Visual power and visibility
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During several decennia visual acuity has been the most popular standard of visual capacities. Besides acuity, however, other visual functions have been subject of measurements and investigations: the contrast sensitivity and the speed of vision. The fact that these faculties were always measured separately suggests that they were supposed to vary independently from each other. The brightness of the visual field appeared to have an important influence on visual acuity, contrast sensitivity and the visual speed. Moreover, a number of other factors affect the results of the measurements. For instance, contrast sensitivity depends on the size of the test objects and on their time of exposure; the visual acuity is influenced by the contrast of test objects and, again, the viewing time.

All these findings have resulted in a very complicated system of relations and dependencies between, on the one hand, the observer represented by his visual acuity, contrast sensitivity, speed of vision and their reaction upon field brightness, and, on the other hand, the so-called visual situation defined by the size and contrast of the test objects, the time of exposure and the brightness of the visual field.

This study was intended to establish a synthesis of all these elements and to define the observer's ability to perceive test objects by one quantity,
SUMMARY

namely that of visual power. This quantity was considered to be a property inherent in the observer and, hence, to be independent of the examining conditions.

An approach to this synthesis is described in section 4 of the first chapter. The fundamental trend of thoughts was as follows. Visual acuity is usually determined by means of test objects with unknown contrast upon a visual field with unknown brightness. This means that the possible effects of these factors are left out of consideration. The test objects differ only in their visual size. The examination is intended to assess the border between the visible and the invisible objects. The place of this border (in this case defined by only one quantity: the visual size (fig. 3a)) gives all the information that is asked for if this type of examination is used.

The introduction of another variable, for instance the contrast, does not cause any fundamental change in the procedure of the examination. The test objects have not only different sizes but also different contrasts (fig. 5). Now the border between visible and invisible objects is not a point but a straight or curved line (fig. 3b). This line gives complete information about the subject's ability to perceive test objects as far as this perception depends on size and contrast. The borderline can be drawn smoothly through a number of points determined at the examination. The shape and place of this borderline, however, is independent of the more or less arbitrarily chosen examining conditions.

The addition of other variables does not alter this conception. In our investigation the number of variables was three: size, contrast and field brightness. In such a case the graphical representation of the border between the visible and invisible objects is not a point or a line but a surface in a three-dimensional diagram with the variables, plotted along the axes (fig. 3c). This surface is again independent from the examining conditions and gives complete information about the observer's visual acuity and contrast sensitivity and their dependency on field brightness.

The first aim of our investigation was to determine this border surface. The illumination of the test chart varied from 5 to 5000 lx, so that the brightness of the almost homogeneous visual field ranged from 0.4 to 400 mL. A special indicating and recording device is described in section 4 of the second chapter. For every subject 40 threshold situations were determined in which the object is just (in)visible to the observer. Each threshold situation is defined by the size and contrast of the test object and the brightness of the visual field. Hence, these threshold situations can be represented in the three-dimensional diagram by a point on the border surface between the visible and the invisible objects.

Such a surface can be replaced by a mathematical equation, in which the constant factors represent what all threshold seeing has in common,
vist the observer’s visual capacities. In order to find this equation the average result of 228 individual records including 9120 measurements was computed in a certain manner as described in the second section of chapter III. It appeared that the results of the “average” subject could be represented by an equation [equation (13)], the so-called threshold equation, containing four constant factors.

These four constants are independent of the examining conditions. So far we reached our aim, but instead of one quantity (the visual power) there are still four factors to be taken into account.

The next step was to compute the average result in the various age groups. It then appeared that the abovementioned threshold equation also applies to separate age groups (with an average age ranging from 8 to 54 years), when the value of only one constant factor is changed in accordance with the computed average result. This factor, g, shows a definite trend to decrease with increasing age. Therefore the decrease of g is likely to be the mathematical equivalent of the decrease of visual power inherent in ageing. Since the other three constants always have the same value, only the value of g has to be determined in order to define the threshold surface between visible and invisible objects and to obtain complete information of the visual capacities as far as they depend on size, contrast and brightness.

Before applying this conclusion to individuals it had to be ascertained whether the threshold equation applying to the “average” subject and to separate age groups is also valid in the case of individual observers. It was found that in the case of 67 per cent of our subjects (the visual type A) this is indeed so and that the remaining 33 per cent showed more or less characteristic deviations. These deviations could be divided into six different types (B1, B2, C1, C2, B1C1 and B2C1), of which two types (C2 and B2C1) were rather scarce. A detailed description of these types is given in section 9 of the third chapter.

In the case of the visual type A it may, therefore, be concluded that the value of the constant factor g in the threshold equation is not only independent of the examining conditions but also completely determines the subject’s visual capacities as far as they depend on size, contrast and field brightness. Hence, it was proposed to base the definition of visual power on the value of this factor g. In order to avoid negative values of the visual power, G, the latter was defined by $G = g$. The unit of visual power was called the snellen.

According to its definition the visual power of a blind man is zero. The highest degree of visual power measured during the examination of 228 subjects was 11 snellen or 110 decisnellen.

From our data it appeared that, on an average, visual power may be considered as being linearly related to the age of the subjects.
In the case of a visual type B, C or BC the value of \( g \) (and, hence, the visual power) is not independent of external conditions. The \( g \)-values, however, show this disadvantage to a much smaller degree than, for instance, visual acuity or contrast sensitivity, so that for most practical purposes subjects of the types B, C or BC can be considered as A-type individuals.

Chapter IV shows that in the various age groups not the visual power, \( G \), but its logarithm, \( g \), is almost normally distributed, the standard deviation being about 0.15. It appeared further that the visual type CI has its greatest frequency in the older age groups and is often combined with low values of the visual power. The occurrence of this type is probably due to the presence of opacities in the refractive media of the eye. The types B1 and B2 do not show a definite relation to the age of the subject. They represent the positive and negative deviations from the normal reaction of the eye upon changes of the field brightness.

The last section of the fourth chapter deals with the physiological meaning of the constant factors in the threshold equation. The factor \( g \) represents by definition the visual power of the observer which probably depends on the size of the perceptive units in the retina. The constant \( n \) is the lowest value of \( -\log B \) (\( B = \) brightness expressed in mL) which still allows of visual perception (by the rod system). Further, \(- (n + p)\) is the value of \( \log B \) at which — theoretically — cone vision changes into rod vision. Although the meaning of the constant \( m \) is not quite clear, it seems to represent the difference between rod and cone vision.

The subject of the last chapter is the definition of “visibility”. Three requirements are set to this definition. Firstly, the visibility of a visual task must show a close quantitative relation to the speed and accuracy with which it can be performed. As a standard of the speed and accuracy we took the visual performance as defined and measured by Weston. The second requirement is that the definition of visibility must allow of a practicable measurement of this quantity. Finally, the visibility of an object in relation to an observer with a given visual power must be easily computable from its visibility to another given observer. If this third requirement is satisfied the visibility of an object to a given observer can be computed from its so-called specific visibility, which is defined as the visibility to an observer with a visual power of 1-snellen.

Three definitions of visibility were tested by these requirements: the size reduction factor (i.e. the ratio between the actual size of the object and the smallest perceptible size at the same values of contrast and brightness), the contrast reduction factor and the visibility determined by means of the so-called LM-visibility-meter developed by Luckiesh and Moss, which reduces the contrast and field brightness at the same time. Our objections against methods involving brightness reduction are discussed
in section 3 of this chapter. It appeared that only when the size reduction factor is taken as the standard of visibility, does the latter answer all the abovementioned requirements. Visual performance (Weston) can be considered as being equal to the logarithm of the visibility. Moreover, visibility as thus defined appears to be the product of specific visibility and the observer's visual power. Finally, the size reduction factor can be easily measured, for instance, by means of a negative lens.

This chapter is concluded with a survey of the units and definitions introduced in this study and their mutual relations.

Appendix I.

The physiological meaning of the constant factors in the threshold equation

When, in accordance with its place in the threshold equation, \(-a\) is considered as the logarithm of a brightness, then this brightness is 0.000 035 mL. This is about the lowest level at which an object of lower brightness can be distinguished from its surroundings.

In order to find the physiological meaning of the constants \(p\) and \(m\) we have to postulate that the threshold equation in the range of rod vision has the same shape as that applying to cone vision and that it only differs from the latter by the value of one or more constant factors. On the strength of this postulation the threshold equation applying to cone vision may be written as

\[
\log D_0 + g' = p' \log C_0 + m',
\]

where the suffix ' indicates that the quantity refers to rod vision.

Since it only depends on the field brightness which of the two systems, cones or rods, is functioning, the borderline between rod and cone vision in the surface of threshold situations (fig. 10) follows a course perpendicular to the log \(B\) axis and is, therefore, a straight line following an equation of the shape

\[
\log D_0 = a \log C_0 + b, \tag{ii}
\]

As this borderline belongs to the threshold surface in the range of cone vision as well as to that in rod vision, from (ii), (14) and (i) it follows that

\[
a = \frac{p}{\log B_0 + n} = \frac{p'}{\log B_0 + n'}, \tag{iii}
\]

and that

\[
b = \frac{pm}{{\log B_0 + n} - g} = \frac{p'm'}{{\log B_0 + n'} - g'}. \tag{iv}
\]