed the earlier finding that brighter colours appeared nearer than dark colours.

In an out-door viewing condition Mount et al. (1956) found a clear demonstration of the effect of hue on the perception of distance, but he could not get any clear-cut differences

between one hue and another.

Other researchers, such as Bruecke (1868), Einthoven (1885), and Belaiew-Exemplarsky (1925) investigated the phenomenon. In an experiment by Belaiew-Exemplarsky, the distance of illuminated bits of Hering's papers were compared and equated as to distance by moving the one that seemed nearer back until it seemed to be as far away as the other. The long wave colours seemed nearer than short wave colours. Red and blue showed striking differences.

Pillsbury and Schaefer (1937), using red and blue lights, found, contrary to the findings of the earlier studies, that blue seemed nearer than red for eleven of the fifteen subjects. For two subjects red appeared nearer.

To attach any value to these studies we must examine their experimental conditions, methods and controls used, for the results in a particular experiment may be artifacts of the experimental conditions. Most of the experiments mentioned above had defects in their controls. These are discussed below:

1. Inadequacy of the fixation objects: The screen edge, used in several investigations, could not possibly provide an accurate fixation point. In any case where head-position is not rigidly controlled, the results cannot be accurate. Slight movement of head may change the situation.
2. The intensity and size of the object: In most of the studies intensity of light was not controlled. In the study by Taylor and Sumner, stated above, intensity and brightness factors were not effectively controlled and they got the

results that the brighter the colours the nearer they appear. Size is a powerful cue to distance, but in many studies the size factor was not controlled.

3. Other factors: In many of the experiments, mentioned above, there were two stimulus objects; one was called movable; the one the subject moved near or farther, and the other stationary. And in some, the movable pole was always on the right of the subject. As a result, the movable pole might get more attention and due to that, the movable pole (that is the object or colour on that pole) might appear nearer. On the other hand, in some experiments, the coloured objects appeared always on the preferred hand side (to be moved near or farther) which might cause them to get more attention and so appear nearer.

Many of these defects were removed and effective controls introduced in a recent study by Over (1962) in which subjects were presented with two stimuli subtending the same visual angle and of the same luminous intensity but of different wavelength. He found that the stimulus of longer wavelength would be judged to be both larger and nearer. In this experiment Over did not control the size of the stimulus in the sense that the size was dependent on distance. As the stimulus was moved farther away or nearer, the projected size decreased or increased accordingly. So size was a cue. He predicted in his experiment that a stimulus

of longer wavelength would appear larger in size and nearer in distance. With this hypothesis, he divided his subjects into two groups; one group made size judgements and the other group distance judgements. From the instructions he gave to his subjects, it appears that the former group became size-oriented and the latter distance-oriented. We are not sure whether the distance factor in the size-oriented group and the size factor in the distance-oriented group were eliminated or not. Over then combined the results of both the groups and concluded that a stimulus of longer wavelength would appear bigger (given by the size-oriented group) and nearer (given by the distance-oriented group). But, in fact, the two groups overlapped each other in many respects.

In the review, above, we have seen the findings of different experiments and discussed the methods and controls used in them. Here we shall discuss the different theories that have been put forward to explain the phenomena. The following hypotheses have been offered by different authors as an explanation of the phenomena:

1. Difference in brightness rather than hue;
2. The effect of chromatic aberration of the eye;
3. Colours are originally depthless and acquire depth as a result of learning;
4. The different refractive indices of the eye media for radiant energy;
5. An attention factor;
6. Insistence quality of certain colours.

It is very difficult to find a commonality among these diversified theories, though they are offered to explain the same phenomenon. The explanation that it is a brightness effect rather than hue effect was put forward by those investigators who failed to control brightness and intensity factors. This theory cannot explain the results where brightness is equated.

Secondly, chromatic aberration has been offered as an explanation of the phenomenon. Before we go to discuss the role of chromatic aberration in depth perception, we propose to study critically the phenomenon of chromatic aberration.

A beam of light, which consists of rays of all wavelengths, when it passes through a wedge-shaped piece of glass or some other transparent dense medium, is refracted towards the base of the wedge. During this refraction the rays of short wavelength, such as violet, green and blue, suffer a greater amount of refraction than do the rays of longer wavelengths, such as yellow and red rays. Due to this factor, the foci for different colours do not lie exactly at the same distance back from the lens. The coloured images, as a result, do not exactly lie on the same point. This phenomenon is known as "chromatic aberration".

It is to be noted here that by means of special combinations of refracting surfaces the foci for light of different colours can be made to coincide and in that case the phenomenon of chromatic aberration disappears.

This phenomenon of chromatic aberration, which is found to occur in physical optics, is also said to occur in physiological optics. Many investigators have studied what they call "chromatic aberration of the human eye." Thomas Young (1801) was of the opinion that the lens system of the eye suffers from chromatic aberration. Fraunhofer (1814), Matthiessen (1847), Helmholtz (1867) and many others have measured the chromatic aberration of the eye. A recent study was made by Hartridge (1947; 1950).

The effects of chromatic aberration in the eye are said to be:

1. That the foci of light of different wavelengths do not lie on the same point;
2. That colours of short wavelengths, such as violet, blue and green, stand nearer than those of longer wavelengths, such as red and yellow.
3. That a blur circle is formed in the retina instead of a clear image of the point source.

There are strong criticisms against the notion of chromatic aberration in the eye. Some of such criticisms are mentioned below.

1. In ordinary vision, colour dispersion and the reported blur circle are scarcely noticeable at all.
2. Many experimenters did their experiments with artificial eyes composed of pure water assuming that the dispersion rate of water is the same as that of the aqueous and vitreous humors (Helmholtz's Treatise on the Physiological

Optics, Vol. 1 & 2, p.173). But this is a doubtful assumption. The viscosity of water is not the same as that of the humors. The temperature may be different. Even if the temperature of water is taken to be the same as that of the humors, the temperature of humors (in a living physiological system) may quickly change, being affected by light more than that of water. The increased temperature would have the effect of reducing both refraction and dispersion. Moreover "the eye media do not consist of pure water but also of protoplasm containing proteins, salts, and other substances which would have the opposite effects" (Hartridge, 1950, p.87).

3. As the distinctness of visual images is so little affected by chromatic aberration that some investigators, such as D'Alambert (1767) and Forbes (1849), pointed out that the eye is absolutely perfect so far as the effect of chromatic aberration is concerned. Ganot (1882) suggested that the aperture of the eye is small and that light rays meet the refracting media at almost the normal incidence.
4. Another group of investigators think that there is a possible physiological mechanism which tends to neutralize the effects of chromatic aberration in the eye. Gullstrand (1924) has offered such an explanation. Gullstrand pointed out that chromatic aberration results in two related phenomena: chromatic difference of focus and chromatic

difference of magnification. By the former is meant the distance between the two focal points due to two different kinds of light; and the latter is proportional to the difference between the primary focal lengths of the system.

Hartridge (1941) showed that there are two factors which tend to reduce chromatic difference of focus: one operating where the diameter of the pupil is large, and the other operating when it is small. The former is the retinal directional effect on light intensity, discovered by Stiles and Crawford (1933). They found that light rays passing through the periphery of the pupil are less effective than are those which have passed through its centre. In effect, in order that the two rays match one another in brightness, the peripheral ray has to be as much as four times the intensity of the central one.

The second factor which operates at small pupil diameter is diffraction. Hartridge continues, "at a certain aperture between these two extremes the two defects are found largely to neutralize one another to produce an almost colourless image," (p. 97-98).

Gullstrand (1924) explains that perhaps the chromatic difference of magnification is neutralized by the same physiological mechanism as for the focus difference. What happens when the size of image is larger? The chromatic difference of magnification increases with the size of the image, but at the same time the ability to see the coloured borders diminishes, because they fall on parts of the retina that are farther removed from the place of most distinct vision. Now, if this decrease of visual acuity

were proportional to the increase of the width of the coloured border, the phenomenon of the chromatic difference of magnification, although physically present on the retina, would not be physiologically revealed by the visible appearance of coloured fringes. This physiological mechanism is adequate to mask the chromatic difference of magnification in the outlying portions of a larger retinal image.

Thus from the above discussion, it may be concluded that the physical phenomenon of chromatic aberration is physiologically neutralized or effectively masked in the eye. Perhaps when such a mechanism is disturbed due to some defect or injury in the eye, the effects of chromatic aberration may reappear. This conclusion seems to be validated by the findings of Allen (1964). He found that most of the drivers he investigated had eye defects (called chrome steropsis) which caused them to think that red tail lights are farther away than they are (a chromatic aberration effect). The physiological mechanism to neutralize the effect of chromatic aberration in the eye might have been impaired due to this defect (chrome steropsis).

Even if we accept the view that the eye suffers from chromatic aberration, this hypothesis has met with great difficulty in explaining the perception of depth due to colour. The role of chromatic aberration in depth perception has been extensively studied by Karwoski and Lloyd (1951). Red, yellow, green and blue spots of light were judged for depth perception. They found that accuracy for judging depth for different spectral lights

decreased in the order yellow, red, green and blue. They framed a further hypothesis that the above order was due to chromatic aberration effect, i.e. where the stimulus object was perceived as blurred. This blurredness accompanying chromatic aberration, which according to them was the highest in blue, was given as the causal factor for blue being perceived as further. On the other hand, the threshold detectability curve plotted against wavelength by Harvich and Dorothea (1953) shows that the visual system is most sensitive to light in the green part of the spectrum and least to that in the red. In this connection Dember (1960) says, "..... if it is desirable to maximise the detectability of a stimulus and that stimulus must be monochromatic, then green is the colour to choose. On the other hand, to minimise detectability, you would use red light." (p. 126-127). Further, if chromatic aberration with its blurredness effect is offered to explain blue as the most blurred light, and as such, perceived as farther away, how can the results of Pillsbury and Schefer, and the negative results of Luckiesh, as mentioned above, be explained where blue was perceived as nearer? Hence, from the above discussion it may be concluded that the chromatic aberration hypothesis can not effectively explain this phenomenon.

A third kind of theory put forward to explain this phenomenon is that colour is originally depthless but acquires depth as a result of learning. This explanation, of course, partially accepts hue as a distance cue. When the situation of perceiving the distance of a brightly coloured object occurs, the conscious

sensation involves the association of past experience with aerial perspective as a learned cue in depth perception. This theory tends to account for the results in terms of an associative rather than a retinal mechanism. Johns and Sumner, reported earlier, suggest, for example, that blue objects are judged to be farther away than red objects because of past experience with aerial perspective.

In essence this theory is not very different from that of chromatic aberration. The theory of chromatic aberration of the eye explains blurredness as a cue to distance by a retinal mechanism, whereas the association theory explains the same thing (that is, shady and hazy objects appear further and distinct and clear objects nearer) by an association process with past experience. This theory cannot explain those results where blue objects appeared nearer.

Another explanation is that the different refractive indices of the ocular media for radiant energy may be responsible for causing this effect. Blue light suffers refraction more than red light. Microelectrode and EEG studies (Bushkirk, 1952) show that the nerve impulse due to blue rays is weaker (smaller) than that due to red rays. Moreover, blue light loses much of its intensity in the ocular media than red light (Benoit, 1964).

Attention has also been used to explain the phenomenon under investigation. Arguments are put forward that those stimuli which are more interesting, pleasant and attractive will

catch a subject's attention and so those things will appear nearer than dull things. This explanation has been especially offered by those investigators who did not control the stimulus presentation. For example, in the study by Taylor and Sumner, reported earlier, the movable pole was always on the one side of the subject, mainly on the right. Some of the investigators asked the subjects to move the coloured objects consistently with the right hand. As a result, those objects might get more attention. But this effect could be neutralised as far as possible by providing one stimulus on the stationary pole half of the time and on the movable pole another half of the time and appearing at subject's right half of the time and at left another half of the time.

Another explanation, offered by Katz (1935), Exner (1906), Belaiew-Exemplarsky (1925) and others, is the insistence quality of certain colours. Certain colours are more intense or in Katz's term more "eindringlich" by which is meant that they seem to stand nearer. Red has certainly this quality. To quote Katz "this difference in insistence is the basis for the fact that reds seem to stand nearer to us than blues" (p. 69). What does this term "insistence" or its German counter-part "eindringlich" really mean? Katz defines "insistence" (his own translation of eindringlich) as "the power of catching the eye more readily and of holding it more steadily" (p. 108). But why is red more insistent than blue? Katz does not seem to answer this question. Belaiew-Exemplarsky uses the term "grellheit" to

describe the quality that makes a colour appear nearer. The two terms are almost identical in their meaning, but grellheit is more specific. It means the strength with which light affects, stimulates physiologically. Actually speaking, they are not explanations, they are merely descriptions.

From the above review, it appears that many of the studies mentioned were lacking proper controls and that most of the theories, many of them arising from the experimental conditions, are either unsatisfactory or inadequate to explain the phenomenon of the effect of colour on the perception of distance.

(2) The present investigation

The hypothesis

Our hypothesis is that for red and blue light spots, at the same distance, of the same intensity and of the same size, when presented in reduced cue conditions (in dark-room, using one eye and with rigid head fixation), red would appear nearer than blue.

A preliminary experiment

To test the above hypothesis we carried out a pilot experiment with ten students of the Psychology Department, University College London. The apparatus consisted of a wooden box (67 cm. x 15 cm. x 18 cm.) painted black inside and outside and divided longitudinally into two alleys. At the end of each alley there was a 40 watt fluorescent lamp giving an illumination of 15 FC. Red and blue filters (Kodak Wratten Gelatine Filter) were used to provide coloured illumination.

The stimulus objects were two circular grey spots (1.5 cm. in diameter). The two grey spots were, under the coloured illumination, visible by both the eyes of the observer. Subjects were asked to equate them for distance by moving them nearer or farther by means of strings and pulleys. The results showed that to equate the two spots, Ss had always to move the spot under red illumination. This means that under red light the spot appeared nearer than it did under blue light.

MAIN EXPERIMENT

Subjects

Forty Ss, thirty four males and six females, were employed in this experiment. They were all students of the University of London. Each S was tested for colour blindness by the Ishihara Test.

Apparatus and method

On the basis of the pilot study the apparatus was modified as follows:

1. Though there was a partition separating the two light spots in the box, the two spots sometimes superimposed on each other making their perception difficult. This difficulty was removed in our new apparatus by introducing mirrors so that Ss could see the two spots quite clearly without their being superimposed.
2. The size of the spot was used as a cue by almost all Ss. When Ss moved either of the spot forward or backward, the

size changed with corresponding change in distance. Thus they used size as a cue to distance. Over (1962) found that a stimulus of longer wavelength would appear bigger and nearer than the one of a shorter wavelength. The question arose: to what Ss responded, to size or to distance? It is difficult to get the answer from Over's design. To avoid these two difficulties we presented the stimuli in our new design of the apparatus in such a way that the size of the retinal image of the stimulus would remain constant no matter whether it is moved farther or nearer. This was achieved by having a light-chamber run over a rail. The aperture of the light-chamber became smaller or bigger as it was moved nearer or farther. Figures 1, 2 and 3 show the general features of the new apparatus. Two scales were attached to two sides of the box over which ran a pin attached to the rail to give a reading of how far S had moved the light-chamber.

3. We did not use a head-rest in the pilot study. But we found that slight head movement could change successive perceptual readings. So, we introduced in the new apparatus a chin-rest and a rigid head-rest.

General procedure

The two light spots (red and blue), equated for brightness by each individual S, were presented at five different distances from Ss eyes $\nearrow$ 55 cm., 60 cm., 65 cm., 70 cm. and 75 cm., the order

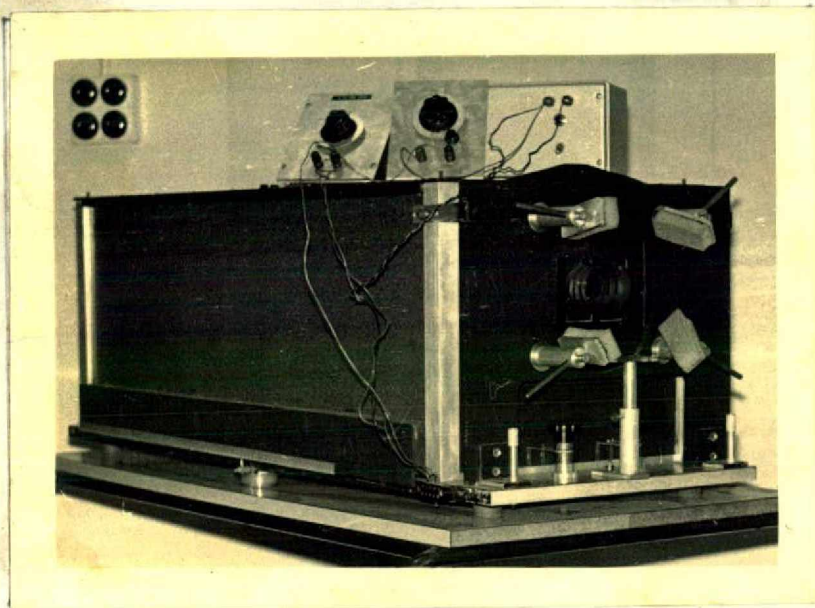


Fig.1. Apparatus used for the investigation of the effect of colour on the perception of distance.

being randomised and the two light spots being presented at equal distances each time. In half the trials S moved the red spot, blue being stationary, and in another half he moved the blue spot, red being stationary. So, in each position there were two conditions (once red being movable, and once blue being movable) and for each condition S had two trials. Thus, in all there were twenty trials with each S. With alternative Ss, stimulus-side was changed, i.e. with one S red having on the right and blue on the left, the next S had red on the left and blue on the right and so on.

The experiment was carried out in a dark room. Before the start of the experiment each S was given a colour blind test (the Ishihara Test). When he qualified in the test, he was led to the experimental room and was seated before the apparatus. He had his chin and head rigidly fixed by a chin and head rest to prevent the head moving laterally.

He was then given the following instructions:

When right-hand side spot is movable:

"You are to look through this aperture with your one eye. You may use your preferred eye. You are seeing two coloured spots. What I want you to do is to make them appear equal in distance from you by moving this knob at your right (showing the knob). Remember, clock-wise movement of the knob moves the right-hand side spot farther and anti-clock-wise movement brings it nearer. When you think that the two spots are at the same distance from you, say 'yes' and take your hand from the knob."

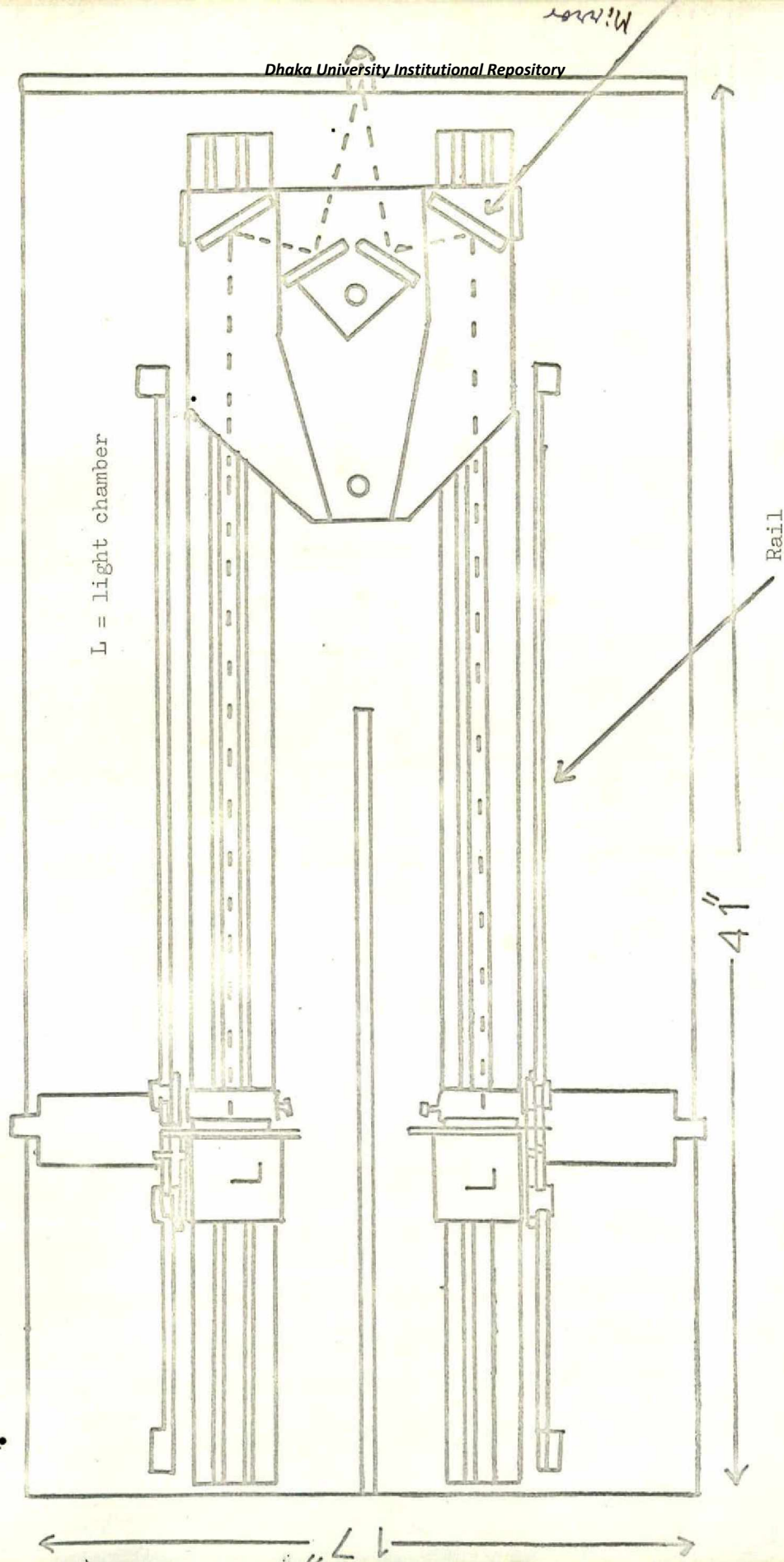


Figure 2. Inside top view of the apparatus shown in Figure 1.

When the left-hand side spot is movable:

"Now you are to do exactly what you have done before; but this time you are to use the knob at your left. Remember, in this case clock-wise movement of the knob brings the coloured spot at your left-hand side nearer and anti-clock-wise movement moves it farther."

To make it sure whether S had followed the instructions, he was given some practice trials before the experiment was started. Before each trial the light in the box was put off and the two spots were reset. Care was taken that S might not know at all where E was putting the two spots before each trial. Each S had some rest during the resetting of the two spots before each trial. He had, in addition to that, a five minutes' rest at the middle of the experiment.

Though the projected size of the two light spots was made independent of distance, it is possible that under red light the spot may appear bigger to Ss. To check this the last five Ss in Group A were instructed to report on the relative sizes of the two spots before they started moving them.

In Group A, Ss compared red and blue spots directly. In Group B, red and blue spots were compared indirectly. In this group there were two sections, in one section Ss compared red with neutral grey and in another they compared blue with neutral grey. This was done to see whether red appears nearer in comparison with neutral grey and blue appears farther away in comparison with neutral grey.

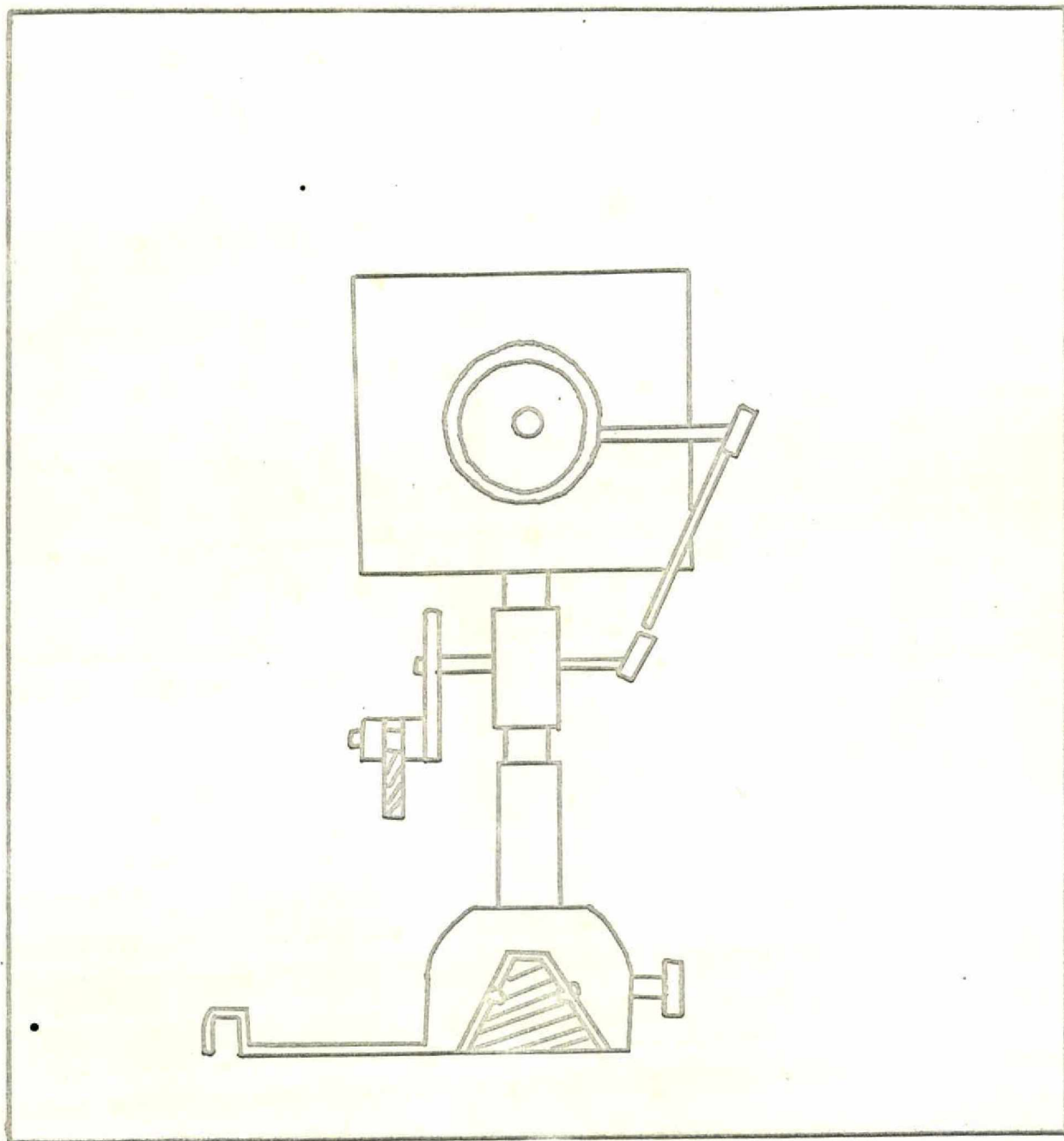


Fig.3. Variable aperture light-chamber shown (L) in Fig.2.

Ss	1					2			3
	Distances at which the stimuli were presented					Score		Sign	X = $\frac{\Sigma +ve - \Sigma -ve}{N}$
	55 cm.	60 cm.	65 cm.	70 cm.	75 cm.	+ve	-ve		
13	+18.9	+32.7	+20.0	+1.8	+10.6	5	0	+	84.0
14	+14.1	+23.4	+10.2	+17.9	+20.0	5	0	+	85.6
15	+20.2	+9.5	+4.2	+37.0	+38.5	5	0	+	109.4
16	+4.7	+14.8	-4.3	-3.5	+9.2	3	2	+	20.9
17	+5.0	+7.8	+15.2	+1.5	+21.8	5	0	+	51.3
18	+32.0	+16.5	+36.5	+36.3	+23.0	5	0	+	144.3
19	+16.7	+19.3	+26.1	+11.8	+13.8	5	0	+	87.7
20	+31.3	+48.5	+46.3	+54.9	+60.0	5	0	+	241.0
21	+8.5	+16.3	+19.5	+12.5	+9.0	5	0	+	65.8
22	+19.5	+16.0	+20.8	+8.2	+10.2	5	0	+	74.7
23	+17.3	+21.5	+26.0	+43.7	+38.1	5	0	+	146.6
24	+21.7	+31.7	+42.3	+44.5	+43.7	5	0	+	183.9
25	+9.5	+13.0	+8.0	+12.3	+7.3	5	0	+	50.1
26	+26.3	+38.7	+48.0	+56.4	+58.2	5	0	+	227.6
27	+15.8	+24.4	+41.1	+32.7	+34.8	5	0	+	148.8
28	+9.2	+23.0	+26.0	+42.1	+21.5	5	0	+	121.8
29	+2.5	+7.8	+6.5	+4.1	+0.3	5	0	+	21.2
30	0.0	+2.8	-0.5	+6.2	+4.5	3	1	+	13.0
Mean	11.43	14.77	17.61	19.85	21.63	-	-	-	85.29

Statistical analysis

1. Sign test: Sign test (Siegel, Non-parametric statistic, p. 68) was computed between positive and negative scores (column 2, Table 1) as follows:

$$Z = \frac{(x + .5) - \frac{1}{2} N}{\frac{1}{2} \sqrt{N}}$$

Where x = number of lesser signs, 2 in our case;

N = total number of signs, 30 in our case.

If $Z > \alpha$ then Z is significant, where α = probability at which level the test is to be ($\alpha = .05$) judged.

$Z = 4.56$, $P < .001$, so Z is significant.

2. Analysis of variance

One way classification analysis of variance was done for all five distances in order to determine whether distance was a significant source of variation.

Table of analysis of variance

Source	d.f.	Sum of squares	Mean Sum of squares	F	5% F	Conclusion
Between	4	1976.55	494.14	$\frac{494.14}{250.07}$	2.43	F not significant so distance was not a significant source of variation
Within	145	36259.70	250.07	= 1.98		
Total	149	38236.25	-			

3. t-test (related measure) was done between sum of plus scores (red being behind blue) and that of minus scores (red being in front of blue) ($\Sigma +ve - \Sigma -ve$, Column 3, Table 1).

$$t = \frac{\bar{x} \sqrt{N}}{\sigma}$$

$$\bar{x} = 85.29$$

$$N = 30$$

$$\sigma = 110.54$$

$$t = 4.22$$

d.f. = 29, t is significant ($P < .0005$, one-tailed test)

This means the difference between red and blue with reference to distance is highly significant. That is, according to our hypothesis red appears nearer than blue.

Group B

The following figures show the actual physical distances in centimetres between red and neutral grey when they appeared to Ss to be of equal distance. Plus sign means red was behind neutral grey and minus sign means red was in front of neutral grey.

Table 2
(Comparison between red & neutral grey)

Ss	1					2		Sign	3
	Distances at which the stimuli were presented 55 cm. 60 cm. 65 cm. 70 cm. 75 cm.					Score +ve -ve			
1	+11.7	+14.5	+12.0	+19.0	+5.4	5	0	+	62.6
2	+34.0	+50.5	+18.2	+33.0	-3.3	4	1	+	132.4
3	+2.2	+16.8	+7.6	+1.8	+27.9	5	0	+	56.3
4	+16.5	-1.8	+31.1	+35.1	+28.3	4	1	+	109.2
5	+4.8	+14.5	+12.8	+13.1	+13.8	5	0	+	59.0
6	+13.5	+23.0	+23.4	+29.7	+24.3	5	0	+	113.9
7	+2.3	+5.1	+11.4	+11.0	+3.9	5	0	+	33.7
8	+9.4	+11.5	+11.2	+6.0	+19.8	5	0	+	57.9
9	+2.3	+13.2	+17.1	+0.8	0	4	0	+	33.4
10	+4.9	+10.8	+5.3	+21.8	+3.2	5	0	+	46.0
Mean	10.16	15.81	15.01	17.13	12.33	-	-	-	70.44

Statistical analysis

1. Sign test

Sign test (between positive and negative scores, Column 2, Table 2) showed that minus signs (fewer signs) had a one-tailed probability of occurrence under H_0 of $P = .001$.

2. t-test

t-test (related measure) was done between sum of plus scores (red being behind neutral grey) and that of minus scores (red being in front of neutral grey) ($\Sigma +ve - \Sigma -ve$, Column 3, Table 2) as follows:

$$t = \frac{\bar{x} \sqrt{N}}{\sigma}$$

$$\bar{x} = 70.44$$

$$N = 10$$

$$\sigma = 82.10$$

$$t = 2.71$$

$$d.f. = 9, t \text{ is significant } (P < .025, \text{ one-tailed test})$$

Significant t shows that red appeared nearer than neutral grey.

• Group B

The following figures show the actual physical distances in centimetres between blue and neutral grey when they were equated in distance by Ss. Plus sign means blue was in front of neutral grey and minus sign means blue was behind neutral grey.

Table 3

(Comparison between blue & neutral grey)

Ss	1					2			3
	Distances at which the stimuli were presented					Score		Sign	X = $\sum +ve$ - $\sum -ve$
	55 cm.	60 cm.	65 cm.	70 cm.	75 cm.	+ve	-ve		
1	+5.9	+3.0	+11.7	+14.4	+8.7	5	0	+	43.7
2	+9.9	+7.4	+1.7	+11.4	+10.9	5	0	+	41.3
3	-12.6	+9.9	+9.8	-8.0	+22.0	3	2	+	21.1
4	+7.4	+22.0	+23.7	+18.1	+26.0	5	0	+	97.2
5	+9.6	+6.9	+5.0	+8.4	-0.7	4	1	+	29.2
6	+11.2	+11.7	+20.1	+24.9	+28.7	5	0	+	96.6
7	+11.2	+19.5	+22.0	+28.5	+20.4	5	0	+	101.6
8	+9.6	-1.8	-3.7	+5.6	+1.6	3	2	+	11.3
9	+12.0	+21.4	+29.0	+27.2	+25.0	5	0	+	114.6
10	-5.0	-2.2	+5.6	+15.2	+18.3	3	2	+	31.9
Mean	5.92	9.78	12.49	14.57	16.09	-	-	-	58.85

Statistical analysis

1. Sign test

Sign test (between positive and negative scores, Column 2, Table 3) showed that minus signs (fewer signs) had a one-tailed probability of occurrence under H_0 of $P = .001$.

2. t-test

t-test (related measure) was computed between sum of plus scores (blue being in front of neutral grey) and that of minus scores (blue being behind neutral grey) ($\Sigma +ve - \Sigma -ve$, Column 3, Table 3) as follows:

$$t = \frac{\bar{x} - \sqrt{N}}{6}$$

$$\bar{x} = 58.85$$

$$N = 10$$

$$6 = 73.25$$

$$t = 2.54$$

d.f. = 9, t is significant ($P < .025$, one-tailed test)

Significant t shows that blue appeared farther away than neutral grey.

DISCUSSION

From the results (Table 1) it appears that to equate in distance Ss had to move the red light spot farther away or the blue light spot nearer towards them. The difference between the two light spots in physical distance, when they appeared to be of equal distance, was highly significant ($P < 0.0005$). Hence, it may be concluded that red appeared nearer than blue. Only one subject (S11, Table 1) consistently perceived blue as nearer.

In our design of the apparatus (Figures 2 and 3), the presentation of the stimulus objects was such that their projected sizes remained the same no matter whether they were moved farther away or nearer. That is, the effect of size on the judgement of distance was minimum. From this it may be concluded that Ss responded to the variation in wavelengths of the radiant

energy and not to the size of the stimulus. To check this, we asked the last five Ss in Group A to report on the relative sizes of the two coloured spots before they started moving them before each trial. They all reported that the two spots were equal in size. After the experiment, each S was asked as to how he made the adjustment (to equate the two spots in distance). No one could give any definite clue, and most of them said that they did it just by seeing them.

In Group B, we found that when Ss were asked to equate the red and neutral grey spots, red was moved farther away. This means that red was perceived nearer than neutral grey. Secondly, when they were asked to equate the blue and neutral grey spots, blue was brought nearer. This means that blue was perceived as farther away than neutral gray. So, it may be concluded that red advances and blue recedes.

Error in the judgement of distance under coloured light

Figure 4 shows the percentage error in the perception of stimulus objects under red and blue light. There is more error in the perception of distance under blue light than under red light. And the direction of error was that under red light things appeared nearer than under blue. Contrary to these findings, Allen (1964), in his study of night vision of drivers, found that most of the drivers studied, perceived red as farther than blue or green. How can these contradictory results be explained?

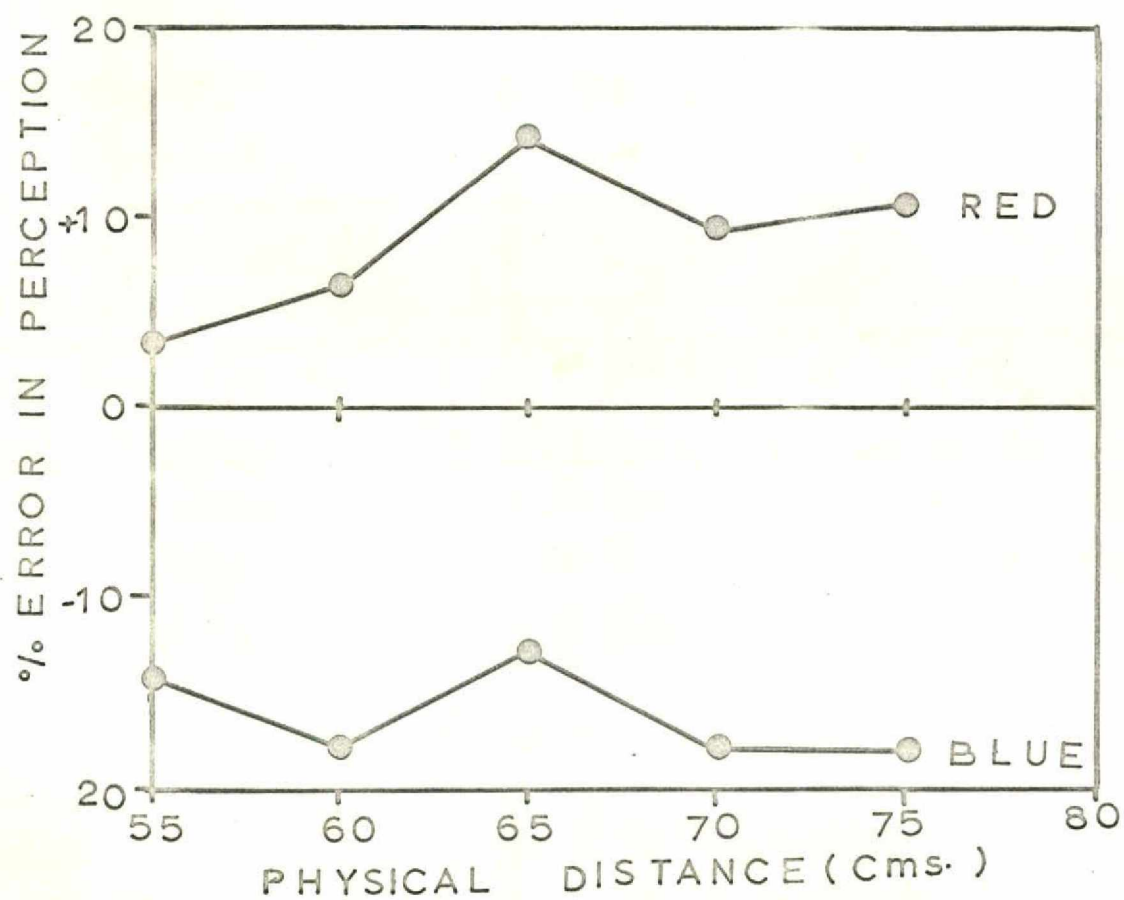


Fig.4. Error in judgments of distance under red and blue light.

Let us consider the method and procedure of Allen's and our experiments. The distance judged in our experiment was comparatively short, ranged between 55 cm. - 75 cm. Though there is no mention of the range of distance Allen used, it may be assumed from the surroundings of his experiment, that he was concerned with longer distance. We are not sure, whether the phenomenon we studied would be reversed in cases of longer distance. Mount et al. (1956), however, found that comparatively red appeared nearer than blue when the stimuli were presented at a distance of 200 ft. from Ss.

The second factor to be considered is that whereas we were concerned with monocular vision, Allen was concerned with binocular vision. At this stage we cannot say how far this factor was responsible for the differences in results in the two experiments. However, Mount et al. (1956) obtained results similar to ours in binocular vision.

Thirdly, Allen noted that most of the drivers he studied had eye defects (called chromostereopsis) which he said made them think that red was farther than green or blue. We may not rightly comment on this point because we did not test our subjects for chromostereopsis. Allen may be right that in persons with chromostereopsis the perceived relative locations of red, green and blue change in which red appears farther than blue or green. Allen also described two other defective visions which

might reverse the phenomenon we studied. One is protanopic vision in which there is a reduced sensitivity to red. The loss in perceived brightness or sensitivity to red is interpreted by protanopic persons as an increase in distance. The second factor is hypermetropic vision. Under this condition, wrote Allen, red objects will appear most blurred. This condition of the eye causes red light to appear less bright and out of focus as a result of which red appears farther away than blue or green.

However, we can only conclude that in short distance and in monocular vision red appears nearer than blue. To determine whether this error in perception was a function of different distances judged, analysis of variance for the five distances was done. The F ratio (2.43) was not significant at the .05 level. This shows that the error in the judgement of distance under the two coloured lights was independent of distances judged. Nevertheless, 65 cm. distance (Fig. 4) had distinct but opposite effects on the judgement of distances under red and blue light. At this point, the error increased under red light but decreased under blue. It is, however, not clear why it so happened at this particular point.

The question still remains as to the reason for these results. There is, however, experimental evidence for the proposition that red light stimulates physiologically more than blue does (Goldstein, 1942; Gerard, 1958) and it is possible it is this difference between the two colours to which underlies the

distance judging phenomena. Regarding the effects of colour as a physiological stimulus, Gerard (1958) has reported:

- (a) blood-pressure increases under red light and decreases under blue light;
- (b) in palmer conductance, both colours produced immediate increase, but conductance after a period of time was consistently higher for red than for blue;
- (c) respiratory movements increased during exposure to red light and decreased during exposure to blue light;
- (d) in heart rate there was no appreciable difference between the stimulation by red and blue light;
- (e) frequency of eye blinks increased during exposure to red light and decreased under blue light; and
- (f) about EEG arousal, the brain was markedly affected by the introduction of the two lights, but with time, activation remained consistently greater for red than for blue. Data on the differential effects of red and blue light on EEG activity have been reported by Carterette and Symmes (1952) and recently by Sanders and Liske (1967).

We have seen that red activates, but what about blue? Why does it not do so? Why red affects the autonomic nervous system more than blue was extensively studied by Benoit (1964) and Hollwich (1964). Their studies were mainly concerned with the photo-neuro-endocrine effects of light.

Lens, cornea and other optic media absorb light in the

blue end of the spectrum more than in the red end. This has been clearly shown in duck experiments by Benoit. As has been already mentioned, immature male ducks were submitted to illumination by monochromatic light (ultra-violet, indigo, green, blue, yellow, orange and red being studied) with the same quantities of energy (40.4 foot candle). The testes of the ducks (light being applied to the eyes of the ducks) only responded to orange and red radiations. Hollwich (1964), in a similar experiment on immature male ducks, confirmed this maximal activity of red radiation.

When Benoit repeated the same previous experiment with a quartz rod technique which enabled him to throw light directly on the hypothalamus, the testes responded to short wavelengths (indigo and blue) as well as to long wavelengths (red and orange). Another experiment by the same author proves this conclusively. Two ducks were placed at a distance of two metres from a 25 watt source of light. One duck was intact, another was submitted to removal of the eye and orbital tissues and perforation of the orbital bones, so that light could fall directly on the hypothalamus. Under these conditions, the size of the testes increased more in the operated than in the intact animal.

Penetration of light to the hypothalamus across the eye and the orbital tissues has been studied by Benoit by means of both photographic and photo-electric methods. He found the transmittance through the tissues is very weak for short wavelengths (violet,

blue, green) but greater for longer wavelengths (yellow, red). So, red rays can penetrate to the hypothalamus with sufficient intensity to activate the deeper photo-receptive structures than can the shorter wavelengths such as blue.

Another quality of red is that its nerve transmission is faster than that of blue. Chang (1952) found that the conduction velocity of nerve impulses due to red light is faster than the nerve impulses due to blue light. Lennox (1958) also found that short wavelengths (blue end) are preferentially signalled by fibres of slow conduction velocity and long wavelengths (red end) by fibres of faster conduction velocity.

Thus it has been established that red light is more potent in causing arousal in the organism than is blue light. But it is still necessary to see that this quality of red is responsible for red being perceived as nearer. We shall describe below an experiment to investigate this problem further.

A further investigation into the problem of distance perception as a function of colour

Our first experiment has shown that light of long wavelength produces an apparent decrease in distance as opposed to light of short wavelength. We tried to explain this phenomenon in terms of the differential physiological effects of the two colours on the organism. It was not, however, clear from the previous experiment whether perceived hue as opposed to incident wavelength was the crucial factor. In this experiment we want to examine whether long

wavelength radiation outside the visible spectrum also provides an apparent decrease in distance. Infra-red radiation was chosen to study because to infra-red there is no perceived hue but the wavelength is near to that of red.

With this purpose we had two stimulus conditions, one, white light with infra-red and the other, white light without infra-red. We wanted to investigate whether the white light with infra-red would be perceived as nearer than the white light with infra-red being cut off.

The hypothesis

Hot white light would be perceived as nearer than cold white light.

Subjects

Ten subjects were employed in this experiment. All of them were students of the Psychology Department of University College London. Their ages ranged between 18 years and 24 years.

General procedure

A plan of the apparatus used in this experiment is shown in Fig. 5. The apparatus consists of two powerful lamps (300 watt, emitting white light and infra-red heat). There is a water-cell in front of one lamp and during the experiment cold water was passed through the cell with the help of a water pump. The two light spots were at a distance of 35 inches from the observer's eyes. There was a screen before the observer with two holes 2½ inches apart through which he would look at the light spots.

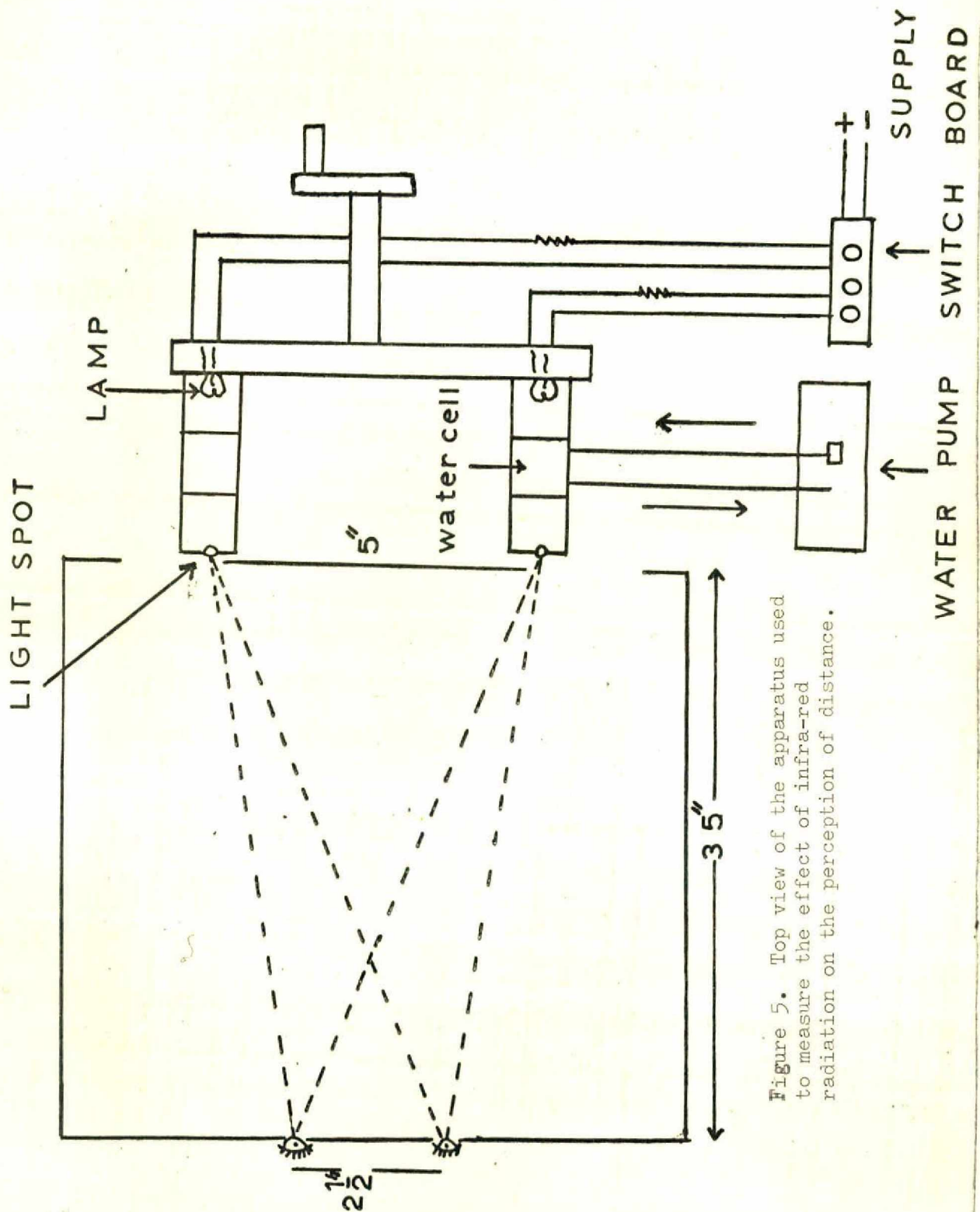


Figure 5. Top view of the apparatus used to measure the effect of infra-red radiation on the perception of distance.

Table 4

Ss	HL	HR	HR	HL	HR	HL
1.	-	+	+	-	-	+
2.	+	-	+	+	-	+
3.	-	+	+	-	-	-
4.	+	-	+	+	-	+
5.	+	-	-	+	-	+
6.	+	-	-	+	-	+
7.	-	+	+	+	+	+
8.	-	+	+	-	+	+
9.	-	+	+	-	+	+
10.	-	+	+	-	+	-

($P = 0.60$). So, it seems that infra-red did not have any perceptual effect of any significance on the observer. In other words, long wavelength radiation outside the visible spectrum fails to produce the effect observed in the first experiment. This is, however, not surprising. The human eye may not be sensitive to infra-red radiation. Griffin and Hubbard^{and Wald} (1947) found that the human retina (central fovea) is not sensitive to radiation beyond 1000 $m\mu$. They also found that the peripheral retina is not sensitive beyond 1050 $m\mu$. Beyond this range, they found, radiation should be felt more readily as heat by the skin than seen as light by the eye.

The non-significant results in this experiment suggest the following alternatives:

- (a) Hue is important for the phenomenon observed in the first experiment; or
- (b) Infra-red is not as activating as red, or indirectly, activation is important for the phenomenon to occur; or
- (c) Both (a) and (b). That is, perceived hue and activation together may be responsible for the phenomenon of an apparent decrease in distance observed in our first experiment.

P A R T I I

The perception of time and the effect of light and colour

1. A review of the studies of the phenomenon of time perception

"The psychological problem of time is no longer to know either what time is or what is the nature of our notion of time, nor is it even to seek the genesis of time in some intuition or construction of the mind; it is to understand how man reacts to the situation imposed on him of living in time," (Fraisse, 1963, p. 10). With this notion, the phenomenon of the perception of time (which once was in the domain of purely philosophical speculation) has been subjected to scientific experimentation more vigorously in this century. Since then different aspects of this problem have been studied, such as:

- (1) The perception of short and long time intervals;
- (2) The perception of filled and unfilled time;
- (3) Individual differences in the estimation of time (Woodrow, 1933);
- (4) Sex differences in time estimation (McDougall, 1904);
- (5) Sleep and time perception (Boring and Boring, 1917; Brush, 1930);
- (6) The estimation of time under hypnosis (Richardson and Stalnaker, 1930; Loomis, 1951; Cooper and Ericson, 1954);
- (7) Occupation and estimation of time (Gulliksen, 1927);
- (8) The judgement of temporal intervals and the spatial circumstances in which they arise (Abe, 1935; Abbe, 1936; Price-Williams, 1954; Cohen et al., 1955);
- (9) Physiological variables, such as, circulation, heart rate, respiration, temperature, and chemical changes of the metabolism, and the estimation of time (Pieron, 1929, 1952;

Francois, 1927; Hoagland, 1933, 1934-35, 1943, 1950; Gardner, 1935; Schaffar and Gilliland, 1938).

A detailed discussion of these phenomena would be out of place in our present study. However, there are one or two interesting findings in some of these studies which require some consideration. Some of the studies show that there is a wide discrepancy between real time and perceived time. An interval of physical time that is filled with pleasant events usually seems to be shorter than the same interval which is filled with monotonous or painful events (Gulliksen, 1927). The time spent in learning a single task will seem to be shorter than the same period of time spent in learning several shorter tasks of identical character (Hartn, 1939). A familiar journey seems to take less time than an unfamiliar one (Cohen, 1954).

On the other hand, that man is able to estimate time accurately is proved by every day experience and by results from controlled experiments. Certain individuals, for example, are able to awake at a predetermined time (Boring and Boring, 1917; Hall, 1927; Brush, 1930; Clauser, 1954), to state the time of the day on demand without any reference to environmental changes (Hall, 1895), and to reproduce time intervals with great precision (Woodrow, 1930; Sturt, 1923). Animal studies also show this temporal orientation. Bees were given water containing different concentrations of sugar at different times of the day,

after a few days most of them arrived at the time when the strongest concentration was due (Wahl, 1933). Fish used to come every day at the same time to the same place at which they were fed (Braunschmid, 1930, reported by Fraisse, 1963). The experiment by Renner in 1955 (reported by Fraisse, 1963) is even more conclusive. He trained bees to come for food at a certain hour in an experimental room in Paris. They were then moved, between two feeding times, from Paris to New York. Here they were placed in an identical room and deprived of food. On the following days they came for food at the same time as in Paris, regardless of the difference in the time of day between Paris and New York. When the experiment was repeated taking back the bees from New York to Paris, the same result was obtained.

Different theories have been put forward to explain these phenomena.

According to one group of theorists "duration" is a fundamental aspect, attribute, or dimension of experience, and this forms the basis of temporal judgements (Titchner, 1909). Others hold the view that judgements of temporal interval are derived from the synthesis of sensory data, chiefly from sensations or feelings of strain (Munsterberg, 1889). For another group, the perception of duration arises only with change. According to them, time stops, if all change stops. "..... that time does not exist without change" (Aristotle Physics, Book IV, reported by Fraisse, 1963).

Still another group talks about temporal signs. Lipps (1883), for instance, ^{says} ~~syas~~ that sensations are born and then obliterated; the degree of obliteration of two sensations at a given moment corresponds to their position in time. James (1908) adopted the view of Lipps, save that he restated it in terms of brain traces. The fainter the trace, he held, the longer seems the time since the impression that carried it.

Another group proposes that temporal cues consist of processes connected with the activity of attention. As a result of the act of attention various feelings or sensations may be supposed to occur. Some sort of strain, attributed to the process of attention, is the cue for judgements of duration. Katz (1906, reported by Fraisse, 1963) has expressed this as follows: "Every time we turn our attention to the course of time, it seems to grow longer." In connection with attention, Schumann (1893) also stressed the role of the feeling of surprise when the end comes sooner than expected and that of the feeling of intensified expectation when the end is delayed.

Another group of experimenters have shown that the perception of time is related to and dependent upon the perception of space and movement. Abe (1935) and Abbe (1936) in Japan and recently Cohen and co-workers (1955) have shown this phenomenon. The experiment by Cohen and co-workers is interesting. They showed the subject a repeated succession of three equal flashes of light. The distances separating the lights were varied by the experimenter.

S was asked to adjust the time interval, which he could do by adjusting a lever, so that the temporal interval between flashes 1 and 2 was equal to flashes 2 and 3. Curiously enough, S increased the temporal interval as the relative distance between the corresponding flashes was increased. The authors designated this phenomenon as the 'Kappa-effect' to distinguish it from its counterpart the 'tau-effect' which was discovered by Helson and King (1931). Price-Williams (1954) has carried out independent experiments confirming this effect.

A distinct and quite different approach to the study of time perception was introduced by Pieron (1929, 1952) and his pupil, Francois (1929). Pieron (1923, quoted by Fraisse, 1963) first put forward the hypothesis that experienced time will be proportional to the speed of certain on-going physiological processes: " And if the speed of organic processes is modified, by variations in temperature for example, mental time will increase or decrease proportionately." In line with this, Francois (1929) showed that raising temperature of his Ss by diathermy was accompanied by an increase in the unit of perceived time.

This work has been elaborated further by Hoagland (1933, 1935, 1936, 1943, 1950). He was influenced by the work of Pieron and Francois and by those works on the spontaneous firing of nerve cells by Adrian and Buytendijk (1931). Investigators have shown that rhythmic fluctuations of electrical potential occur in groups of cells in respiratory centres of the nervous system. These

fluctuations produce bursts of nerve impulses over efferent nerve fibres. This basic activity has been shown to be quite independent of afferent control (Adrian and Buytendijk, 1931). The relation of temperature to the rhythmic execution of creeping movements in poikilothermic animals, and of such rhythmic phenomena as the stridulations of crickets led Crozier and Stier (1924-25) to suggest that the particular mechanism underlying each of these effects ^{is} ~~is~~ of the nature of an irreversible chemical reaction in cells of the nervous system. The frequency of the emission of bursts of efferent impulses was assumed to be directly proportional to the velocity of the underlying reactions.

The repetitive discharge of nerve impulses from the lateral-line receptors of fishes (Hoagland, 1936) and the effect of temperature on the frequency of these impulses considered in the light of the fore-going facts, suggested to Hoagland the possibility of investigating the estimation of duration as a function of temperature. If our judgements of time depend upon an underlying chemical 'master-reaction' in cells of the brain, modification of the internal body temperature might be expected to alter judgements of time.

In his first experiment, Hoagland asked an influenza patient to count 60 seconds to herself at a rate of what she believed to be 1 per second. The actual duration of the count was marked with a stop watch. Following are the data of this experiment taken over a period of 48 hours:

Table 5

Temperature ($^{\circ}\text{F}$)	Mean secs. per counted minute
103.0	37.5
102.0	36.0
99.6	46.0
99.0	48.0
100.0	43.5
97.4	52.0

(from Hoagland, 1933)

To eliminate the influence of pathological factors which might have been involved in this experiment, he repeated the experiment on a normal subject, who agreed to submit himself to diathermy treatment. The subject was exposed to a high frequency alternating current until his temperature (by mouth) reached 38.8°C . At each of several temperatures the subject was asked to estimate the intervals of one minute by the method of the previous experiment. The results confirm the findings of the previous experiment.

These data led Hoagland to suggest that there is a specific chemical clock located in the nervous system which furnishes its possessor with a subjective time scale. Various changes in the immediate environment of this chemical clock may modify its velocity. Such changes may be those of temperature or variations in the activity of sensory and motor areas of the brain, acting to

accelerate or to inhibit the continuous chemical mechanism. A good example of this kind of effect is provided by the activity of the respiratory centre. The excised brain stem of the goldfish has been shown by Adrian (1931) to emit rhythmical fluctuations of electrical potential at exactly the frequency of normal, resting opercular breathing rhythms of intact fishes. "It is, not unreasonable," says Hoagland, "to suppose that chemical changes locally produced in the brain by excited groups of neurons would increase the velocity of our hypothetical clock, making time appear to pass more rapidly when we are active" (Hoagland, 1933, p. 277).

The basic notion of this chemical clock of Hoagland has been challenged by the works of other experimenters such as those of Stevens (1902), Schaffer and Gilliland (1938), Gardner (1935) and others. But their results cannot be accepted without criticism, for, there seem to have been some flaws in the methodology of some of these experiments. For example, in their experiment, Schaffer and Gilliland, it appears, used the same group of subjects in the two sessions of the experiment, namely the normal session (physiological readings normal) and the excitation session (increased physiological functions followed by vigorous exercise). It seems that they used the same intervals of time to be estimated in both the sessions. As a result, learning to estimate time in the first session helped Ss in the second session. So, the effect of increased physiological functions (physiological processes studied were pulse rate, heart-beat, breathing rate, and blood

pressure) on the estimation of time might have been compensated for by the effect of training which Ss got in the first session. So, although these findings show that one should be cautious about accepting the 'chemical clock' hypothesis of Hoagland, they in no way pose a serious counter-argument against this hypothesis.

Animal experiments also lend support to the internal physiological clock hypothesis of Hoagland. In an experiment it was found that bees, trained to come for food at a certain time, would come early if the temperature is raised and late if it is lowered (Wahl, 1932, quoted by Fraisse, 1963). Renner's experiment on bees, mentioned earlier (page 70), also supports this hypothesis.

The pharmacodynamic effects of certain substances on the estimation of time also provide evidence for this hypothesis. Lavery and Franks (1956), who administered sodium amytal, a depressant, to a group of neurotic patients to observe its effect on their behaviour, found that many of the patients reported the experiment was soon over and it did not take a long time. But the control group reported that it took a long time. The physiological effect of the drug was that it significantly reduced the respiratory movements of the patients. The drug had a differential effect on the EEG readings, depressing the function relating to the orbital surface (where respiratory movements are controlled) to a greater extent than those related to the convexity surface. Lindemann (1932) found that normal Ss also tend to underestimate

time when under the influence of sodium amytal. Grabensberger (1934, quoted by Fraisse, 1963) found that bees and wasps trained to a 24 hour rhythm arrived early in the next morning if they were given iodothyroglobulin, which accelerates cellular exchanges. But they arrived late when administered with quinine.

As a general rule, it seems that all drugs which accelerate vegetative processes lead to the overestimation of time and those which inhibit them have the opposite effects. Under the influence of hashish and mescaline (both stimulants) time seems to be longer (Moreau de Tours, 1845; Pick, 1919; Bromberg, 1934; Favilli, 1937). Similarly, thyroxine (Sterzinger, 1935, 1938), caffeine (Frankenhaeuser, 1959) and metamphetamine (Frankenhaeuser, 1959) have the effect of making time appear longer. On the other hand, pentobarbital (Frankenhaeuser, 1959) and nitrous oxide (Steinberg, 1955; Frankenhaeuser, 1959), both depressants, make us underestimate time (all the studies referred to in this paragraph, have been reported by Fraisse; the Psychology of Time, 1963, p. 228-229).

While reviewing the different studies on the problem of time perception, we have seen the different aspects of the problem; the effect of environmental factors, internal as well as external. However, one factor was found to be conspicuously absent. It was the effect of light and colour on the perception of time. Experimental evidence exists for the fact that light and colour do cause a significant change in the physiological processes in the organism (Goldstein, 1942; Gerard, 1958; Benoit, 1964; Hollwich, 1964).

We have seen above, while discussing Hoagland's experiments, that changes in the immediate environment of the 'chemical clock' may modify its velocity. So, the external factors, such as light and colour, which cause marked physiological changes in the organism may also affect such a hypothetical clock and thus influence the judgement of time.

This hypothesis is investigated in the following experiment.

2. The present investigation

The problem: The problem of the present study is to investigate the effect of light and colour and darkness on the estimation of time.

The hypotheses:

1. Time would seem to pass more slowly (in other words, would appear longer) under red light than under blue light.
2. Time, during a dark interval, would appear to pass less slowly in comparison to that under red and blue light. We would expect that the order of the change of time under these three conditions would be as follows: red (more slowly), blue (less slowly) and darkness (far less slowly).

Subjects: 40 subjects, all students of the University of London, 14 females and 26 males, were used in this experiment. Their average age was 23 years. Each subject was tested for colour blindness by the Ishihara test.

Method, terminology and procedure

Investigators have pointed out four major methods by which short time intervals are judged in time estimation experiments.

They are:

1. Method of verbal estimation: In this method, E delimits a given interval operationally (i.e. demonstrates the duration of the standard) and S is asked to estimate verbally its duration in terms of seconds or minutes.
2. Method of production: In this method, S is instructed to delimit an interval (the judgement) operationally of a given duration (the standard) stated verbally by E.
3. Method of reproduction: In this method, E operationally delimits an interval (the standard) and then asks S to reproduce operationally an interval (the judgement) of the same duration.
4. Method of comparison: In this method, E presents two intervals consecutively and asks S to judge their relative duration by saying which one is the longer. It resembles the method of reproduction in that both involve an operative presentation of the standard.

This method has been mainly used in the investigation of contextual effects upon the estimation of time (Wright, Goldstone, Boardman and Lhamon, 1958; Weinstein, Goldstone and Boardman, 1958; Goldstone, Boardman and Lhamon, 1958; Weinstein, Goldstone and Boardman, 1958).

The relative effect of the different methods on the judgement of temporal intervals has been investigated by different researchers (Clausen, 1950; Gilliland and Humphreys, 1943; Bindra and Waksberg, 1956; Wallace and Rabin, 1960; Kruup, 1961). Most of them investigated the first three methods. Gilliland and Humphreys (1943) and Clausen (1950) found no significant alterations in results in the three methods. Kruup (1961), on the other hand, found noticeable differences between the methods.

Clausen (1950) found that the method of verbal estimation results in more overestimation of time than the other methods employed and that the method of reproduction is less consistent and less reliable. Contrary to Clausen's finding, Kruup (1961) found that in the method of verbal estimation, the majority of Ss estimated the intervals as shorter than the actual stimulus intervals.

On the basis of the above discussion, and considering the nature of the present study, the method of verbal estimation was used in this experiment. It has been pointed out that the method of verbal estimation deals with the relation of subjective time to objective (clock) time (Clausen, 1950; Kruup, 1961). So, this method would be best suited to the present problem, as this method allows an investigation of the length of the subjective temporal scale. Secondly, this method was found useful from the point of view of eliminating all possible cues which Ss might use. For example, in counting or in tapping situations, the

repetition of the sequence may help Ss as a cue. But the method of verbal estimation leaves Ss to guess only. This subjective guess was emphasised in this experiment. Thirdly, this method was especially useful when S's EEG was recorded along with his estimation of time. Movements on the part of Ss to indicate the estimation operationally during the experiment would have disturbed the EEG recording.

Some confusion has arisen from the terms used to describe the results from time studies. In some cases, for example, overestimation has been used when the response interval was longer than the stimulus interval, in other cases when the stimulus interval was longer. An apparent confusion may also arise about the terms over- or underestimation from the actual procedure by which S will indicate his estimation of time. For example, consider the data in Table 5 (page 74). The standard interval was 60 sec. and S's estimates are given in the right hand column against the temperature readings. The estimates are shorter than the standard. Now consider the results if the same experiment were done with a slight change in procedure, namely, S had to count at a rate what she believed to be 1 (one) per second until E stopped her, and E stopped her after 60 secs. (clock time, standard interval). As it appears, S would count faster with higher temperature and as such she would count more numbers giving larger estimates than the standard. Though the nature of Ss

response remained the same (faster counting under higher temperature) in the two cases, the results are described in the first case in terms of underestimation, and in the second in terms of overestimation. Thus, the terms over- or underestimation may give a wrong impression about the results if we do not take into account the method which was followed for time estimation.

We found it more reasonable to take the stimulus interval delimited by E as the standard interval and use the term overestimation when S's estimated time is longer than the standard, and underestimation when the estimated time interval is shorter than the standard.

General procedure

Ss were required to estimate time under three different conditions: (a) in darkness, (b) under red light, and (c) under blue light. The physical temporal intervals to be used were 10 sec., 25 sec., 45 sec. and 60 sec. To these conditions and time intervals Ss were randomly assigned.

The illumination was provided by a 300 watt tungsten lamp 37 inches from S's eyes. Kodak coloured filters (no. 25 for red and 38A for blue) were used to provide coloured illumination. The two coloured lights (red and blue) were equated for brightness.

Ss were asked to look at the light as soon as it was switched on and to keep on looking until it was switched off. They were then required to report as to the length of time (in seconds) for

which the light had been on, Immediately before the beginning of each trial E gave a warning signal. Ss were asked not to count during the period of illumination. The same procedure was followed during the dark session, save that Ss were asked to sit quietly without counting and to report the time between two auditory signals given by E (the words 'yes' and 'now').

3.

RESULTS

The following figures show the time in seconds estimated by S. L.C = different lighting conditions. T.I. = physical time interval in seconds.

Table 6

L.C.	Dark	Red	Dark	Blue	Red	Blue	Red	Dark	Blue	Dark	Blue	Red
T.I.	10	25	45	60	45	25	10	25	10	60	45	60
Ss												
1	30	50	45	80	60	40	20	35	20	70	60	90
2	25	35	60	75	65	40	20	40	20	80	60	85
3	7	20	35	30	22	10	14	9	4	29	18	45
4	12	30	60	90	70	40	28	40	25	120	60	120
5	30	60	65	65	65	35	20	35	12	65	54	70
6	10	12	25	23	15	10	4	10	4	18	15	28
7	10	60	70	120	140	60	20	50	20	150	100	180
8	7	20	45	50	40	20	10	20	10	40	40	55
9	18	35	90	97	76	52	19	53	17	110	77	123
10	7	10	24	30	25	10	5	12	3	25	25	30
11	12	15	28	35	25	20	8	20	5	45	30	50
12	17	20	35	35	38	12	4	28	5	60	40	75

Table 6 (contd.)

L.C.	Dark	Red	Dark	Blue	Red	Blue	Red	Dark	Blue	Dark	Blue	Red
T.I.	10	25	45	60	45	25	10	25	10	60	45	60
Ss												
13	10	20	30	28	25	12	3	18	2	30	25	35
14	15	30	45	60	60	25	6	30	5	75	45	75
15	10	15	35	30	25	15	7	13	8	40	20	35
16	9	12	15	25	20	15	7	12	5	25	15	35
17	5	15	25	30	30	15	5	10	5	40	25	36
18	10	25	45	45	30	20	5	15	4	30	20	45
19	8	13	25	30	18	10	5	12	4	40	16	35
20	8	20	35	40	25	14	8	20	6	35	25	45
21	9	15	30	40	25	20	10	20	5	35	15	50
22	14	20	35	55	35	20	12	28	10	80	35	80
23	9	27	35	60	50	25	10	25	10	55	30	60
24	10	25	50	60	30	15	5	20	5	50	20	60
25	10	15	25	25	25	8	3	15	4	30	20	40
26	20	50	100	100	45	35	10	25	7	50	40	98
27	18	36	50	60	55	40	12	45	11	75	50	65
28	7	10	15	15	20	10	4	12	3	60	15	25
29	5	10	15	30	28	10	5	15	5	40	30	60
30	20	30	55	45	30	10	5	15	5	20	20	50
31	19	20	50	45	48	30	15	20	10	45	25	60
32	5	25	35	40	40	30	12	20	10	50	35	45
33	18	25	30	40	20	15	8	18	6	33	25	42
34	15	20	40	45	30	25	10	20	10	60	35	60
35	10	25	40	50	45	20	8	25	7	70	35	50
36	13	18	50	40	35	15	6	25	5	56	25	45
37	25	45	55	45	40	25	7	15	5	50	35	55
38	5	12	12	20	10	6	4	12	3	15	10	25
39	7	17	30	32	28	14	12	17	7	30	24	34
40	10	28	35	35	30	25	10	25	10	45	30	45

Mean 12.72 24.75 40.60 47.50 38.57 21.82 9.65 22.47 8.05 51.90 33.10 58.52

Percent
of OE +27.2 -1.0 -9.7 -20.8 -14.2 -12.7 -3.5 -10.1 -19.5 -13.5 -26.4 -2.4
or UE

N.B. OE = overestimation of time

(+) sign means overestimation

UE = underestimation of time

(-) sign means underestimation

The following figures show the mean percentage of over- or under-estimation of overall time intervals. Plus (+) sign means over-estimation and minus (-) sign means underestimation of time.

Ss	Red	Blue	Dark	Differences		
				(R-B)	(R-D)	(B-D)
1	+70.83	+56.66	+64.16	+14.17	+6.67	-7.50
2	+56.52	+54.58	+69.16	+1.94	-12.64	-14.58
3	-14.03	-57.50	-41.97	+43.47	+27.94	-15.53
4	+88.88	+73.33	+53.33	+15.55	+35.55	+20.00
5	+75.27	+22.08	+73.19	+53.19	+2.08	-51.11
6	-58.00	-62.08	-43.61	+4.08	-14.39	-18.47
7	+162.77	+115.55	+76.38	+47.22	+86.39	+39.17
8	-9.86	-11.94	-20.83	+2.08	+10.97	+8.89
9	+75.97	+77.69	+93.83	-1.72	-17.86	-16.14
10	-51.11	-50.11	-46.75	+5.00	-4.36	-9.56
11	-30.28	-36.25	-15.69	+5.97	-14.59	-20.56
12	-17.64	-38.69	+14.94	+21.05	-32.58	-53.63
13	-44.03	-57.44	-27.83	-13.41	-16.20	-29.61
14	+9.58	-12.50	+23.75	+22.08	-14.17	-36.25
15	-39.03	-41.39	-25.89	+2.36	-13.14	-15.50
16	-44.80	-53.75	-46.75	+8.95	+1.95	-7.00
17	-40.83	-46.11	-46.94	+5.28	+6.11	+0.83
18	-27.08	-40.14	-22.50	+13.06	-4.58	-17.64
19	-55.47	-58.61	-37.44	+3.14	-18.03	-21.17
20	-27.36	-40.44	-25.97	+13.08	-1.39	-14.47
21	-25.28	-42.50	-26.25	+17.22	+0.97	-16.25
22	+2.77	-12.64	+15.77	+15.41	-13.00	-28.41
23	+4.77	-8.33	-10.13	+13.10	+14.90	+1.80
24	-20.83	-36.39	-6.34	+15.56	-14.49	-30.05
25	-47.19	-60.47	-33.61	+13.28	-13.58	-26.86

Table 7 (contd.)

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Ss	Red	Blue	Dark	Differences		
				(R-B)	(R-D)	(B-D)
26	+40.83	+16.38	+51.38	+24.45	-10.55	-35.00
27	+23.63	+20.27	+49.02	+3.36	-25.39	-28.75
28	-58.47	-67.91	-37.16	+9.44	-21.31	-30.75
29	-36.94	-48.33	-47.50	+11.39	+10.56	-0.83
30	-20.00	-47.64	+3.88	+27.64	-25.88	-51.52
31	+9.16	-12.36	+14.02	+21.52	-4.86	-26.38
32	-4.03	-8.89	-27.22	+4.86	+23.19	+18.33
33	-26.39	-39.44	-6.58	+13.05	-19.81	-32.86
34	13.33	-11.80	+4.72	-1.53	-18.05	-16.52
35	-9.16	-22.22	+1.38	+13.06	-10.54	-23.60
36	-28.80	-41.94	+8.61	+13.14	-37.41	-50.55
37	+7.63	-24.30	+28.88	+31.93	-21.25	-53.18
38	-62.03	-72.61	-62.58	+10.58	+0.55	-10.03
39	-23.28	-41.83	-36.33	+18.55	+13.05	-5.90
40	-11.58	-18.75	-11.60	+7.17	+0.22	-6.95
Mean	-5.45	-19.86	-1.53	14.41	-3.92	-18.33

Statistical analysist-test (related measure):

(a) Comparison between red and blue:

Mean diff. = 14.41

$\bar{C}$ = 12.39

t = 7.35

d.f. = 39, t is significant at 0.0005 level (one tail)

(b) Comparison between red and dark:

Mean diff. = 3.92

$\bar{C}$ = 21.57

t = 1.15

d.f. = 39, t is not significant ($P > .05$)

(c) Comparison between blue and dark:

Mean diff. = 18.33

$\bar{C}$ = 20.24

t = 5.72

d.f. = 39, t is significant at 0.001 level (two tail)

DISCUSSION

1. The effect of red and blue illumination on the estimation of time

From the results (Table 7) it is seen that the mean percentage difference between the estimation of time under red and blue light is highly significant ($P < 0.0005$). Thus under red light time appeared to pass more slowly than under blue light. Under both colours time was underestimated, but the degree of underestimation

was significantly greater under blue light than under red light. This is shown in Figure 6.

Underestimation of time under blue light was expected according to the hypothesis of photo-activation. It is not clear, however, why time was generally underestimated under red light. It is not possible to indicate how far the underestimation of time in the present experiment is due to the method we used (method of verbal estimation). Clausen (1950) found that the method of verbal estimation generally gives rise to the overestimation of time than the other methods. Kruup (1961), on the other hand, reported data supporting the view that the method of verbal estimation results in underestimation of time.

Whatever may be the reason, the underestimation of time under red light does not necessarily go against the photo-activation hypothesis. The comparatively higher percentage of underestimation of time (19.86%) under blue light and the low percentage of underestimation of time (5.45%) under red light show that comparatively time seemed to pass more slowly under red light than under blue light. That is, the speed of the physiological clock went up under red light more than under blue light. The physiological clock, running, in ordinary conditions, at a very slow speed and thereby giving rise to a higher degree of underestimation of a physical temporal interval, may be speeded up thus decreasing markedly the degree of underestimation, but still may remain below the threshold of overestimation. So, perhaps, it all depends upon

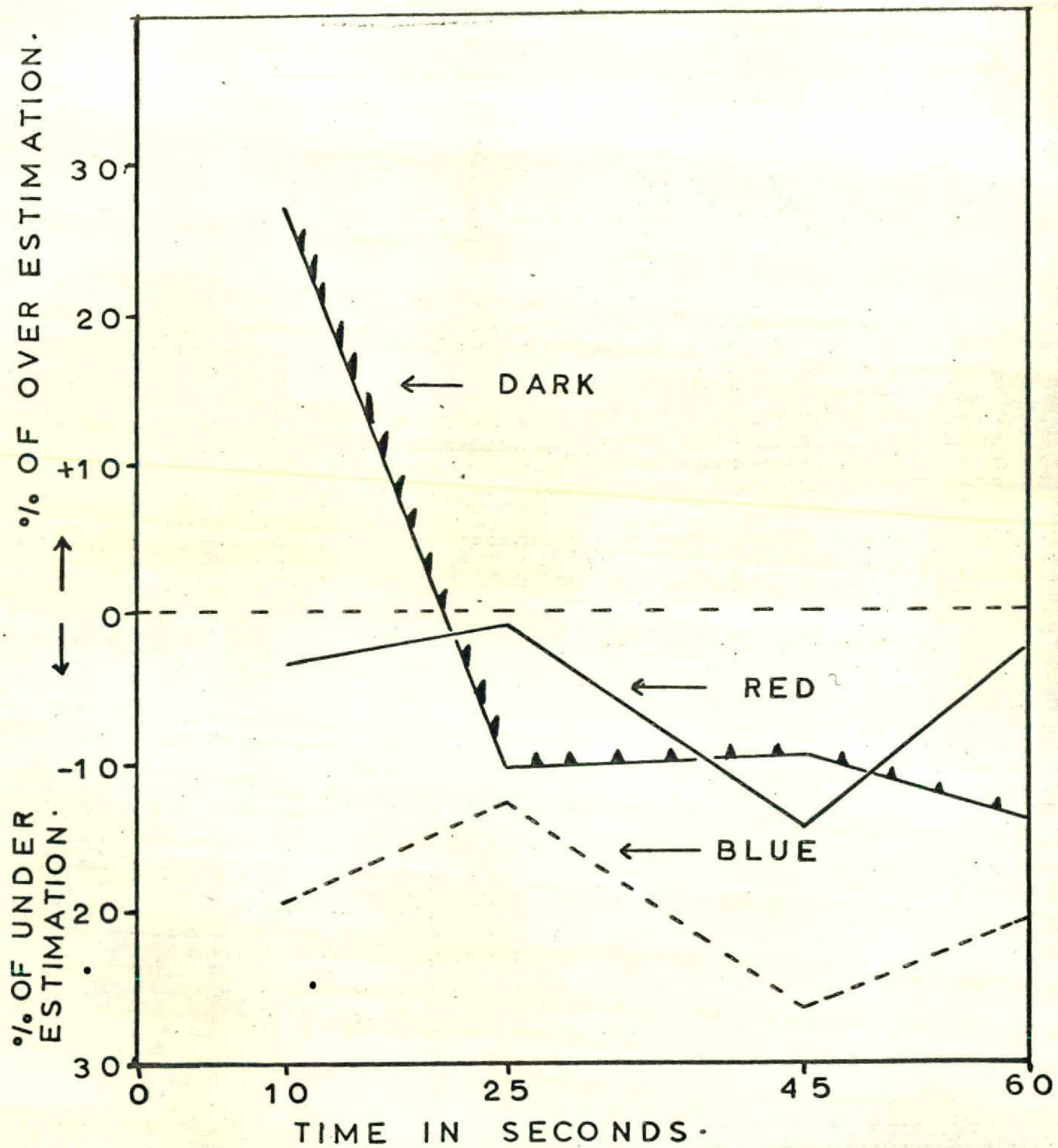


Fig.6. Estimation of time under red and blue light and in darkness.

the initial speed of the individual's physiological clock as well as upon the intensity of the stimulation.

The effect of colour on the estimation of time was recently investigated by Nakshian (1964). He got no significant differences between red, green and grey on the estimation of time. His non-significant result may be attributed to the method and procedure he followed. He designed his experiment to investigate the effect of coloured surroundings on the estimation of time. As coloured stimuli, he painted the wall of his experimental cubicle red, green and grey. During the experiment, the overhead light in the room was switched off. Moreover, it is not clear from Nakshian's report whether his Ss were instructed to look at the painted wall during the experiment or they were free to engage their attention anywhere they liked. In the latter case, Ss might have ignored the coloured surroundings and instead paid their whole attention to the estimation of time.

2. The effect of darkness on the estimation of time

From the results (Table 7) it appears that red and dark periods had similar effects on the estimation of time. When the results of red and dark periods are compared, the difference is not significant ($P > .05$). When the results of blue and dark periods are compared, the difference is highly significant ($P < 0.001$). As under red illumination, time seemed to pass more slowly in the dark period than under blue illumination.

In line with the photo-activation hypothesis, it was expected that time, during a dark interval, would seem to pass less slowly than under red or blue illumination. But the results do not support this expectation. It was also expected that the order of the mean percentage change of the estimation of time under the three different conditions would be red (more slowly), blue (less slowly) and darkness (far less slowly). But the results show that the mean percentage for dark period occupies the middle position. A closer analysis, however, shows the effects were dependent upon the length of intervals judged. Thus, the curve (Fig. 6) for the dark period had its highest peak at the 10 sec. interval, a 27.20% overestimation. At the 25 sec. interval there was a 10.10% underestimation and at 60 sec. a 13.50% underestimation. Thus, the short interval was overestimated and longer intervals were underestimated. It is possible that for short intervals, particularly during a dark period there may be a feeling of boredom which decreases with habituation to the situation. So, the results suggest that short intervals in the dark may produce overestimation of time and long intervals may, on the other hand, produce underestimation of time. There is, however, evidence to support that long periods in the dark are underestimated. Thus some French miners (reported by Fraisse, 1963), following a pit disaster were trapped in a gallery from which they escaped after three weeks of effort. Their estimate, however, of the time spent underground was only four or five days. A similar experience has been described by Ferrari (1909, re-reported by Woodrow, 1951; and Fraisse, 1963).

Three brothers were entombed for 18 days by the earthquake of Messina. When they were asked, after rescue, to estimate the time they spent, they estimated it to be four or five days. There is some experimental evidence for this phenomenon. In recent studies in France (reported in The Times, London, March 13, June 24, 25 and July 6, 1965 and November 1966), it was found that the longer the period spent in the dark, the higher was the degree of under-estimation, a finding consistent with those of Vernon and McGill (1963) who reported that time ^(long interval) was consistently underestimated in darkness.

To sum up, the results of the present experiment show that, relatively, time seems to pass more slowly under red light than under blue light. One explanation (Hoagland, 1933) is that the rate of the physiological clock upon which time estimations are made may vary as a function of temperature and illumination wavelength. We do not know yet what effects, if at all, red and blue lights have on biochemical events in the CNS. But experimental evidence exists for the fact that light and colour affect temporal parameters of cellular activities in plant life. Some of these experiments relevant to the present problem will be discussed below.

Thus many experiments have demonstrated the existence in plants of such periodic changes as leaf movements, growth, photosynthesis, respiration and flowering (Wilkins, 1958; 1959, 1960; Ingold and Cox, 1955; Bunning, 1957, 1959, 1960; Ball,

Dyke and Wilkins, 1957; Hastings and Sweeney, 1958; Pittendrigh et al., 1959). The observation that these rhythms continue in plant tissue deprived of periodic stimuli indicates the presence of a time-keeping mechanism or oscillator.

Recent investigations (Wilkins, 1960; Hamner, 1960) have also shown that plant rhythms are affected by light. Wilkins (1960) found that the rate of carbon dioxide emission increases when leaves are illuminated and decreases during a dark period. Ott (1964) found different streaming movements of chloroplasts within the cells of *Elodea* grass under different wavelengths of light. Attempts have been made to determine which wavelengths of light are active in regulating the biological clocks. In *Odeogonium* (Buhemann, 1954, quoted by Wilkins, 1960), although blue light is effective in entraining the rhythms, red light is far more efficient. Continuously illuminating plants with light of different wavelengths has shown that the blue region of the spectrum is active in inhibiting the clocks (Wilkins, 1960; Ball and Dyke, 1954).

A few experiments of the types described above have been carried out with animals. These studies show that a similar time-keeping mechanism may be involved. Thus rhythmic fluctuations of electrical potentials, which are quite independent of environmental influences, have been found to occur in groups of cells in the nervous system (Adrian and Buytendijk, 1931; Adrian, 1931). Crozier and Stier (1924-25) found rhythmic creeping movements in

poikilothermic animals and such rhythmic phenomena as the chirping of crickets. Renner's experiments (1955, 1960) with bees show quite clearly that bees have a time-keeping mechanism which is able to function independently of diurnal exogenous factors.

From these considerations and the present data it may be argued that humans, who display by far the most precise temporally oriented behaviour, may also possess such a biological time-keeping mechanism located somewhere in the cells of the nervous system. Thus, Halberg (1960) reported diurnal variation in (a) the number of certain cells of the blood; (b) the frequency of mitotic division in epidermal tissue and (c) the body temperature. Halberg supported the view that these variations are endogenous by noting that they persist through periods of electric shock. Aschoff (1965) has found rhythmic activities in body temperature, urine excretion and in sleep and wakefulness. He concluded that a self-sustained oscillator with an inherent frequency, underlies human 24 hour rhythmicity.

However, the nature of the biological oscillator, the effect of light and colour on the activity of such an oscillator and its relation to the individual's estimation of time, remain to be studied experimentally. This problem was investigated in the experiments described in Part III of the present study.

P A R T I I I

EEG activity and the appreciation of the change
of time under the influence of red and blue light

1. A review of the relevant literature

In Part II of the present study we found that time estimation depends to some extent upon the wavelength of incident light. A particular time interval was estimated to be longer under red light in comparison with the same interval passed under blue light. In Part III we wish to investigate whether cerebral cellular processes, especially EEG activity, are in any way related to this phenomenon of time perception. Before starting the experimental study we shall review some of the relevant studies on the nature of EEG activity, its activation pattern and EEG activity and the perception of time.

(a) EEG, its components, origin and activation pattern

While Caton (1875) was the first to report observations of the electrical activity of the cortex in animals, it was Berger (1929) who first demonstrated electrical activity recorded from the human brain through the intact skull. This electrical activity was termed the electroencephalogram (EEG). In normal records EEG components are classified as follows:

- (a) Alpha rhythm: A rhythm of 8-13 c./sec.
- (b) Beta rhythm: A rhythm with a frequency of 14-30 c./sec.
- (c) Gamma rhythm: A rhythm with a frequency of 30-50 c./sec.
- (d) Delta rhythm: Frequencies of 3.5 c./sec. or below
- (e) Theta rhythm: Frequencies from 4 to 7 c./sec.

It should be noted that most of the EEG studies so far reported are mainly concerned with alpha rhythm. The present study will also deal mainly with alpha rhythm.

The nature of alpha rhythm and its origin

Alpha rhythm refers to the synchronized electrical activity of the cerebral cortex. It is characterized by (i) its size or amplitude of waves (in resting alpha the amplitude is generally longer), (ii) its frequency or number of waves per unit time (generally, 8-13 c./sec.) and (iii) the cycles that are repetitive, i.e. a particular wave is similar to its predecessor as well as to its successor. Another characteristic of alpha rhythm is that it is abundant in the occipital region of the cortex. Alpha waves are mostly found in normal human adults when they are awake and relaxed.

Origin of alpha activity

Cortical areas:

By placing electrodes in many different positions on the human skull, investigators have found that different waves are stronger in different places. There are four foci for the alpha waves (Lindsley, 1938). One is in the lower occipital region around the striate area, another is in a higher occipital region of the postcentral and precentral cortices, and the fourth one is in the temporal region. The strongest source of alpha is usually the occipital region and particularly the upper part of it.

For that reason some have thought that alpha is generated in the

occipital cortex and carried to other regions (Adrian and Yamiguva, 1935). However, alpha rhythm is not necessarily related to the visual cortex.

Cortical origin

Our knowledge of the physiological origin of the normal alpha rhythm is still scanty. The electrical potentials arise from the cortical cells, probably the large pyramidal cells (Hughes, 1961; Ochs, 1965). The destruction of successive layers of the cortex abolishes the brain waves in the region of injury (Dusser de Barenne et al., 1936, reported by Jasper, 1937). Such experiments as these might make us think that brain waves come from the cortex.

Other experiments, however, make it seem that waves in the cortex are conveyed from lower, sub-cortical centres. It is possible, for example, to abolish the waves in a cortical region simply by destroying the fibres that project to the region (Walter and Dovey, 1944). Brain waves comparable to alpha waves moreover occur in the thalamus of an animal that is completely decorticate (Morison and Bassett, 1945). Some have seemed to locate some waves in the hypothalamus (Murphy and Gellhorn, 1945). So it seems that brain waves involve not only the cortex but other centres as well.

Alpha rhythm, its behavioural correlates and the effect of activating stimuli

Behaviourally, the alpha rhythm is connected in some way with the subject's state of activity, having "optimum alpha rhythm" in

relaxed wakefulness, and a depression of alpha rhythm in strong emotion (Lindsley, 1952). Lindsley (1952) has presented a table of psychological states, their EEG and behavioural correlates showing that behavioural efficiency is closely related to the alpha rhythm. The state of wakefulness and sleep of normal individuals has been related successfully to changes in EEG (Adrian, Bremer and Jasper, 1954). A number of investigators (Blake, Gerard and Kleitman, 1939; Loomis, Harvey and Hobart, 1937) have found that varying depths of sleep, as measured by the intensity of tones required to awaken the subject, are related to the amplitude and frequency of delta-type electroencephalographic patterns. Simon and Emmons (1956) found that as the quality and quantity of alpha increases so does the probability that a stimulus will be reported heard when it occurs, and correctly recalled later. They employed 21 normal adult male subjects. The subjects retired to sound-proof and air-conditioned rooms for their night's sleep. Their EEG was recorded continuously. They were asked factual questions on history, science, sports and the like. Their results show that (1) the ability of subjects to recall and give immediate responses corresponds to the alpha amplitude and frequency, and (2) when alpha and delta frequencies are mixed, the probability of recall is related to whichever of these components predominates; if alpha predominates the probability of recall is greater. In other words, as the percentage of alpha continues to decrease in amplitude and frequency, there is a corresponding decrease in the probability of responding or recalling.

The pattern of EEG activation and its behavioural correlates

By means of electrodes placed in the brain-stem reticular formation (BSRF) in relaxed or somnolent cats, Moruzzi and Magoun (1949) were able to show that repetitive stimulation was effective in transforming a slow wave sleep pattern to low amplitude, fast wave pattern characteristic of the wakeful state. These authors have called this EEG change as 'arousal' or 'desynchronization.' On the other hand, progressively more rostral sectioning of the BSRF results in the appearance in EEG of hypersynchronous activity (characterized by the presence of distinct slow waves and frequently also rhythmic faster activity called sleep spindles), very similar to that seen in normal sleep, with corresponding behavioural somnolence (Lindsley, Bowden and Magoun, 1949). After bilateral lesions of the thalamus, through which the ascending neuronal relays funnel, hypersynchronous EEG activity is persistent with corresponding behavioural somnolence (Starzl, Taylor and Magoun, 1951). Chronic cats, with bilateral hypothalamic lesions or with rostral-midbrain section of the BSRF, remain somnolent as long as they survive, and hypersynchronous activity persists in their EEG (Lindsley, Schreiner; Knowles and Magoun, 1950). If, however, some of the BSRF is spared, there is a tendency for EEG pattern (along with behavioural pattern) to return to normal with time (Knott, Ingram, Wheatley and Summers, 1951). Animals prepared with lateral destructions including the specific sensory pathways appear to be alert and awake, but animals with

midbrain destruction of the BSRF are somnolent with hypersynchronous EEG activity (French and Magoun, 1952).

The above experimental studies show the EEG activation pattern and its behavioural correlates, the arousal mechanism lying somewhere in the brain-stem reticular formation. However, recent findings show that this relationship is not that simple. There are certain situations where this parallelism does not work. There are two such situations, the first arises from the recent works on EEG in sleep and the second arises from experiments with drugs. First, the studies on EEG in sleep. The work of Adrian, Bremer and Jasper (1954) and those of others (Blake, Gerard and Kliezman, 1939; Loomis, Harvey and Hobart, (1937), mentioned earlier, show that the state of wakefulness and sleep of normal subjects is related to changes in EEG pattern. Thus the low voltage, high-frequency desynchronized pattern was related to waking state and the high voltage, low-frequency EEG pattern to sleeping state. But the recent works of several investigators (Aserinsky and Kliezman, 1955; Dement and Kliezman, 1957; Dement, 1958; Jouvet, 1961, 1963 - reviewed by Routtenberg, 1966) have shown that this parallelism does not always hold good. Thus Dement and Kliezman (1957a) have shown that during certain periods of sleep (called REM periods) the EEG showed a desynchronized pattern, similar to that seen in the waking subjects. Jouvet (1960) called this period of sleep "paradoxical sleep."

However, a close examination of those results shows that the desynchronized pattern of EEG during the REM period of sleep may be justified since this period is akin to the waking state. Thus, Aserinsky and Kletman (1955) noted that during the period when subjects' EEG records showed a desynchronized pattern, subjects also showed rapid eye movements. Dement and Kletman (1957b) showed that during the REM periods subjects were most likely dreaming. The finding that barbiturate (a depressant) suppresses REM periods (Rossi, 1962; Oswald et al., 1963) shows that there may be some relationship between arousal and dreaming, at least in the sense that REM periods are not states of non-arousal relative to other stages of sleep.

Secondly, the paradoxical situations that arise from the experiments with drugs. It seems that the low voltage fast activity EEG is not an inevitable concomitant of behavioural arousal. Thus in animals treated with atropine, behavioural alerting occurs against a background of a slow EEG similar to sleep record (Funderburk and Case, 1951; Bradley and Elkes, 1953). On the other hand, reserpine may produce a sleep like state associated with low voltage fast EEG (Killam et al., 1957). Similarly, a high voltage slow activity following stimulation of ponto mesencephalic RF in anaesthetic animals has been reported by Prince and Shanzer (1966).

It seems that the above results cannot be explained by the present concept of the arousal mechanism (the ascending reticular

activating system of Moruzzi and Magoun). One solution to this problem has been offered by Routtenberg (1966). He has suggested two arousal systems, one based on the classical arousal system originally described by Moruzzi and Magoun (1949) and the other on the limbic midbrain system described by Nauta (1958). Thus in the case of atropine, it may be possible that atropine ~~is~~ differentially affects the 2 arousal systems, so that alertness is maintained by one, while high voltage slow EEG synchrony is brought about by the depression of the other.

(b) EEG activity and the perception of time

Comparatively little attention has been given to the problem of time perception and its possible relation to EEG, especially alpha rhythm, activity. Hoagland (1933) was probably the first to suggest that there might be a possible relationship between the individual's appreciation of the passage of time and his cerebral molecular processes. He demonstrated that with increased body temperature, psychological time passed more quickly and physical time more slowly. From this he suggested "it is not unreasonable to suppose that chemical changes locally produced in the brain by excited groups of neurons would increase the velocity of our hypothetical clock, making time appear to pass more rapidly when we are active. This effect might be especially apparent when the activity involves extensive excitation of higher levels of the central nervous system" (Hoagland, 1933, p. 277). Next, he

hypothesized that chemical ~~Dhaka University Institutional Repository~~ processes of the cerebral cortex were altered by changes in body temperature and that these metabolic processes were the essential causal mechanism (Hoagland, 1936). Hoagland (1936) found that increased body temperature resulted in an increase of the frequency of the alpha rhythm. He suggested therein that the frequency of the alpha rhythm reflected the velocity or rate of the underlying cortical metabolic processes. Thus Hoagland foresaw a possible relationship between alpha rhythm and the perception of time, but since his original work suggesting a constitutional cerebral factor in time perception, little attention has been directed to the study of cerebral processes affecting time judgement.

Only recently, Holuber (1960) found, in a conditioned reflex experiment, that alpha rhythm plays an important role in the mechanism of time sense in man. He established, in normal human subjects, conditioned GSR to temporal intervals, using nociceptive stimulation as the US presented at regular 30 sec. intervals. Changes in EEG were recorded continuously. The conditioned time reflexes were tested in three conditions, namely darkness, continuous illumination and flickering light. In dark and continuous light conditions, the intervals of conditioned responses were found to be very accurate, but during the flickering condition, the intervals changed profoundly, depending on the rate of flicker per sec. During flicker of 7 cycles per sec. the interval was shortened to 14 sec. and during 14-15 cycles per sec. to 15.5 sec. During flicker of 10 cycles per sec. no shortening of

interval was observed and during flicker of 5 and 20 cycles per sec. only an insignificant change was noted. Holuber concluded that the disturbance of time sense by photic stimulation was due to the fact that the rhythms induced by flicker spread quickly over large areas of the brain thus affecting alpha frequency.

Holuber and Machek (1962) verified these findings in an investigation on epileptic patients. Their aim was to see whether in epileptics there is a correlation between alterations of the time sense and changes in the EEG. Their study revealed the importance of brain waves in the mechanism of time sense. The pathological activity of slow waves in epileptics was in most cases accompanied by changes in the temporal intervals. In most cases the intervals were prolonged. This suggests that slow alpha rhythm betokens a decrease in velocity of the biological clock with a consequent ^{decrease} increase in experienced time. Werboff (1962) carried out similar studies on normal human subjects. He found that subjects with more than 50 percent alpha in their eyes closed resting EEG overestimated time in the eyes open condition in contrast to those subjects with less than 50 percent alpha. This fact shows that there might exist important and significant correlations between EEG activity and time sense.

Another study on this problem was made by Anlinker (1963). His study also demonstrated the positive relationship between alpha rhythm and the perception of time. In his study, human

subjects were instructed to respond to 3-second intervals regularly while their brain waves were recorded. When subjects were in their normal condition, the time between two successive responses did not vary greatly. But when they became increasingly drowsy, the interval of responses lengthened and the mean of the alpha frequency decreased. This suggests that slow alpha frequency is an index of a decrease in velocity of the physiological clock with a consequent decrease in experienced time.

More recently, Surwillo (1966) reported results of an experiment on the relationship between EEG and the estimation of time. He selected two groups of subjects, one group consisting of subjects ('old' Ss) with alpha frequencies less than 9 c./sec. and the other group consisting of subjects ('young' Ss) with alpha frequencies more than 10 c./sec., to estimate a 30 sec. interval. The results showed no significant difference between time estimates of the two groups.

There were some difficulties with Surwillo's procedure. He himself pointed out the following flaws in his procedure. EEG records in his study were resting records and, since EEG frequency varies with a subject's level of alertness, they might not have been representative of the electrical activity present when subjects made their time estimates. The age of his subjects was not mentioned, but it may be supposed that one group (old) might have a better notion of the duration of a (physical) second than the other (young) group.

In order to meet these difficulties, Surwillo suggested the following:

- (1) EEG to be recorded while Ss were making their estimates;
- (2) data to be obtained from a single S in a single test session;
- and (3) the hypothesis to be tested in each individual S rather than in a group. Later, in an experiment employing one individual subject and using a 'high intensity flash' as photo-stimulation, he got a significant correlation between alpha rhythm and time estimation.

In sum, the above review suggests that EEG activity, especially its alpha rhythm component, may be related to the organism's appreciation of the passage of time. However, it still remains to be seen whether alpha rhythm, the so-called biological oscillator, is affected by the wavelength of the incident light with a consequent change in the individual's time sense. This problem has been investigated in the experiments described below.

2. The Present Investigation

The problem

The nature of the present problem is to investigate the phenomenon of time perception as a function of EEG activity as influenced by red and blue light.

The hypotheses:

Since an activated EEG is characterized by a decrease or abolition of synchronized 8-13 c./sec. (alpha) rhythms and the appearance of low amplitude fast activity, it was predicted (1) that red light will cause a greater decrease in alpha amplitude and time percent alpha than will blue light, and (2) that with fast activity low amplitude alpha under red light, time would appear longer than with comparatively slow activity and high amplitude alpha under blue light.

Subjects:

Twenty-four subjects, eight females and sixteen males, were employed in this experiment. Their ages ranged between 18-28 years.

All were tested for colour blindness by the Ishihara Test.

Experimental Design

The stimulus, red or blue light, was presented to the subject at an interval randomly selected from 10 sec., 25 sec., 45 sec. and 60 sec. It was evident from a preliminary study that the estimation of a particular interval of time may be affected according to whether it appears at the beginning, in the middle or at the end (i.e. by the order of presentation). This effect may be minimized by randomly presenting the intervals in such a way that each interval has an equal chance of appearing at the beginning, at the end or in the middle. Subjects were divided into eight groups of three subjects in each, with each group given a different colour and temporal sequence as follows:

Sequence	Ss	R-10	B-60	R-60	B-10	R-25	B-45	R-45	B-25
I	1								
	2								
	3								
		B-10	R-25	B-25	R-60	B-45	R-45	B-60	R-10
II	1								
	2								
	3								
		B-60	R-10	R-25	B-45	R-45	B-25	R-60	B-10
III	1								
	2								
	3								
		R-45	B-10	B-45	R-25	B-25	R-60	R-10	B-60
IV	1								
	2								
	3								

Sequence	Ss	B-25	R-45	R-10	B-60	R-60	B-10	B-45	R-25
V	1								
	2								
	3								
		R-60	B-25	B-10	R-45	B-60	R-10	R-25	B-45
VI	1								
	2								
	3								
		B-45	R-60	R-45	B-25	R-10	B-60	B-10	R-25
VII	1								
	2								
	3								
		R-25	B-45	B-60	R-10	B-10	R-45	B-25	R-60
VIII	1								
	2								
	3								

Laboratory conditions and apparatus

Figure 7 gives a general picture of the experimental room. S was seated on an easy chair in a sound-proof cubicle. E had his table and apparatus in a second room outside S's cubicle. The EEG machine, tape recorder and the EEG frequency analyser were placed in a third room. A technician was in charge of the recording devices. S was provided with a microphone via which he gave his time estimates. A record was kept of air temperature in the experimental cubicle.

The Kodak colour filters (No. 25 for red and 38A for blue) were used to provide coloured illumination. The light source was

PHYSICAL LAYOUT

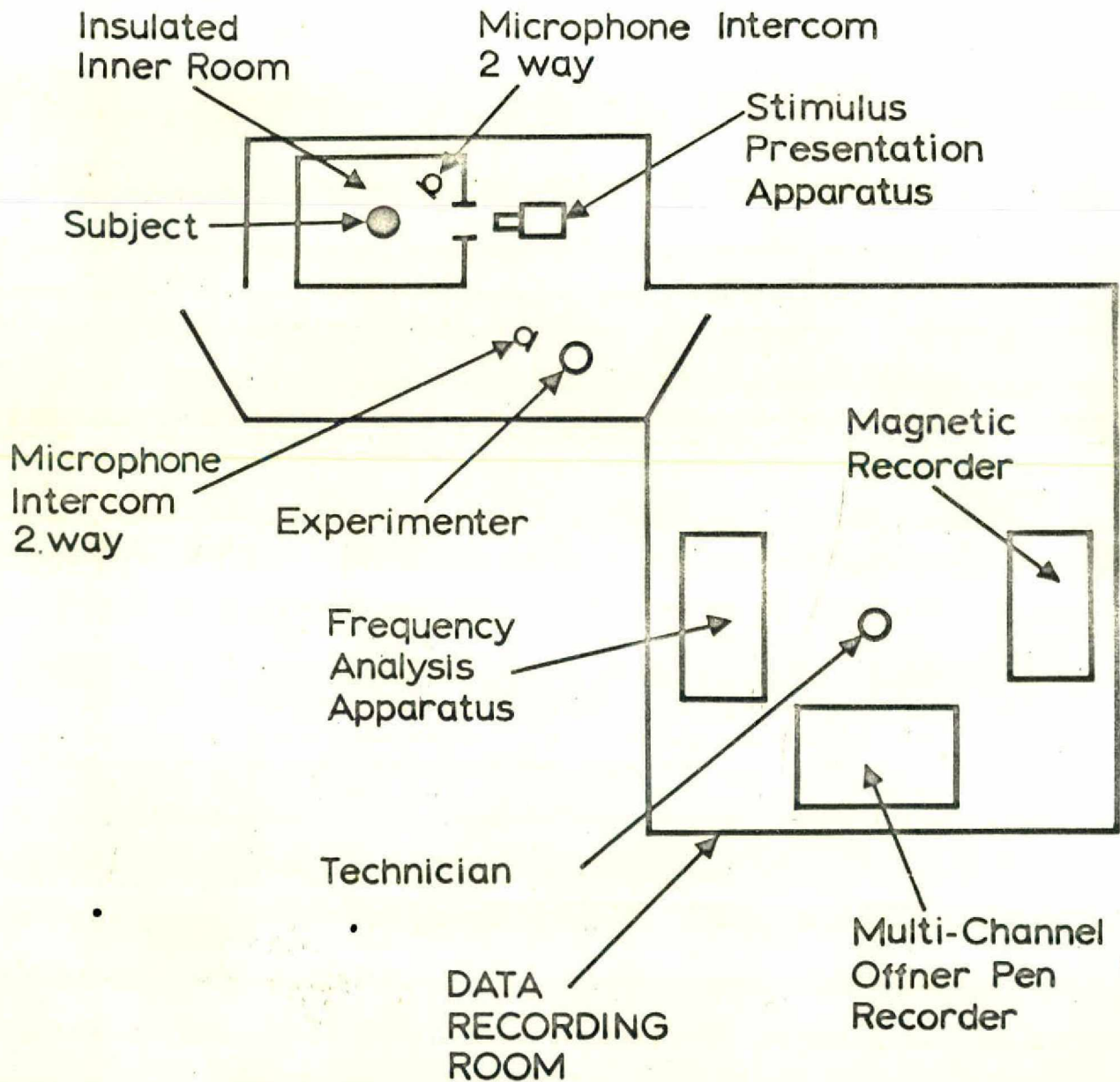


Fig.7. A general picture of the experimental room.

E.E.G. RECORDING

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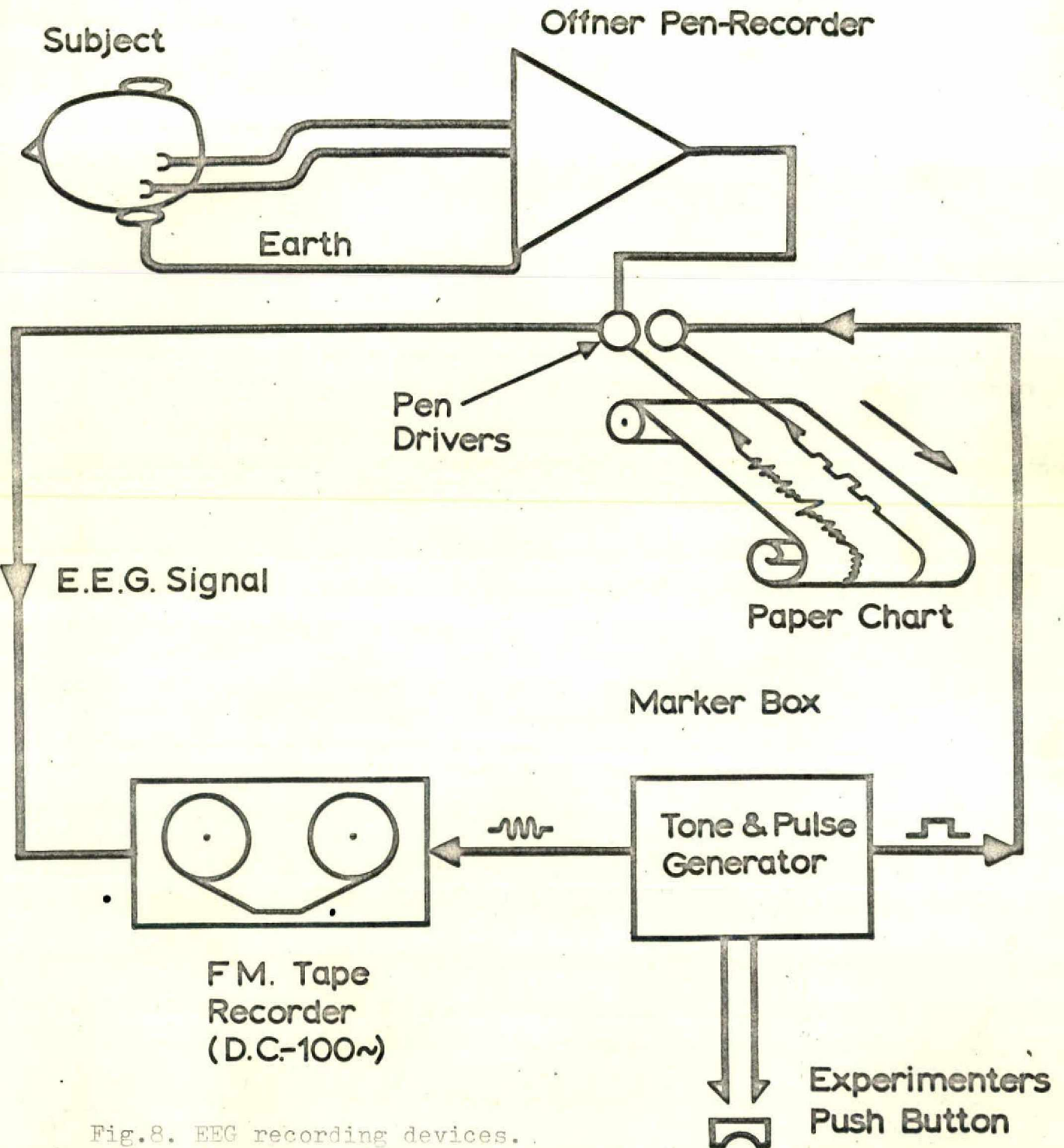


Fig.8. EEG recording devices.

ELECTRODES

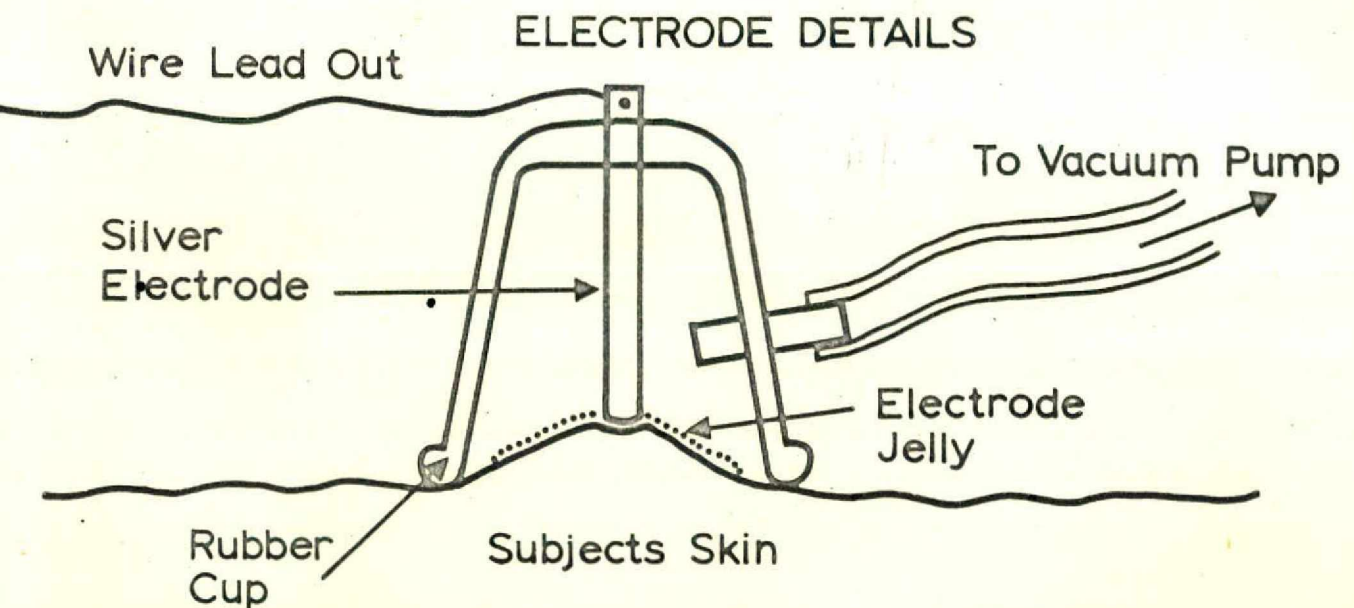
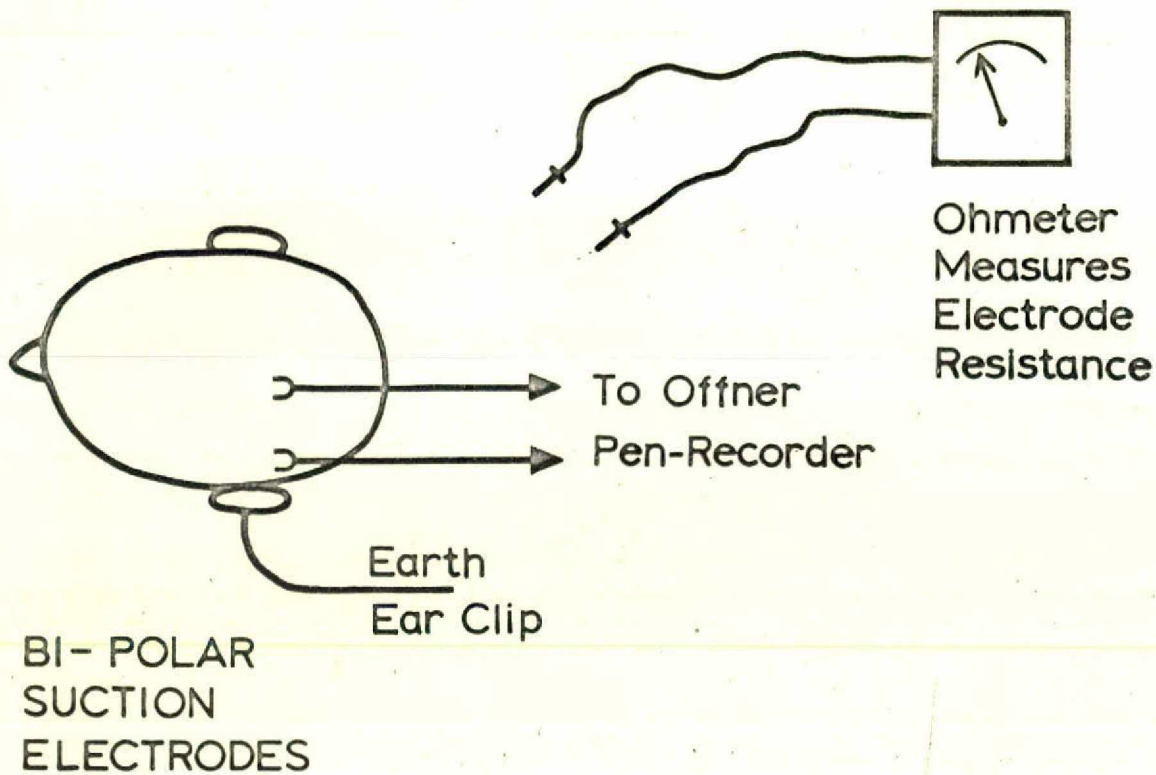


Fig.9. A general feature of electrodes used.

FREQUENCY ANALYSIS

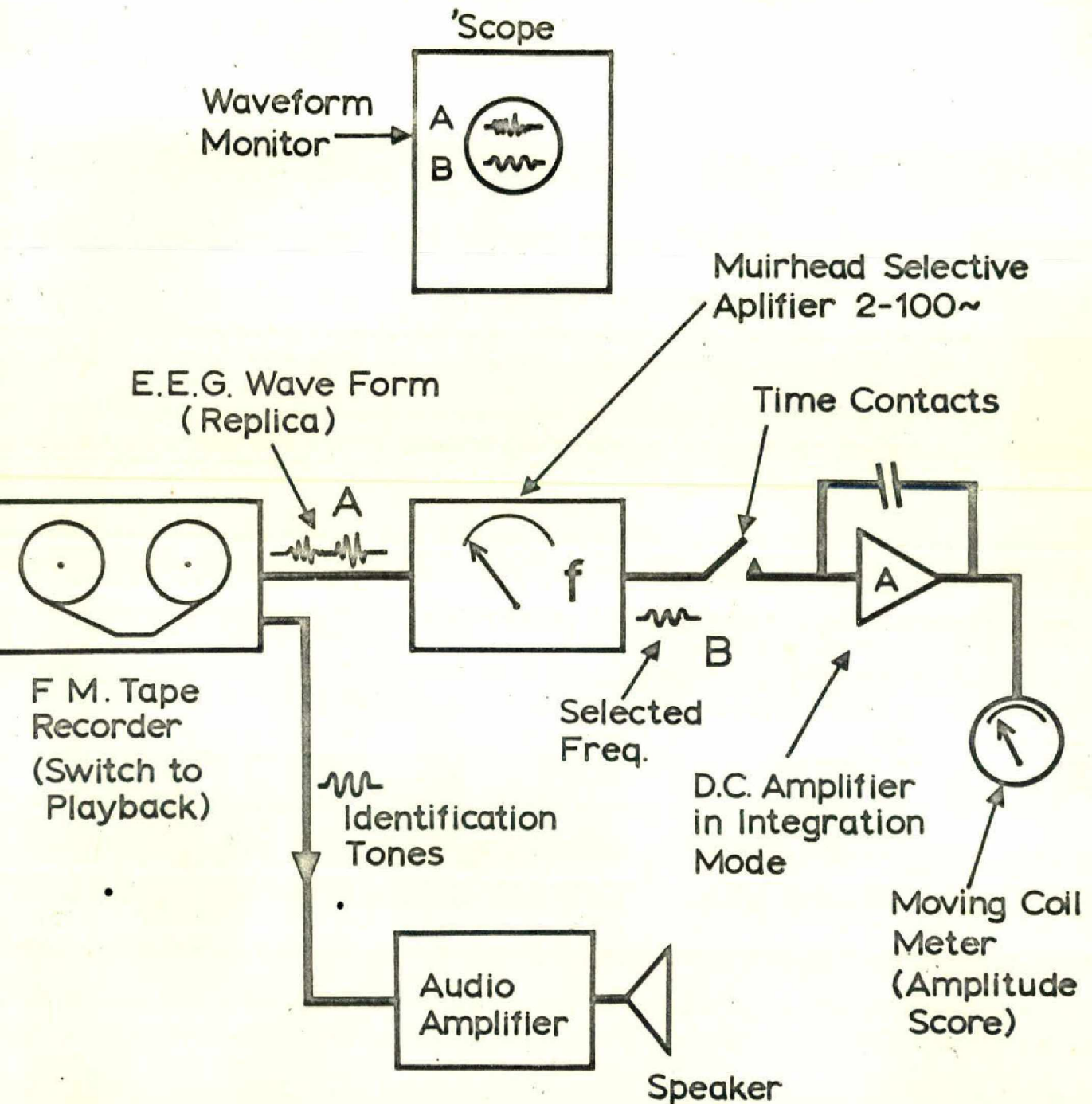


Fig.10. Frequency analysis equipments.

a 300 watt tungsten lamp, 30 inches from S's eyes. Light was thrown on a screen ($2\frac{1}{2} \times 3\frac{1}{2}$) in S's cubicle, the screen being 25 inches in front of him. The two coloured lights were equated for brightness.

Figure 8 gives a general picture of the recording devices of the EEG. A four-channel Offner Dynograph Type R amplifier was used. Bipolar electrodes were positioned on the parieto-occipital region, on the same hemisphere approximately 5-6 cm. apart and about 8 cm. above the inion. A general feature of the electrodes used is given in Figure 9. The earth one was placed on S's ear lobe. With a separate channel EEG was recorded on electro-magnetic tapes for further analysis. E could indicate in the tracing papers and tapes when the light was on and when it was off by pressing push-buttons.

Methods of EEG analysis

(a) ^{Alpha amplitude} ~~Frequency~~ analysis: The electro-magnetic tapes were replayed and fed through a Muirhead low frequency analyser, the ~~low~~ ^{alpha} output of which was fed to an integrator which drove a low inertia motor and counter. Figure 10 shows the sequence of frequency analysis.

(b) Alpha index classification: Alpha waves in the range of 8-13 cps. with a minimum amplitude of 20 μ V were underlined and the time of these periods measured. The total alpha time divided into the total time during a particular interval multiplied by a hundred determined the time percent alpha (alpha index).

General procedure:

S was seated on an easy chair in the sound-proof cubicle and EEG suction electrodes for bipolar recording were attached on his skull, as described on page //4. Following a resting record for one minute in the dark with eyes closed, S was given the following instructions:

"You need to sit quietly and not move. You will see a light on the screen before you. As soon as you see the light look at the screen and keep on looking until it is turned off. You are required to estimate the time for which it was on. When the light goes off, tell me the time you think the light was on for in terms of seconds. You must not count. I am concerned only with the time as you feel it is, that is, as it appears to you. As soon as the light goes off, just speak your estimate into the microphone."

S was given 20-25 sec. rest before each trial so that alpha rhythm may settle down. The four stimulus intervals (10 sec., 25 sec., 45 sec., and 60 sec.) under each colour (red or blue) were presented to S in random order as shown on page 108-109. Each S had eight trials.

A technician remained in the recording room throughout the experiment to check the various recording devices.

After the experiment S was taken out from the cubicle and interviewed about his experiences during the experiment. The following information was obtained:

1. Name, 2. age, 3. education, 4. how he estimated time, 5. what was his feeling during red or blue illumination, and 6. what was his feeling regarding the passage of time during (a) the red

interval, (b) the blue interval.

RESULTS

1. EEG and coloured light

Alpha amplitude

The change in integrated alpha amplitude as recorded magnetically, under red and blue illumination was examined.

Table 8 shows the results.

Table 8. Alpha amplitude under red and blue illumination

(The following are integrator readings; their voltage reference was: an EEG input of 1.75 μ V at 8-13 cps.
= 100 units)

Ss	Under Red	Under Blue	Resting
1	148.82	195.91	204.31
2	114.58	195.12	464.12
3	108.98	166.86	516.75
4	131.16	188.09	761.08
5	127.20	166.13	466.66
6	135.39	204.23	671.33
7	231.75	274.47	418.28
8	93.45	141.75	628.66
9	72.33	139.22	492.90
10	161.23	267.30	512.33
11	112.39	153.90	461.67
12	86.82	140.85	473.82

Table 8 (contd.)

Ss	Under Red	Under Blue	Resting
13	108.02	145.48	511.18
14	71.49	128.80	302.50
15	129.97	185.58	861.78
16	146.25	188.87	449.00
17	189.37	154.28	655.71
18	89.30	171.83	576.21
19	106.13	128.44	395.00
20	99.68	148.48	639.97
21	141.39	262.70	834.75
22	123.11	125.54	200.21
23	103.18	150.76	265.55
24	144.45	192.32	704.90
Mean	124.02	175.70	519.53

Statistical analysis

Related t-tests were performed between mean alpha amplitude changes during red and blue illumination as follows:

$$M_1 \text{ (red)} = 124.02 \quad t = 8.88$$

$$M_2 \text{ (blue)} = 175.70 \quad \text{d.f.} = 23$$

$$\text{Mean diff.} = 51.68 \quad t \text{ is significant (} P < 0.0005, \text{ one tail)}$$

$$\text{Sigma} = 28.45$$

Time percent alpha

Next the change in time percent alpha under red and blue illumination was examined. Table 9 shows the results.

Table 9. Time percent alpha under red and blue illumination

Ss	Under Red %	Under Blue %	Resting %
1	10.44	28.71	95.13
2	9.77	33.01	96.86
3	5.98	28.13	94.00
4	12.04	28.82	93.60
5	11.67	34.31	86.73
6	10.76	28.79	95.20
7	24.74	44.83	83.54
8	4.57	24.23	82.93
9	8.65	26.66	71.20
10	10.30	32.40	78.00
11	5.15	24.36	83.46
12	10.78	27.83	67.60
13	9.57	26.28	76.93
14	5.09	19.36	69.33
15	10.80	32.00	91.53
16	13.79	29.54	96.66
17	35.79	25.80	97.06
18	8.06	35.07	92.20
19	9.86	17.92	48.00
20	19.18	32.06	83.52
21	10.74	30.74	82.86
22	7.62	16.82	52.20

Table 9 (contd.)

Ss	Under Red %	Under Blue %	Resting %
23	10.21	28.63	87.60
24	11.98	32.00	94.86
Mean	11.40	28.68	83.37

Statistical analysis

Related t-tests were performed between mean time percent alpha changes during the two coloured lights as follows:

$$M_1 (\text{red}) = 11.40 \quad t = 12.33$$

$$M_2 (\text{blue}) = 28.68 \quad d.f. = 23$$

$$\text{Mean diff.} = 17.28 \quad t \text{ is significant } (P < 0.0005, \text{ one tail})$$

$$\text{Sigma} = 6.85$$

(ii) Time estimation and coloured lights

Next the change in mean time estimation under red and blue illumination was examined. Table 10 shows the results.

Table 10. Percentage of over- or underestimation of time under red and blue illumination. Plus (+) sign means overestimation and minus (-) sign means underestimation

Means of four time intervals (10 sec., 25 sec., 45 sec. and 60 secs.)

Ss	Under Red	Under Blue	Diff. (R-B)
1	+7.08	-46.05	+53.13
2	-8.94	-49.03	+40.09
3	-14.86	-18.89	+4.03

Table 10 (contd.)

Ss	Under Red	Under Blue	Diff.(R-B)
4	-45.22	-53.00	+7.78
5	-43.78	-61.30	+17.52
6	-30.86	-60.83	+29.97
7	+5.05	-28.11	+33.16
8	+26.11	-12.22	+38.33
9	+26.52	0.00	+26.52
10	-37.86	-62.91	+25.05
11	-5.83	-15.22	+9.39
12	+29.99	-6.94	+36.93
13	+21.61	-7.78	+29.39
14	-18.33	-26.58	+8.25
15	+15.22	-37.50	+52.72
16	-26.58	-42.94	+16.36
17	-41.19	-32.50	-8.69
18	+44.58	-55.89	+100.47
19	-26.58	-31.66	+5.08
20	+16.11	-22.50	+38.61
21	+10.86	-11.94	+22.80
22	+18.36	-23.89	+42.25
23	+40.08	-7.08	+47.16
24	+4.24	-37.00	+41.24
Mean	-1.42	-31.32	+29.90

Statistical analysis

Related t-tests were performed between the mean percentage

changes of underestimation of time under red and blue light as follows:

$$\begin{array}{ll}
 M_1 \text{ (red)} = -1.42\% & t = 9.49 \\
 M_2 \text{ (blue)} = -31.32\% & \text{d.f.} = 23 \\
 \text{Mean diff.} = 29.90 & t \text{ is significant } (P < 0.0005, \text{ one tail}) \\
 \text{Sigma} = 15.48
 \end{array}$$

(iii) EEG activity and time estimation under coloured lights:

An attempt was made to compare the data for EEG activity and time estimation under red and blue illumination. The Pearson Product Moment Correlation Coefficient (r) was computed. For this purpose the data were divided into three sub-groups according to Ss' over- or underestimation of time as follows:

Sub-group A (Underestimation of time under blue light)

Comparison between time estimation and alpha amplitude

$$\begin{array}{ll}
 M_1 \text{ (time estimation)} = 31.32 & \sigma_1 = 18.95 \\
 M_2 \text{ (alpha amplitude)} = 175.70 & \sigma_2 = 41.86 \\
 r = .74, r \text{ is significant } (P < 0.001) \text{ at d.f.} = 22.
 \end{array}$$

Comparison between time estimation and time percent alpha

$$\begin{array}{ll}
 M_1 \text{ (time estimation)} = 31.32 & \sigma_1 = 18.95 \\
 M_2 \text{ (time percent alpha)} = 28.68 & \sigma_2 = 5.79 \\
 r = .56, r \text{ is significant } (P < .01).
 \end{array}$$

Sub-group B (Underestimation of time under red light)

Comparison between time estimation and alpha amplitude

$$\begin{array}{ll}
 M_1 \text{ (time estimation)} = 27.34 & \sigma_1 = 13.94 \\
 M_2 \text{ (alpha amplitude)} = 125.79 & \sigma_2 = 30.57 \\
 r = .62, r \text{ is significant } (P < .05).
 \end{array}$$

Comparison between time estimation and time percent alpha

$$M_1 \text{ (time estimation)} = 27.34 \quad \sigma_1 = 13.94$$

$$M_2 \text{ (time percent alpha)} = 11.24 \quad \sigma_2 = 8.57$$

$$r = .54, r \text{ is not significant } (P > .05)$$

Sub-group C (Overestimation of time under red light)Comparison between time estimation and alpha amplitude

$$M_1 \text{ (time estimation)} = 20.45 \quad \sigma_1 = 12.25$$

$$M_2 \text{ (alpha amplitude)} = 120.94 \quad \sigma_2 = 39.55$$

$$r = -.72, r \text{ is significant } (P < .01)$$

Comparison between time estimation and time percent alpha

$$M_1 \text{ (time estimation)} = 20.45 \quad \sigma_1 = 12.25$$

$$M_2 \text{ (time percent alpha)} = 11.33 \quad \sigma_2 = 5.00$$

$$r = -.44, r \text{ is not significant } (P > .10)$$

DISCUSSION

From the results it appears that under red illumination there was a greater reduction in alpha amplitude and time percent alpha than under blue illumination (Tables 8 and 9). The mean differences of the parameters under the two coloured lights were highly significant ($P < 0.0005$ for both the parameters). Figures 11 and 12 show that at the introduction of both the lights there was an almost similar reduction in alpha amplitude and time percent alpha respectively, but with time there was a large gain in alpha amplitude and time percent alpha under blue illumination. There was no marked increase in these parameters under red illumination. These results confirm the similar findings by Gerard (1958).

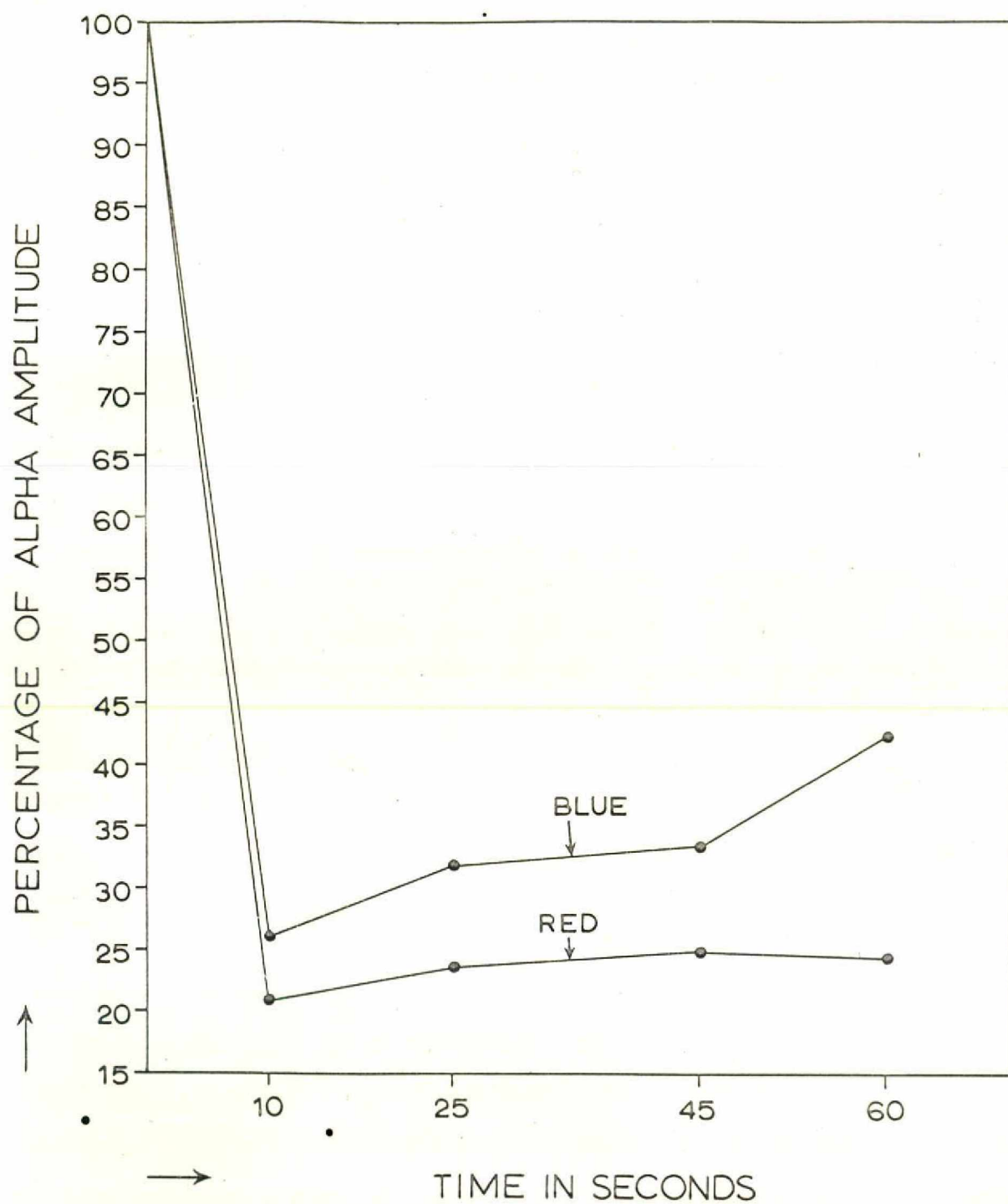


Fig.11. Alpha amplitude changes under red and blue lights.

Similar results of the effects of different coloured lights on brain potentials were also reported by Carterette and Symmes (1952) and by Van Buskirk et al. (1952) and Dixon (1966). In a recent experiment, Dixon (1966) reported data showing more reduced incidence of alpha under red light than under green light. The present data together with these findings suggest that there is a relation between the wavelength of light and arousal. The findings of Gerard (1958), Dixon (1960) and Wilson (1966) support this hypothesis ⁱⁿ ~~on~~ a much more wider psycho-physiological ^{Context} ~~areas~~ (Gerard:- EEG, GSR, blood pressure, heart rate, respiratory movements and eye blinks; Dixon:- recognition threshold; Wilson:- conductance level and GSR). More recently, Sanders and Liske (1967) have reported findings of the potency of red light in altering the visual-evoked potentials. They reported a double-peaked, positive-going evoked response to red light in the eyes closed condition. White, green or blue flash, on the other hand, did not evoke the double-peaked wave.

From our results it appears that cortical activation remained high under red illumination, but not under blue illumination. This pattern of recovery under blue illumination was further investigated. In the present experiment, it was found that with time the recovery was far greater under blue light than under red light. In this experiment the longest time interval in which light was administered was 60 sec. In two subsequent experiments the time interval was increased as follows. In the first experiment

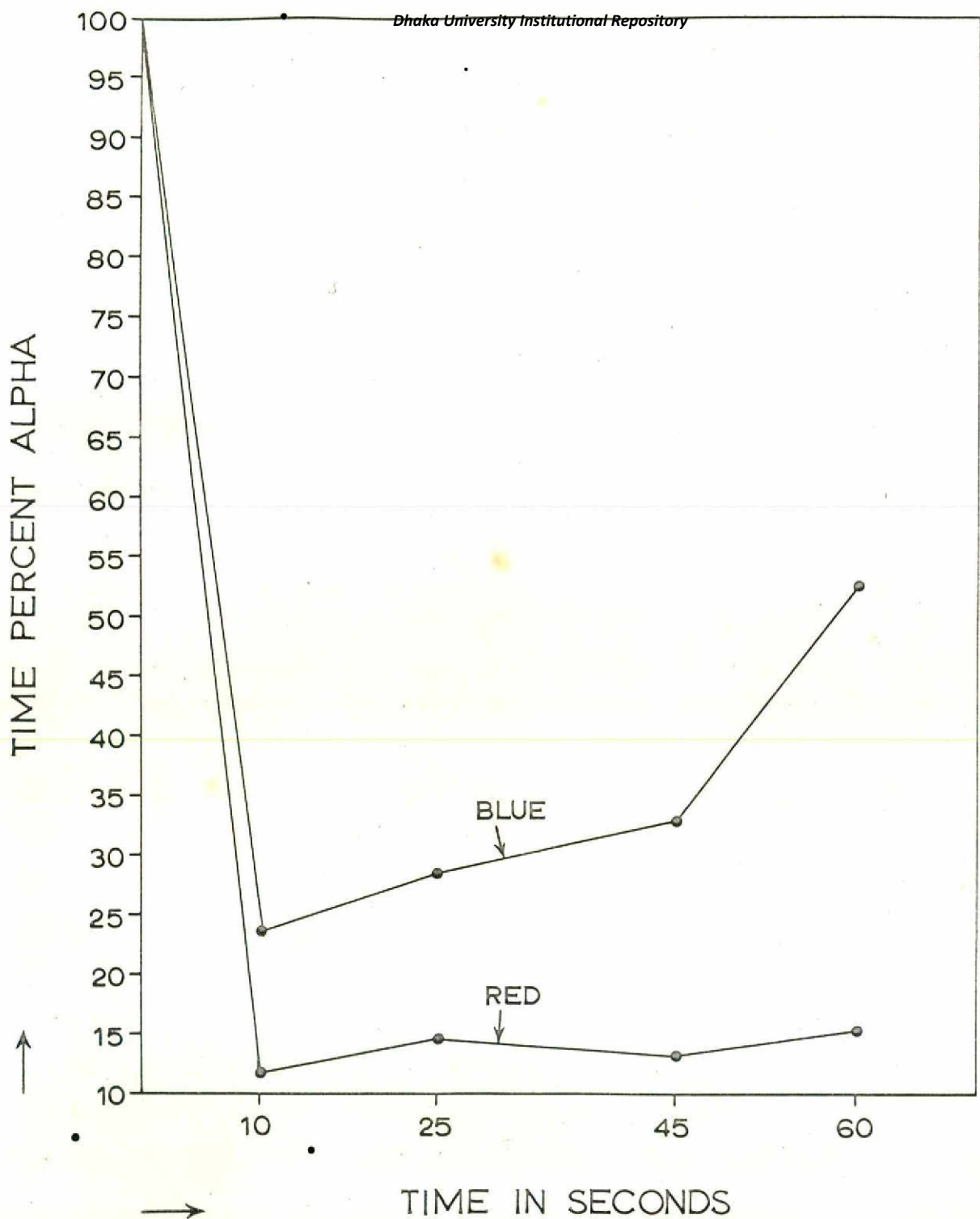


Fig.12. Time percent alpha changes under red and blue lights.

the interval was increased to 300 sec. Arrangements were made to mark the EEG records for every 60 sec. In the second experiment, the time interval was further increased to 600 sec. Results are summarised in Tables 11 and 12.

Table 11. Alpha amplitude changes under red and blue lights

(The following are integrator readings; their voltage reference was as follows: an EEG input of 1.75 μ V at frequency 8 - 13 = 100 units)

	1 min.		2 min.		3 min.		4 min.		5 min.		Resting
	Red	Blue	Red	Blue	Red	Blue	Red	Blue	Red	Blue	
MEAN	109.44	188.28	116.93	180.60	116.75	207.50	111.72	203.94	114.75	220.64	412.89
Per cent %	26.50	45.60	28.32	43.74	28.27	50.25	27.06	49.39	27.79	53.44	100

Table 12. Alpha amplitude changes under red and blue lights

	2 min.		4 min.		6 min.		8 min.		10 min.		Resting
	Red	Blue	Red	Blue	Red	Blue	Red	Blue	Red	Blue	
MEAN	167.50	216.61	197.69	226.72	182.11	247.93	193.76	250.05	196.25	270.96	451.52
Per cent %	38.14	47.97	43.78	50.21	40.33	54.91	42.91	55.00	43.46	60.05	100

The data in Tables 11 and 12 were plotted graphically in Figures 13 and 14 respectively. These two figures show that

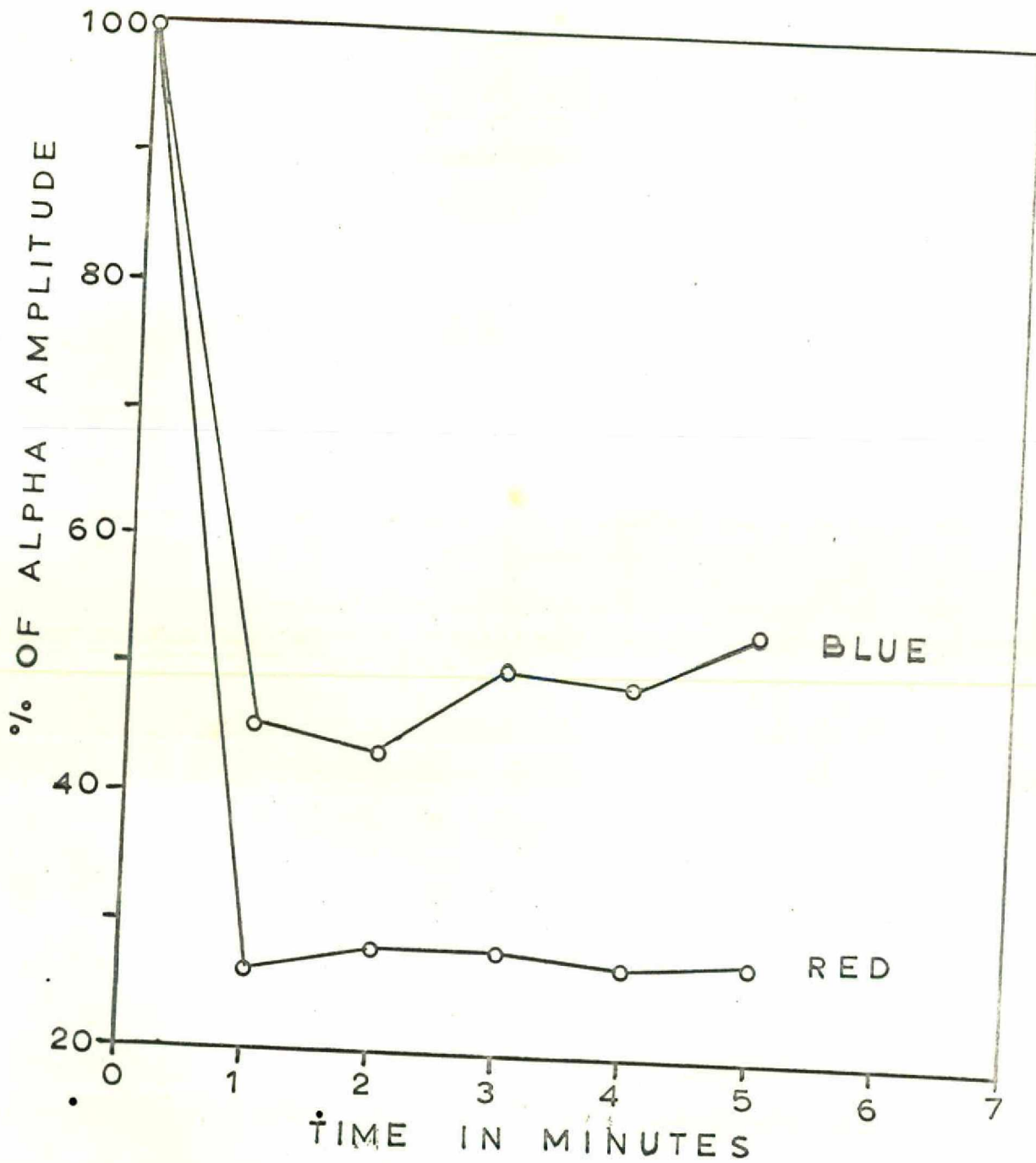


Fig.13. Alpha amplitude changes under red and blue lights.

there was a greater recovery in alpha amplitude (the only parameter investigated) with time under blue light, whereas comparatively there was a very little recovery under red light. This suggests that only red light maintains a state of relative desynchrony. However if we compare Figure 13 with Figure 14, we find that though there is an overall greater recovery in alpha amplitude under blue light with time, the rate of increase under red light is greater. For example, in 5 min. there was an increase of 53.44% in alpha amplitude under blue light with a corresponding increase of 60.05% (a difference of 6.61%) in 10 min. Under red light there is an increase of 27.79% in alpha amplitude in 5 min. with a corresponding increase of 43.46% (a difference of 15.47%) in 10 min. This suggests that possibly after a certain period of time the photic stimulating effect of red light decreases at an increasing rate.

EEG activity and its relation to the estimation of time under the influence of red and blue illumination

During the verbal estimation of temporal intervals under the two coloured lights, EEGs were recorded and subsequently analysed in terms of alpha amplitude and time percent alpha. When the results, i.e. the physiological data of cortical arousal and the verbal estimation of temporal intervals, are compared, it is found that under red light there was, on the one hand, a reduction in alpha amplitude and time percent alpha and, on the other, an increase in the unit of perceived time. Secondly,

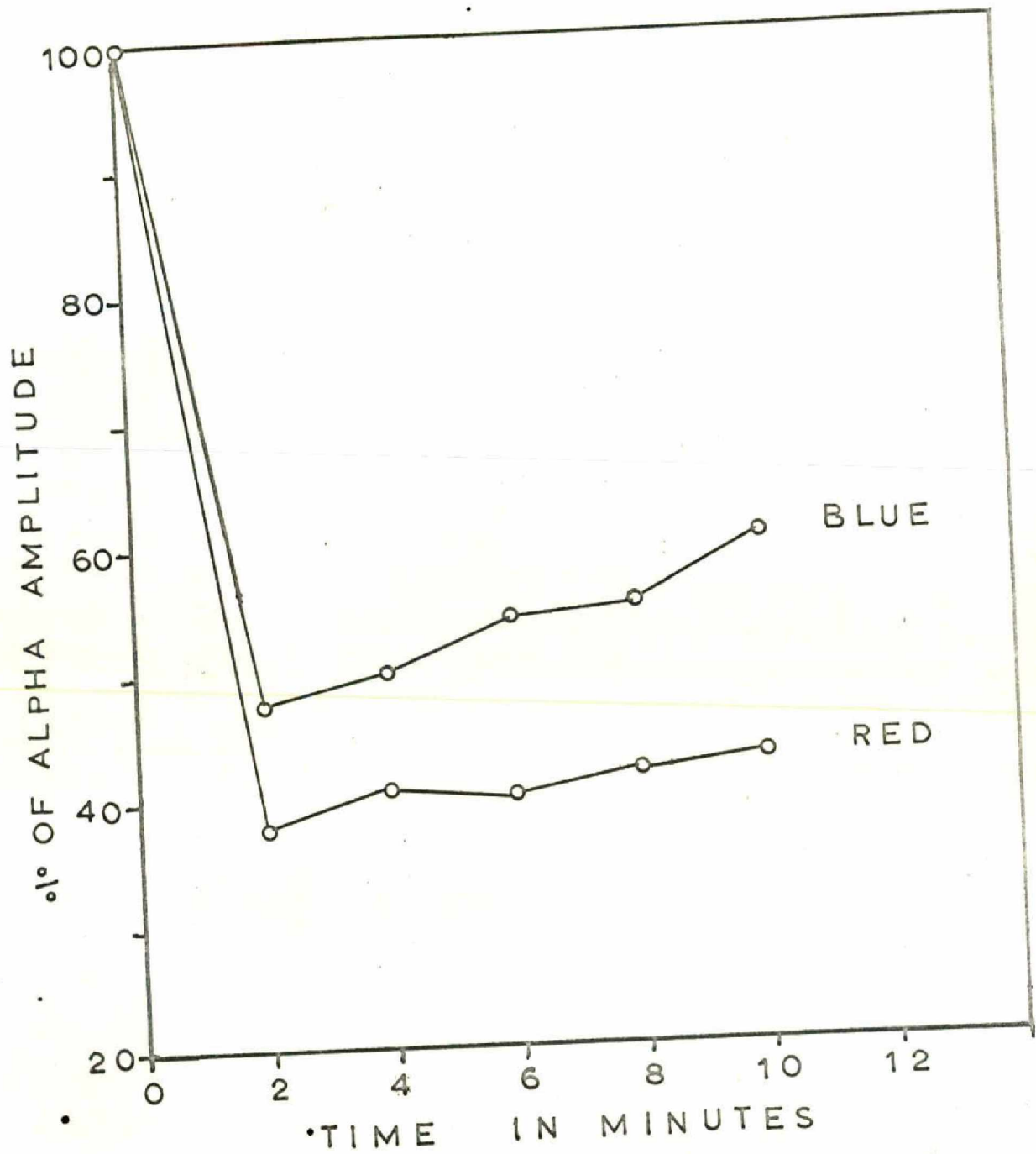


Fig.14. Alpha amplitude changes under red and blue lights.

under blue light there was, on the one hand, less reduction and quick recovery in alpha amplitude and time percent alpha and, on the other hand, a decrease in the unit of experienced time. This shows that EEG activity, especially alpha rhythm, may be related to the individual's personal temporal scale.

The Pearson Product Moment Correlation (r) was computed for the data of time estimation and EEG activity. The tests show that alpha amplitude is inversely related to the overestimation of time ($r = -.72$, significant at .01 level). Time percent alpha is also inversely related to overestimation of time, but r is not significant in this case ($P > .10$). On the other hand, alpha amplitude is positively correlated with the underestimation of time ($r = .74$, significant at .001 level under blue light, $r = .62$, significant at .05 level under red light). Time percent alpha is also positively correlated with the underestimation of time ($r = .56$, significant at .01 level under blue light, $r = .54$, not significant at .05 level under red light). The inverse relation of alpha amplitude and time percent alpha to the overestimation of time is in agreement with the activation hypothesis that the smaller the alpha amplitude or time percent alpha (signifying the cortical activation, i.e. biological clock running fast), the greater is the degree of overestimation of time. On the other hand, the longer the alpha amplitude or time percent alpha (signifying the cortical synchronization), the greater is the degree of underestimation of time. Again, the relationship between EEG activity and time sense seems to be more clear from the following facts. Under red light, thirteen Ss overestimated

A



B

Light on



C

Light on



20 μ V
sec.

time and eleven Ss underestimated it. In spite of the same stimulating agent (red light) EEG activity was correlated to Ss' time estimates as predicted (i.e. alpha amplitude being correlated inversely to the overestimation of time and positively to the underestimation of time).

Thus, from the consistency with which temporal intervals were estimated and its relation to alpha rhythm in the EEG records, it may be concluded that alpha rhythm indicates the speed of the human physiological clock and is related to the individual's estimation of time. This relationship between alpha rhythm and time sense was found in positive as well as in negative results. This is evident from the results of S17 (Table 10) which are different from others in the group. Unlike other subjects in the group, S17 underestimated time more under red light than under blue light. That is, in his case the unit of experienced time reduced under red and increased comparatively under blue. In terms of activation hypothesis, then, his EEG should show more desynchronization under blue light than under red light. Now let us consider his EEG records. Figure 15 shows these (Figure 16 however, shows the general pattern of EEG activity under red and blue light). Alpha rhythm disappeared with the introduction of blue light and remained so until the light was turned off. But under red light, though alpha rhythm disappeared with the introduction of the light, it reappeared quickly with relatively longer amplitude. The reason for this deviant result, however, is not clear to us.

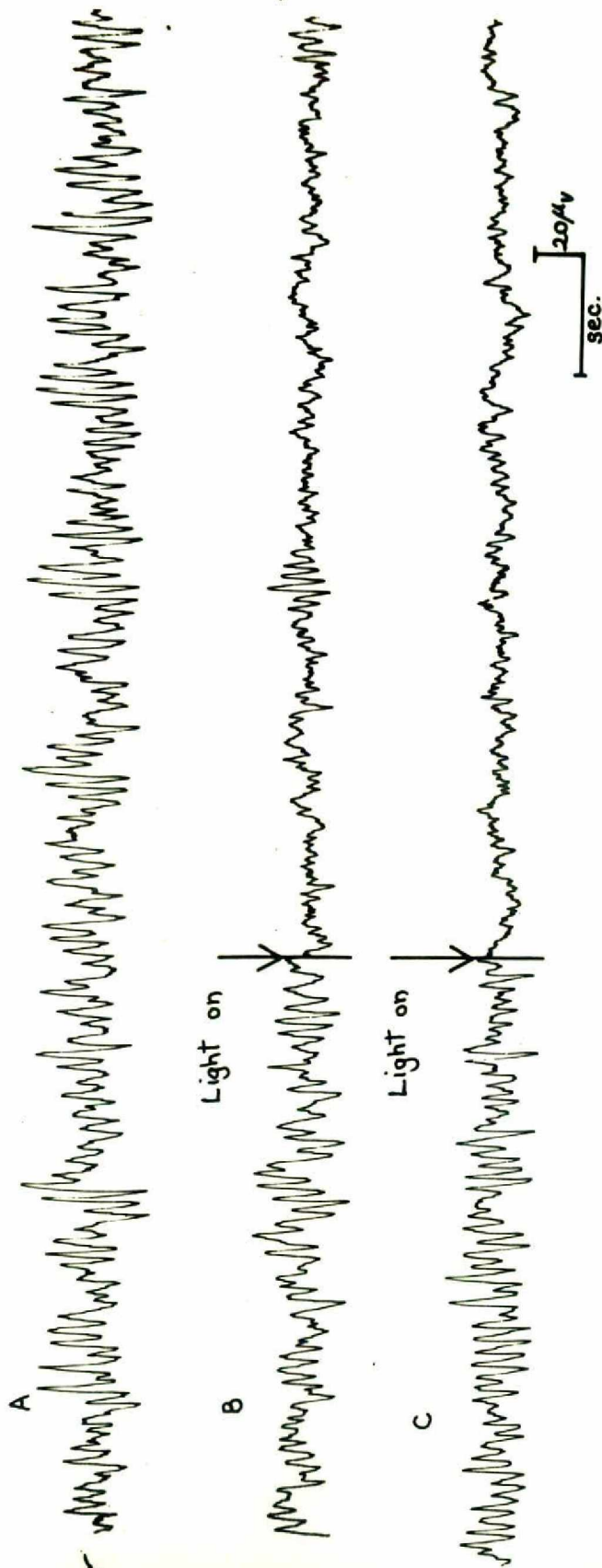


Figure 16. Sample EEG activity pattern under (a) resting condition, (b) blue light, and (c) red light

This subject was not colour blind according to the Ishihara Test. It is relevant to mention here that Walker et al. (1944) found that blue light was a more potent photic driving stimulus in monkeys. Whatever may be the reason for the deviant responses by S17, the interesting point here is the relationship between the pattern of EEG activity and his estimation of time under the two coloured lights. This instance gives more weight to the theory that the state of EEG activity is related to the individual's time sense.

Some subjects in the present experiment overestimated time and some underestimated time. They were, however, consistent in their estimates all along. This raises the question whether individual differences in the estimation of time can be explained in terms of individual differences in the pattern of EEG activity. An answer to this question requires further research. However, Werboff (1962) found that subjects with more than 50 percent alpha overestimated time under conditions of photic stimulation more than subjects with less than 50 percent alpha. In the present study, thirteen subjects out of twenty-four overestimated time under red light. Most of these thirteen subjects belonged to the more than 70 percent alpha group. But this study could not confirm Werboff's findings that persons with more than 50 percent alpha tend to overestimate time under conditions of photo-stimulation, as most of the eleven subjects who underestimated time under red illumination belonged to the more than

50 percent alpha group.

EEG activation and time sense in psychopathological conditions

The activation theory of time sense and the experimental data supporting the theory lead to the examination of cases of time distortion in psychopathological conditions. Psychopathological conditions which produce changes in cerebral rhythms, may produce corresponding changes in human time sense. It is a well known fact from human pathology that alterations of cerebral rhythms occur in various kinds of epilepsy, particularly in seizures or even in subclinical paroxysms characterized by slow EEG rhythms (Holubar and Machek, 1962). These authors found that in epileptics there is a correlation between the alterations of the time sense and those of EEG rhythms. These authors concluded that cerebral rhythms, especially alpha rhythm, represent the speed of the 'biological pendulum' of human time sense.

The distortion of time sense is a common symptom with schizophrenic patients. Thus, schizophrenic patients tend to overestimate time (Lhamon and Goldstone, 1956; Pearl and Berg, 1963; Lhamon, Goldstone and Goldfarb, 1965; Lehmann, 1966). However, Rabin (1957) reported data showing that schizophrenics tend to underestimate longer periods of time more often than they overestimate.

Why do schizophrenic patients tend to overestimate time? Can it not be explained in terms of the cortical arousal hypothesis? There are, however, studies showing that there is a correlation between the schizophrenics' behavioural aspect and level of

physiological arousal (Venables and Wing, 1962; Venables, 1963).

Venables reported that there is a close and consistent relationship in chronic schizophrenic patients between the degree of social withdrawal and level of physiological arousal. The more withdrawn a patient, the higher his arousal. We are not yet sure whether this arousal mechanism is related to the tendency of overestimation of time by schizophrenic patients. This assumption (of physiological arousal being related to overestimation of time in schizophrenics), however, has been supported partly by experimental evidence (Pearl and Berg, 1963). These investigators reported data showing that schizophrenics would exhibit greater distortion in the estimation of time for stimuli relevant to their major conflict areas than for other stimuli. But it is difficult at the moment to postulate that the temporal disturbance in schizophrenic patients is related to arousal level. On the basis of Venables' data (1962, 1963) on the arousal mechanism in schizophrenics, it may be assumed that the degree of temporal distortion in schizophrenics may be related to the patients' EEG activity. However, this assumption requires experimental support.

Another fact, reported in the literature on the distortion of time sense in schizophrenics, is that this distortion is perhaps related more to conceptual disorganization than to the patient's internal timing mechanism. Temporal judgements depend upon many factors, such as focal, background, residual and organismic factors. It might be argued that schizophrenic patients due to their general impairment in thought process fail in harnessing

residual and other socially developed conceptual factors in a temporal judgemental situation. As a result, they may misjudge a particular temporal interval. Their temporal judgement may be impaired yet they may react accurately to a temporally oriented situation. They may fail to conceptualize time yet they may react to it accurately. "The schizophrenic patient may report temporal immobility in a world of the present where time stands still and yet perform tasks that require adaptation to succession and change. This patient may offer judgements about the clock and calendar that reveal altered temporal orientation and yet conform to the work, feeding and sleep schedules of a hospital," (Lhamon, Goldstone and Goldfarb, 1965). This apparent paradoxical response by a schizophrenic patient requires careful attention and extensive experimental and observational studies.

Alpha rhythm as a sensory timing mechanism

Alpha cycle has been assumed as an alternating excitability cycle (Bartley and Bishop, 1933; Bishop, 1936; Bartley, 1939; Chang, 1950, 1951, 1952). Bishop (1933) demonstrated that impulses initiated in the optic nerve of the rabbit found access to the cortex in the form of evoked responses only at certain intervals corresponding to the spontaneous rhythmic or alpha activity cycle. Accordingly, Bishop (1936) interpreted this as evidence of a cortical excitability cycle.

Assuming that alpha cycle represents an excitability cycle, it has been proposed as a means of coding or timing sensory impulses "in order that our perceptual world and our reactions to it are not distorted or smeared by the more or less continuous influx of sensory stimuli," (Lindsley, 1952). The proposed mechanism works as follows. The probability of incoming impulses ~~to~~ causing a neuron to fire will vary with the phase of the excitability (alpha) cycle. Impulses arriving at synapses when the trans-synaptic neuron is in the phase of increased excitability will be more likely to fire the trans-synaptic neuron. Those arriving during the phase of lowered excitability will be less likely to do so. And when the excitability cycles of a group of neurons are synchronized, then the flow of impulses through that group will be timed by the frequency and phase of the cycle. Recent findings (Van der Gon and Van Hinte, 1959; Mundy-Castle and Sugarman, 1960; Surwillo, 1963, 1964a, 1964b; Dustman and Beck, 1965) lend support to this hypothesis.

The great difficulty faced in identifying alpha cycle as a sensory timing mechanism is that the alpha rhythm blocks during the onset of stimulation to which the organism is paying attention. This difficulty is, however, met by drawing a distinction between alpha rhythm and alpha activity (Lindsley, 1952). Alpha activity cycle is presumed to be a basic metabolic or respiratory rhythm of the individual brain cell, and it is only when thousands of

cells are acting in synchrony that there is sufficient voltage summation to produce a recordable alpha rhythm. A low voltage fast EEG, as when the subject is alert, may represent a "fractional synchronization" in smaller aggregates of cells, but with random phase relations. This would mean that alpha activity may exist in smaller aggregates of cells in the absence of a recordable alpha rhythm in EEG.

Neuro-physiological substratum underlying human time sense

The anatomy and physiology of human time sense are complex and far from being completely understood yet. Recent experimental work on rats (Ellen and Powell, 1963) has shown that the extra-pyramidal system, the zona incerta and the globus pallidus in particular, are involved in the temporal patterning of behaviour. Spiegel, Wycis, Orchinik and Freed (1956) reported observations on human patients after bilateral lesions in the region of the dorsomedial and anterior thalamic nuclei. These patients experienced transitory confusion for time (chronotaraxiz) which was usually associated with memory defects. The authors concluded that connections of the thalamic nuclei with frontal lobes, the mammillary bodies and perhaps also the parietal lobes and gyrus cinguli constitute the complex network of circuits involved in the processes of experiencing time. Efron (1963) reported that damage to certain brain areas causes disturbances in time judgement which are regularly associated with aphasia. He speculates that dysfunction of the temporal lobe may be responsible for a

disorder of the 'time-labelling mechanism' which gives rise to the 'déjà vu' phenomenon and he further proposes that analysis of time sequences, intervals and simultaneity is performed in the left cerebral hemisphere. Potzl and Hoff (1934, 1937-38, 1939, reported by Lehmann, 1966) published clinical and pathological studies on a number of neurological patients who experienced a time lapse phenomenon. They felt that time was passing with far greater speed. All these patients had lesions in the right occipital lobe. It may be postulated that possibly the speed with which time passes (slowly or rapidly) is mediated through the activity of the occipital cortex. This is in line with the experimental findings that the speed with which time passes is related to alpha rhythm which is predominant in the occipital cortex. The cortical and sub-cortical mechanisms that are responsible for the determination of alpha activity (and in turn human time sense) will be discussed below.

Thalamic pacemaker for EEG activity

The question whether there is a rhythmical stimulation of the cortex by volleys from a diencephalic pacemaker is not yet fully clear. However, on the basis of the experimental evidence so far available, this would seem to be the most likely possibility. Ellingson (1956) and Ochs (1965) have reviewed such works in detail. By means of subpial knife cuts, 'chronic islands' of

cortex may be prepared with all neuronal connections cut, keeping the blood supply from the surface pial vessels intact (Kristiansen and Courtois, 1949). Only a low level of EEG activity was found remaining in such islands. Though isolated islands of cortex may not show spontaneous EEG activity, they have the ability to respond rhythmically. This is shown by the rhythmic after-discharges which can readily be elicited by means of single shocks (Ochs, 1965). The inference drawn from these findings is that the various regions of the cortex although capable of giving rise to rhythmic activity, require impulses transmitted to them from a pacemaker region to excite rhythmicity. Certain regions in the thalamus appear to have this pacemaker function. Dempsey and Morison (1942a) found that stimulation of the non-specific thalamic nuclei at pulse rate of 5-10 per second could trigger wave discharges in the cerebral cortex which were recorded from all cortical areas. The repetitive waves so evoked in the cortex were similar to 8-13 c./sec. EEG waves which appear spontaneously. Dempsey and Morison (1942b) tried to show a common neural origin for the spontaneous cortical waves and the thalamically triggered recruiting waves.

Recently, Andersen and Eccles (1962) provided a possible thalamic mechanism controlling the phase differences in the cortical rhythm. Their hypothesis is that the brain waves recorded in the cortex are generated intrinsically in the cortical neurons

Mankind changed by need

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keep fires burning

FROM OUR OWN CORRESPONDENT—NEW YORK, OCT.

The discovery of fire may have determined not only man's cultural development but a significant part of his biological inheritance as well.

This striking amplification of the Promethean myth was presented to the National Academy of Sciences, meeting in Durham, North Carolina, by Dr. Kurt Richter, of Johns Hopkins University, Baltimore.

He said that the absence—or at least submergence—of a daily alternation of 12 hours' liveliness and 12 hours' lassitude was a hitherto unrecognized difference between man and other primates. He has detected in rats and several species of monkey an alternation so distinct that it seemed as if a switch had been thrown.

Vestiges apparent

Destruction of the hypothalamus, a specialized part of the middle brain, eradicates the "biological clock", which Dr. Richter believes to be a group of specific cells which function together to arouse and relax the creature in turn. No such cells have yet been identified.

As a mechanism apparently independent of anything else that affects the animals, Dr. Richter said, the "clock" determined when they could emerge from shelter in the morning and when they should return at night. It was a safety device far more effective than direct dependence on light and dark.

This, he suggested, would have also of early man before he discovered fire. Fire gave him light throughout the night and changed his entire pattern of existence. He had to stay awake or wake frequently to tend the fire. Its protection allowed many individuals to gather together to discuss the day's activities and plan ahead without danger of attack from wild animals.

As a result man came to function on a comparatively even level throughout the entire day, and over some 300,000 years there had been natural selection in favour of those whose "biological clock" was not powerfully effective.

Vestiges of its influence could still be seen in the daily pattern of rising and falling body temperature and in people who found it difficult to wake early in the morning. In some mental patients the cycle reappeared as an abrupt change of mood at 12-hour intervals.

HERR BRANDT BRIEFED FOR BRITAIN VISIT

FROM OUR CORRESPONDENT

BERLIN, OCT. 19

Dr. Schröder, the west German Foreign Minister, had talks in Berlin today with Herr Brandt, the chief burgomaster, to prepare Herr Brandt for his official visit to Britain from October 24 to 29.

and a phasing device controlling the rhythm is located in the thalamus. The uniqueness of their hypothesis, however, lies in the fact that the essential phasing device is due to widely dispersed inhibitory postsynaptic potentials that are generated through a recurrent pathway from the axon collaterals of the thalamic neurons. A series of thalamic neurons with their axons projects to the cortex and each receives one excitatory synapse from the medial lemniscus fibres. Collaterals from the axons of the thalamic neurons end in excitatory synapses on interneurons which in turn have inhibitory synapses on the thalamic neurons. They believe that inhibitory interneurons are excited by axon collaterals so that when the thalamic cells discharge, the inhibitory cells are excited and the resulting effect maintains an inhibition of thalamic cells for the duration of one wave of an alpha rhythm.

The above studies elucidate greatly the mechanism of alpha activity which in turn represents the velocity of the human biological clock. The present weight of evidence goes in favour of a biological event-count mechanism the rhythmic phase of which is sub-cortically regulated. Recent findings of Richter (1966) that the destruction of hypothalamus eradicates the biological clock in rats give strong support to this hypothesis.

SUMMARY AND CONCLUSION

The present study was designed to investigate the effects

of visible radiation of various wavelengths on the estimation of distance and time. The study was divided into three parts. The first part dealt with the effects of red and blue light on the estimation of distance. The second part dealt with the effects of these two colours on the estimation of time. Finally, the third part studied the effects of red and blue light on the estimation of time and the relationship between EEG activity and time estimation.

A review of the literature on the effects of light and colour on the organism revealed that light does affect the whole organism. It also showed that light of different colours affects the organism differently. Generally, red light was found to be energizing and blue depressing.

Part I

Part I of the study was designed to investigate the effects of red and blue light on the estimation of distance. The nature of the problem was to investigate the phenomenon whereby of two stimuli on the same plane, subtending the same visual angle and of the same luminous intensity but of different wavelength that of the longer wavelength one would be judged as nearer than that of the shorter wavelength one.

The hypothesis was that under the above conditions red would appear nearer than blue.

The results showed that under red light things do indeed appear nearer than under blue.

To determine whether this effect of an apparent decrease in distance under red light was due to the perceived hue or to the wavelength of incident light, a further experimental investigation was carried out. It was designed to investigate whether long wavelength radiations outside the visible spectrum would produce a similar effect. With this purpose, the effect of infra-red radiation, which has no perceived hue but whose wavelength is near to that of red, on distance perception was investigated. The results showed that infra-red did not have any significant effect on distance perception. These non-significant results suggest that (i) perceived hue is necessary for the phenomenon observed in the main experiment; (ii) infra-red is not so activating as red, or (iii) the phenomenon is a combination of both of these.

Part II

Part II of the study was designed to investigate the effects of red and blue illumination on the estimation of time. The following hypotheses were investigated:

1. Time would seem to pass more slowly under red light than under blue light.
2. Time, during a dark interval, would appear to pass less slowly in comparison to that under red and blue illumination.

It was expected that the order of the change of time under these three conditions would be as follows: red (more

slowly), blue (less slowly) and darkness (far less slowly).

The results confirmed the first hypothesis that time passes more slowly under red illumination than under blue illumination. Time, during dark intervals, also seemed to pass more slowly than under blue illumination. Red light and darkness had similar effects on the estimation of time. This appears contrary to the second hypothesis. But a close analysis of the data showed that in darkness, a short interval was overestimated and longer intervals were progressively underestimated.

Part III

In this part an attempt was made to study the effects of red and blue illumination on the estimation of time and the possible relationship between EEG activity and time estimation. The following hypotheses were investigated.

1. Red illumination will cause a decrease in alpha amplitude and time percent alpha more than that due to blue illumination.
2. With fast activity low amplitude alpha under red light, time would appear to pass more slowly than that with comparatively slow activity and high amplitude alpha under blue light.

The results confirmed the hypotheses. Time seemed to pass more slowly under red illumination than under blue illumination. The results also showed that there is a significant correlation between alpha amplitude and time estimation. Alpha amplitude was correlated inversely to overestimation of time and positively to underestimation of time.

The results were explained in terms of a wavelength sensitive hypothetical biological oscillator the rate of which may indicate the human time sense.

Conclusion

Experimental evidence exists for the fact that the perception of time and distance are interdependent phenomena (Helson and King, 1931; Cohen, Hansel and Sylvester, 1955). The represent research investigated whether the perception of distance and time is affected by the wavelength of visible radiation. The results showed that red and blue (the two colours studied) had opposite effects on the perception of time and distance. Under red light, while there is an apparent decrease in distance, there is an apparent increase in time. On the other hand, under blue light, while there is an apparent increase in distance, there is an apparent decrease in time interval. An explanation for these phenomena was not easy. However, an activation hypothesis to explain the phenomenon of time perception under red and blue light was supported by results from the EEG experiment. It was found that with comparatively desynchronized alpha under red illumination time passed more slowly than with relatively slow waves under blue illumination. But it was difficult to test this hypothesis experimentally in case of distance perception under the two coloured illumination. However, a further experiment with infra-red radiation showed that probably perceived hue and activation together might be responsible

for this phenomenon. A-propos of this we do not, of course, know (a) whether the infra-red radiation used was non activating, nor (b) whether the activating effect of red is through its perceived hue.

Before concluding, the following may be suggested for further research:

1. We discussed before that the present set of theories cannot explain adequately the effects of colour on the perception of distance. For example, the learning theory or perspective theory explains these phenomena in terms of past learning and does not take into account the differential physiological effects different colours might have on the organism during perception. Nor can this theory explain those results where red appears farther than blue or green. However, no experimental evidence exists to discard the learning theory at the moment. The present experiment with human adults could not contribute much on this aspect of the problem. So, experiments with animals and/or children may be undertaken.
2. Due to methodological difficulties and shortage of time, it was not possible to put the photo-activation theory, in case of distance perception under red and blue light, to further experimental verification. It is proposed that with improved techniques the hypothesis may be put to experimental tests.

3. As distance and time perception is found to be affected by the wavelength of incident light, it is proposed to study the kappa-effect (the perception of time being dependent upon that of distance) of Cohen et al. (1955) under different coloured light.
4. A study of time estimation with all colours of the visible spectrum to investigate the order of effects.
5. An investigation of individual differences in both time estimation and alpha index.
6. An investigation with schizophrenic patients on the relationship between the degree of the distortion of time sense and the level of physiological arousal (especially EEG activation). The apparent temporal disorganization in schizophrenics (as shown by their time estimates) while reacting accurately to a temporally oriented situation (as shown by their accurately reacting to hospital feeding and sleep schedules) poses a great challenge to the researchers of the human time sense. Such studies may reveal whether the defect lies with the dysfunctioning of an internal timing mechanism or with their conceptual disorganization.

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