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Paper 29

THE FOUR DIMENSIONAL COLOUR SPACE OF THE EXTRA-FOVEAL RETINAL AREA OF THE HUMAN EYE

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SUMMARY

1. The scotopic receptor of man functions not only at low-intensity brightness levels but also at high-intensity levels of field brightness.

2. The peripheral colour space of human's field of vision is not three-dimensional, but four-dimensional. Three-dimensional equalities for large fields are only approximate; but not absolute colorimetric equalities.
3. Three-dimensional equalities for large fields change when field brightness and the state of the observer's eye adaptation are changed.
4. Four-dimensional equalities are stable. This proves the stability of the spectral photoreceptor sensitivity curves.
5. For practical purposes the application of three-stimulus value curves is quite sufficient. Yet, because of their instability not too much importance should be given to accuracy of these curves at their standardization.

It is known that colorimetric equalities established by the observer in foveal vision are not accepted by him when observing by means of the extra-foveal part of the retina. Thus, for instance, many authors have observed that Raylelgh's foveal equality is not true for the peripheral field of vision. The reason of this phenomenon is not quite clear. The fact that the equality did not also hold true for radiations in which a light with a wavelength less than 540 mμ was absent, suggested the opinion that the phenomenon cannot be sufficiently explained by the pigmentation of the macula lutea. But the final solution of this question could be achieved only through an elaborate colorimetric study of the extra-foveal area of the retina.

The routine colorimetric method of matching two adjacent fields is hardly applicable when peripheral vision fields are concerned. The fact is that, because of the low acuity of peripheral vision, the line dividing the two fields is seen indistinctly. This extremely reduces the precision of colour measurements, and at a distance of about 10° from the fovea renders it practically impossible.

Therefore we resorted to the colorimetric method of replacement.* In this case the radiations to be matched are presented in succession,

* Some advantages of the method of replacement were pointed out by Tichodeev.

replacing one another in time, upon the same retinal area. A replacement occurs sufficiently rarely (once in 1.5 sec.), so the principle of the replacement colorimeter should not be confused with that of a flicker photometer.

The experiment is conducted as follows: a combination of primary colours is chosen to match the test colour. After a colour match is obtained the observer at the moments of replacement sees no changes in the field of vision. It appears that when this method is employed the peripheral contrast sensitivity is much higher than when two adjacent fields are compared. The fields employed in the test were of *5°* diameter with centre removed by 10° from the fovea.

The very first tests showed that the colour space of the periphery is not three-dimensional but four-dimensional, i.e. there are fours of linearly independent colours, whereas any five colours are linearly dependent. This means that on the periphery not three, but four receptors are functioning simultaneously.

Four stimulus value curves for peripheral spectral colours have been obtained, and are shown in *fig. 1. Fig. 1* shows also the curves, theoretically calculated on the presumption that on the periphery act the same three receptors, as in the fovea, and a scotopic reception in addition. A satisfactory coincidence of the theoretical and experimental curves shows that the peripheral colour space is four-dimensional due only to the functioning of the scotopic receptors. (It should be noted that absolute coincidence of the curves is more than should be expected, for the sensitivity curves of the three photopic receptors of the fovea should differ slightly due to the pigmentation of the macula lutea.) The four-dimensionalness of the peripheral colour space was examined at field brightnesses up to 1000 asb.

In connexion with the recorded activity of the scotopic receptors at high brightness, the usual three-dimensional colorimetric equalities for fields exceeding 1.5° should be regarded as approximate, not absolutely precise, equalities. It should be borne in mind that a three-dimensional equality on a large field is to a certain degree aimed at the greatest similarity, but not at a complete identity of stimulation of all the four receptors functioning in these conditions.

As the sensitivity of the scotopic receptors considerably changes at the alteration of field brightness and the state of eye-adaptation, the question arises as to the degree of stability of the three-dimensional equalities.

Tests have been carried out examining the stability of three-dimensional equalities at variable brightness of compared fields and state of the observer's eye adaptation. A ring field with an external diameter of 10° and internal diameter of *2°* was employed. (The central part of the field was excluded as the observer, due to the pigmentation of the macula lutea, would not accept the equality for the fovea and extra-foveal area simultaneously.)

It appeared that the observer, having established by the use of three primary colours a certain equality at a certain brightness and certain preliminary adaptation, would not accept it after a change in the state of adaptation or a change in field brightness (a proportional change of all the radiations involved in the test). To obtain equality in the new conditions it is necessary to change the amount of the primary colours sometimes by 15%.

But the question arises as to whether the inconsistency of the three-dimensional equalities is due to their being only approximate but not exact and precise equalities. Perhaps precise equalities should also change, for instance, because of the changes of the receptor spectral sensitivity curve in adaptation?

To verify this assumption, the stability of the four-dimensional equalities was investigated. The tests showed that observers accepted equalities which they had established by the use of four primary colours after all kind of changes in the state of adaptation and field brightness. In different experiments the field brightness was changed by 4, 20 and 100 times and adaptation to white, red, yellow, green and blue fields with brightness up to 500 asb. was tested. (The same colorimeter field brightnesses and adapting colours were used as in the tests for examining the stability of three-dimensional equalities). Thus it has been proved that the spectral sensitivity curves for the primary photoreceptors do not change after colour adaptation and at alteration of brightness of the viewed field, while inconsistency of three-dimensional equalities for large fields are due to the functioning of the scotopic receptors.

Three-dimensional equalities for fields of 1.5° diameter proved to be sufficiently stable.

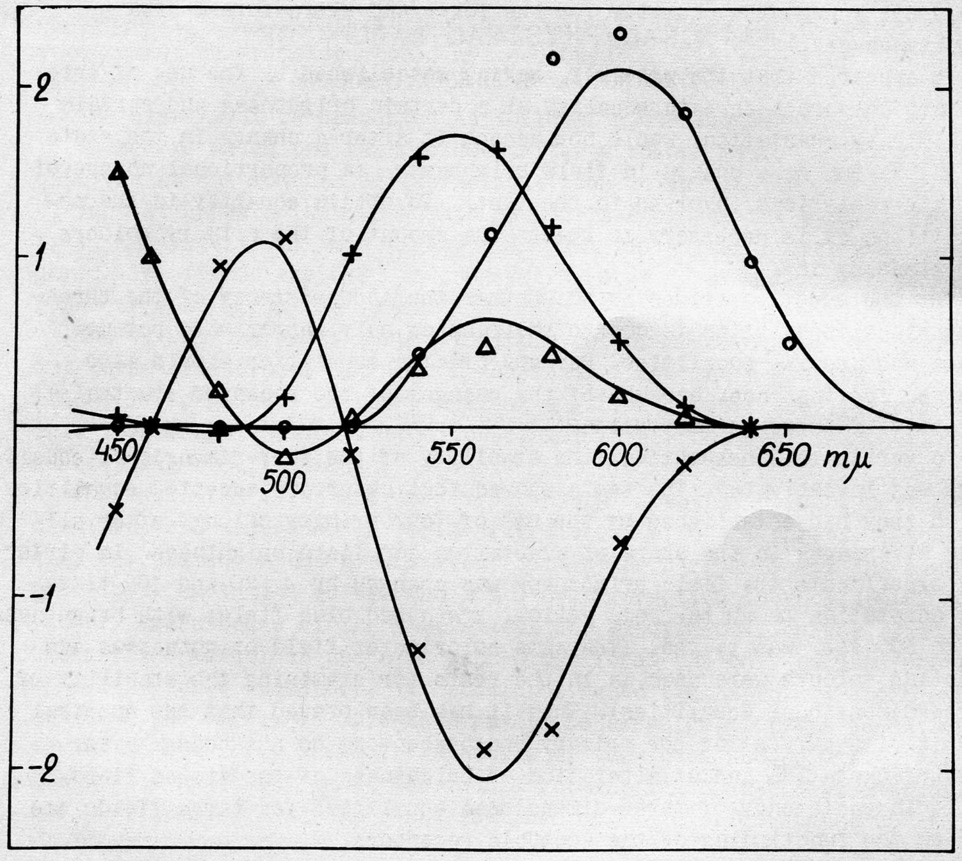

Fig. 1. Four-stimulus value curves for man.

--------------- Calculation curves.

-- o -- --x--
-- + -- --Δ-- Experimental curves.