R. Lubreuk Esq

With the authors Compliments

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Lowne

Vision Phenomena

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On some Phenomena connected with Vision. By B. Thompson Lowne, F.R.C.S., Arris and Gale Lecturer on Anatomy and Physiology at the Royal College of Surgeons, Lecturer on Physiology at the Middlesex Hospital Medical School.

1. On the Physiological Effect of Ruled Surfaces.
2. On the Time required to Produce or Obliterate a Retinal Image.
3. On the Relation of the foregoing Observations to Fechner's law.

1. *On the Physiological Effect of Ruled Surfaces.*

Some months ago it occurred to me that an investigation of the relation of the shades produced by ruled surfaces (as in engravings) with those produced by variations in the intensity of illumination (shadows) would afford useful data in connexion with the physiological action of light upon the retina.

On examining a number of woodcuts and line-engravings I found that there are usually about nine different shades, which may be expressed by the following fractions, which represent the ratio of black to white upon the surface :—

$$\frac{0}{8}, \frac{1}{8}, \frac{2}{8}, \frac{3}{8}, \frac{4}{8}, \frac{5}{8}, \frac{6}{8}, \frac{7}{8}, \frac{8}{8}.$$

Such engravings, when seen at such a distance that every line makes a distinct picture and can be separately perceived, exhibits a sufficiently gradual series of tints or shades passing regularly from white to black. In this case I assume that the intensity of the sensations produced by a given surface is directly as the number of retinal elements stimulated, so long as the nature and intensity of the illumination remain constant.

I next endeavoured to determine the effect of variations in the intensity of the stimulus in the following manner :—

I repeated Lambert's well-known experiment, in which two candles are placed at distances D and D_1 from a screen, an opaque body being interposed so that each candle casts a shadow upon the screen, the light being so arranged that each illuminates the shadow cast by the other. I, however, added a woodcut, in which I had previously determined the ratio of white and black in the shades by examining it with a microscope and low-power objective. This woodcut was so placed that it was illuminated by the light from both candles; by varying the distances of the candles I produced shadows of the same intensity as the shades in the print, determining the intensity of the shadow by making it fall close to the corresponding shade in the print without overlapping it. When the two appeared continuous, viewed at such a distance that the ruled surface was still a ruled surface to the eye if attentively observed, I found the proportion of the reserved white in the ruled surface varied as the square root of the intensity to which the illumination of a wholly white surface had to be reduced to match the other.

I found, for instance, in my first experiment, that when the candles were placed at the distances of two and four feet respectively, the faintest shadow was somewhat brighter than that portion of the woodcut in which $\frac{1}{8}$ was black and $\frac{7}{8}$ white, and the darker was somewhat darker than a half-black surface.

Considering the light thrown on the screen by the nearer candle to have the value of 100 units, that of the more removed gives 25 units. The total illumination of the screen was, then, 125 units—that of the darker shadow 25 units, and that of the brighter 100. The portions of the screen, therefore, have the following ratios of illumination:—

$$100 \quad : \quad 80 \quad : \quad 20.$$

But the sensations produced are nearly equal to those of a shaded surface having $\frac{10}{10}$ $\frac{9}{10}$ $\frac{4 \cdot 2^*}{10}$ white, or as

$$10 \quad : \quad 9 \quad : \quad 4 \cdot 2,$$

the square roots of the luminous intensities nearly.

In every case I found the apparent illumination, measured by a reference to a ruled surface, varied inversely as the distance of the source of light.

There is no difficulty in obtaining a very close approximation, as the eye easily detects a shadow differing by $\frac{1}{64}$ of the whole light, as has been shown by Lambert, Arago, Helmholtz, and others.

The experiments made by the method indicated are vitiated to a certain extent by the difficulty of guarding against diffused light; but when moderate precautions are taken a black surface differs in no perceptible degree from the shadow cast by making the two shadows overlap, so that the diffused light may, I think, be neglected.

†In order to test further the degree of accuracy of which the ex-

* The decimal is only estimated, not measured.

† The account of these experiments was received December 11.

periments are susceptible, on the afternoon of November 29 I made 24 consecutive experiments in two sets. In each case an assistant moved one of the candles until I told him to stop; he then marked the table with a piece of chalk. After each three experiments I took the measurements; these only differed by about 2 to 4 centimetres when the furthest candle was from 1 to 3 metres distant. I calculated the results after all the experiments were finished, and found, in the first case, the shadow had the value of

$$\frac{86}{100}, \frac{86}{100}, \frac{85}{100}, \frac{84}{100}, \frac{84}{100}, \frac{84}{100}.$$

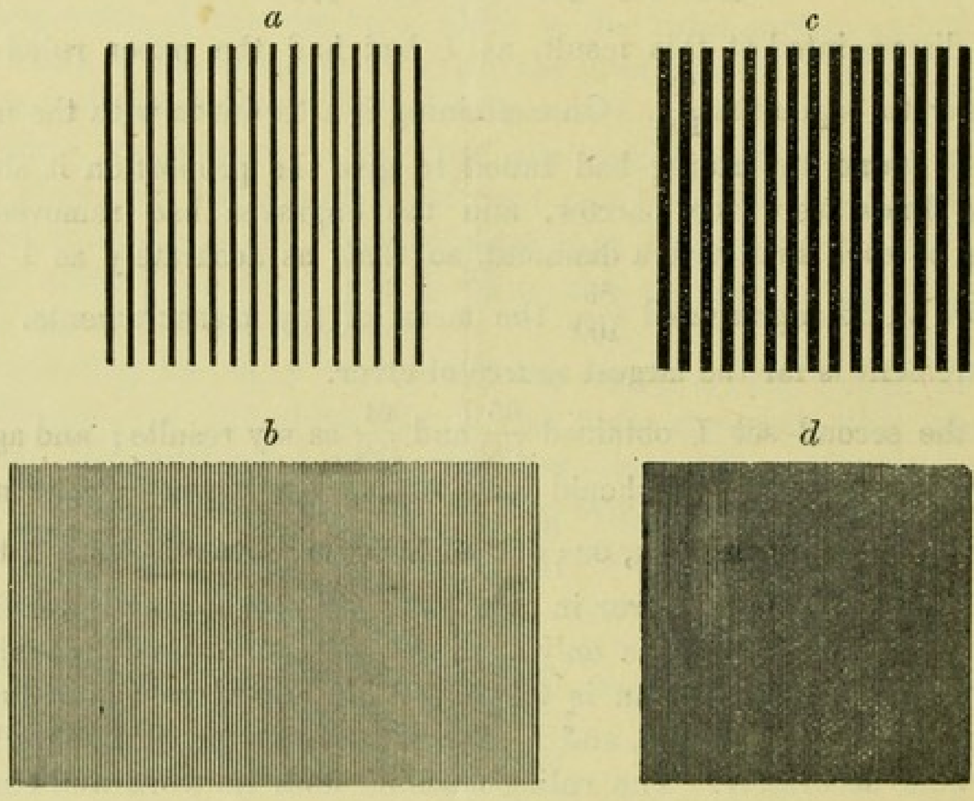
I was disappointed at this result, as I had had the paper ruled very carefully to represent $\frac{75}{100}$. On examining it afterwards with the microscope I found the ruling had failed to give the proportion it should, as the lines were too narrow, and the engraver had removed the centre of each line with a diamond, so that, as accurately as I could measure it, it represented $\frac{85}{100}$, the mean of my measurements. This measurement is far the largest source of error.

In the second set I obtained $\frac{65}{100}$ and $\frac{61}{100}$ as my results; and again I found the ruling, which should have been $\frac{1}{2}$ black, was only, as nearly as I could measure, $\frac{1}{3}$ black, or $\frac{66}{100}$, and in some parts still less. I think, therefore, I may say the error in different cases, eliminating the difficulty of estimating the ruling, is only about 5 per cent. or less, probably not more than 2 when a mean is taken. With regard to the ruling its estimation is more difficult, and I have hitherto found it impossible to get it done accurately. The ruling-machine does its work well enough, but the printing always spoils it. I think, however, the accuracy is sufficient to establish my law.

In my earlier experiments I assumed that the number of retinal elements stimulated by any given surface vary as the amount of the surface left uncovered by the black lines ruled upon it. Of course this is only the case when an accurate picture is made upon the retina of such a size that the lines and spaces fall on physiologically distinct elements; the lines need not be mentally distinguished, but are, I believe, always capable of being distinguished as lines by a mental act.

Professor Stokes first pointed out to me the necessity of proving that in my experiments such a picture is actually formed, and of investigating the effect when the lines no longer produce a perfect picture, but become diffused so as to give what is physiologically equivalent to a shadow. He pointed out that if I were right, such a surface should be fainter in shade—that is, it should appear brighter than a ruled surface.

I found this a by no means easy question to settle; but I easily convinced myself that a ruled surface seen slightly out of focus, or by an astigmatic eye appears lighter than when accurately focused; and this appears to be the case in surfaces of considerable extent, so that it could not be due to the formation of a slightly larger picture. A distant newspaper scarcely differs in appearance from a corresponding sheet of white paper, and two similar prints observed at suitable distances give different tints; the further one, when it no longer produces a distinct picture of the individual line, appears lighter in tone. Still I did not feel quite satisfied until I succeeded in having the accompanying diagram ruled for me.



The squares *a* and *b*, *c* and *d* have respectively the same proportion of black upon the surface: *a* and *b* are $\frac{1}{4}$ black, *c* and *d* half black. At suitable distances the following sensations result:—So long as all the lines are distinct there are four distinct shades; *b* and *d* appear darker than *a* and *c* respectively. When the diagram is seen at a distance of from 15 to 20 feet, *c* and *d* become identical in shade and can no longer be separated, but *b* still appears much darker than *a*. At a still greater distance there are but two shades; and these remain distinct so long as the diagram can be distinguished: the illumination is really different; and no distance makes the sensation the same.

2. *On the Time required to Produce or Obliterate an Image on the Retina.*

Much difference of opinion exists on this point, and many contradictory statements have been made by the first authorities. Schafhaütl *

* Münch. Abh. vii. 465.

states that the time which elapses between intermittent luminous impressions without producing discontinuity of sensation varies as the square root of their luminous intensities ; but Helmholtz seems to regard the statement as doubtful *.

Herman says that the time required to perceive an impression varies in arithmetical progression when the intensity of the stimulus increases in geometrical progression, but does not give his authority. M. Delbœuf †, making experiments with revolving disks, neglected the rate of rotation, and states that no difference occurs in the results whether it is rapid or comparatively slow.

I made a series of experiments with revolving disks similar to those made by MM. Delbœuf and Plateau. A white card disk, 6 inches in diameter, is set into rapid rotation by clockwork. A portion of a sector of the disk is blackened, so that a grey ring appears during rotation: by reducing the breadth of this sector until the ring was no longer visible, and making the experiment by artificial light, I found that the breadth of the sector at the time of disappearance varies as the distance of the source of light, and that by varying the rate of rotation in the inverse ratio of the distance of the light the ring remains just invisible.

I find that a disk with a portion of a sector, occupying $\frac{1}{200}$ of its circumference, blackened, gives no grey ring with a single candle to illuminate it 10 feet from it when it revolves from 5 to 6 times in a second, but by halving the distance of the candle it must revolve from 10 to 12 times in a second before the ring entirely disappears. A white sector on a black disk obeys the same law, but must occupy only $\frac{1}{1000}$ of the circumference of the disk with the same illumination.

I have concluded that when the grey ring ceases to appear the rotation is sufficiently rapid to cause the sector to occupy the same space for too short a time for it to be seen. With a dull light a white streak on a black surface must occupy the same position for about $\frac{1}{5000}$ of a second to be seen at all ; but the time varies inversely as the square root of the illumination. A black spot upon a white ground must rotate much more slowly to be seen. In this case we have to deal with the duration of an exceedingly faint after image—that of the white surface—during the passage of the black spot. The rate of rotation necessary to obliterate the effect of the black spot varies also inversely as the distance of the illuminating source.

3. *On the Relation of the foregoing Observations to Fechner's law.*

A very simple modification of Fechner's convention with regard to sensations and their relation to stimuli will make the foregoing observations accord entirely with his law, and would further change the arbitrary measure of sensation in Fechner's formula into an equivalent measure of

* Helmholtz, Phys. Optique.

† Bulletin Belgique, 1872.

physical nerve change, so that the expression would become a physiological instead of a psychical one.

Fechner regards the liminal intensity of an increment of sensation as an invariable unit, whilst, as is clearly shown, the liminal increment of the stimulus varies as a function of the stimulus already existing. This is an entirely arbitrary convention. If we regard the value of the liminal increment of sensation as a variable depending for its value on the already existing sensation, we may take

$$2K\int\frac{dx}{\sqrt{x}}=K\sqrt{x}=S, \text{ or } \frac{\Delta x}{\sqrt{}}\propto\Delta S,$$

instead of Fechner's expression

$$K\int\frac{dx}{x}=K\log x=S,$$

where x represents the stimulus and S the sensation.

This relation is further borne out by the beautiful experiments of Mr. Dewar and Dr. McKendrick, which show that the electric variation in the natural current of the eye varies as the square root of the intensity of the stimulus; although those authors have attempted to make their results accord with Fechner's formula, they have only done so by the erroneous use of one of M. Delbœuf's constants, which gives a very wide range of arbitrary adjustment.