treated grains, the growth of the radicles was strongly inhibited.

(3) The growth of the coleoptiles is less affected than that of the radicles. This stands out clearly in cases where there was definite growth of the coleoptiles but none of the radicles. (These seeds are designated as not germinated.)

TABLE 3

INHIBITION CAUSED BY BOILED SALIVA

Cases	Fresh saliva	Boiled saliva
2	0 (0, 0)	0 (0, 0)
2	58 (10,90)	66 (10,90)
2	84 (25,90)	88 (50,90)
6	10 (10,50)	20 (10,40)

(4) The degree of inhibition varied individually.

(5) The inhibition caused by the saliva of the same individual taken at different times differs sometimes.

(6) The inhibition does not depend on sex or age, nor does it show any relation to the condition of the teeth (*4*).

When dilutions of the saliva are used, the inhibition decreases strongly (Table 2). The growth of the radicles, however, is inhibited even in the higher dilutions, whereas the coleoptiles are less affected. It is a strange fact that in some cases the inhibition is stronger in a 50% dilution than in the original saliva.

TABLE 4

VOLATILITY TEST

Cases	Germination index of fresh saliva	Volatility effect
2	0 (0,0)	84 (98,100)

When the fact that human saliva acts as a germination inhibitor had been established, the nature of the inhibiting agent was investigated. Osmotic pressure and pH, which in some cases are partly or mainly responsible for the inhibition (*2*), could be excluded, as an osmotic pressure of 1 atm and a pH of 6.4–7.0 do not cause any inhibition of germination (*2, 3*).

TABLE 5

INHIBITION AFTER DIALYSIS

Cases	Germination index of fresh saliva	Germination index of dialyzed saliva
2	6 (8, 60)	80 (50, 50)
1	0 (0, 60)	76 (88, 96)
6	64 (54,100)	82 (50,100)

The inhibiting factor is heat resistant, as boiling does not affect the inhibition (Table 3). The inhibition factor is nonvolatile (Table 4). The volatility test was conducted in the usual way (*3*) by putting the saliva into a large Petri dish into which a small Petri dish containing the test seeds was placed.

The inhibiting factor is mostly removed by dialysis (Table 5). In these experiments the saliva was dialyzed for 70–75 hrs. All the chlorides and the rhodan present in the saliva were removed by the treatment, whereas the urea content was not changed.

References

1. EVENARI, M. *Pal. J. Bot. Jer.*, 1940, Ser. 2, 1–5.
2. EVENARI, M. *Bot. Rev.*, in press.
3. KONIS, E. *Pal. J. Bot. Jer.*, 1940, Ser. 2, 6–27.
4. ———. *Dent. Items*, 1946, **68**, 1199.

The Visibility of Moving Objects[1]

ELEK LUDVIGH

Howe Laboratory of Ophthalmology,
Harvard University Medical School

The visibility of moving objects and the converse problem of the visibility of stationary objects while the observer is moving are of practical importance and have received little study. The visibility of moving objects imaged on the peripheral retina has been investigated by Low (*1*). The present author (*2*) has shown that, even when the eye is permitted to move in an effort to follow a moving object, visual acuity deteriorates rapidly with increasing angular velocity of the object. This paper is concerned with visibility at higher angular velocities than those previously considered by the author and with the practical problem of the effect on visibility of the aspect from which the object is viewed. For the present purposes visibility is understood to require the recognition of the general form of the object, not the mere detection of its presence.

Let us consider the case of a thin disc-shaped object which moves in a straight line in a plane passing through the observer's eyes. Assume further, that this straight line is parallel to a line joining the nodal points of the two eyes. The normal or line perpendicular to the disc is in this horizontal plane and is normal to the line of flight. The maximum surface is presented to the eye under these conditions at the point of nearest approach of the disc. Movement of the observer's head or adjustment of any auxiliary apparatus readily permits realization of these conditions. The disc is assumed to be of negligible thickness and will, in general, produce an elliptical retinal image because of obliquity of view. The visibility of the image, were it stationary, would be closely proportional to its area provided that the ratio of the major to minor axis is not greater than 9 : 1 (*2*). However, the object is not stationary, and the eye follows it by moving in the direction of the minor axis of the retinal image of the object. This movement reduces acuteness of vision, and, for present purposes, the lesser dimension of the retinal image will be considered as the dimension determining the visibility or lack thereof of the object. Take the nodal point of one eye as the origin

[1] This investigation was supported in part by a grant from the American Optical Company.

of a two-dimensional rectangular coordinate system. In the lesser, or x, dimension the disc subtends at the eye an angle $\theta^0 = \tan^{-1}\frac{sy}{x^2+y^2-\frac{s^2}{4}}$, where s is the diameter of the disc in feet. Since this angle is small and $x^2+y^2 >> s$, $\theta^0 = 57.3\frac{sy}{x^2+y^2}$. This is the angle available for vision.

The angle necessary for vision, however, is dependent upon the angular velocity of the object. The data presented in Fig. 1 show some results obtained by the author

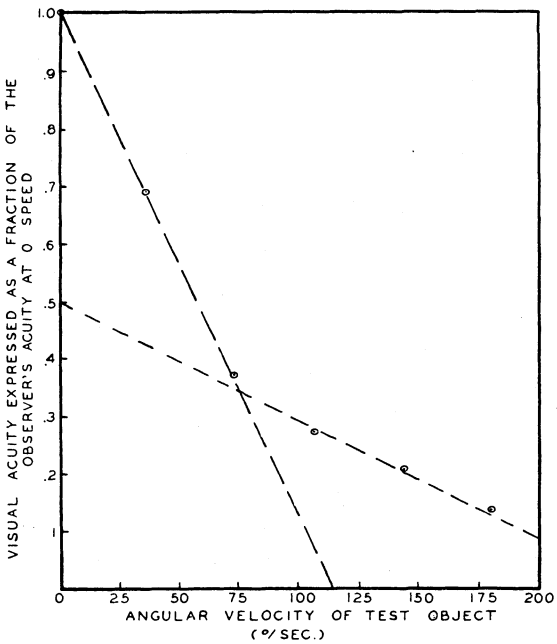

FIG. 1

during a general experimental investigation of visual acuity for a moving object. These data are more extensive and involve higher angular velocities than have been previously employed (*3*). The data are for monocular vision and constant angular velocity around the nodal point of an eye in the horizontal plane with head erect. The test objects were Landolt rings.

At relatively low angular velocities the expression $V.A. = 1 - .0088\alpha$ is a reasonable empirical fit to the data, while at high angular velocities the expression $V.A. = .5 - .0021\alpha$ is more appropriate. In general, $V.A. = a - b\alpha$ for a limited range of values of α. A stationary black disc on a bright background may be seen when its diameter subtends 25–30″ of arc at the eye (*4*); however, its shape cannot be discerned. On the other hand, some internal detail of an object may be perceived if the whole object subtends 5′ of arc (*4*). We may assume an intermediate value of 2′ of arc, or .033°, as the angle necessary to recognize a disc as a disc when it is stationary. The angle necessary for vision of the disc as a disc when acuity is reduced by moving the object is then $\beta = \frac{.033°}{a - b\alpha}$, where α is the angular velocity in degrees/sec. This velocity is given by $\alpha = 57.3\frac{vy}{x^2+y^2}$, where v is the linear velocity in feet/sec, or, substituting $\frac{1}{z} = \frac{y}{x^2+y^2}$, $\alpha = 57.3\frac{v}{z}$.

For visibility, $\theta = \beta$, or $57.3\frac{s}{z} = \frac{.033}{a - 57.3\,b\frac{v}{z}}$. From this, $v = \frac{1}{57.3\,b}\left(az - \frac{.033\,z^2}{57.3\,s}\right)$ and, setting $\frac{dv}{dz} = 0$, the maximum velocity at which the disc can be perceived as such is given by $v_{max} = \frac{7.5\,a^2\,s}{b}$. This equation permits the calculation of the maximum velocity in m.p.h. at which a disc of a given number of feet in diameter can be recognized as a disc at any point along its course. If contrast, aspect of view, and other conditions of vision are not optimal, the maximal velocity allowing recognition will be still lower, and the disc cannot be seen anywhere along its course.

It may be calculated from the last equation that a teacup 4″ in diameter traveling at velocities greater than 205 m.p.h., that a saucer (6″) traveling more than 306 m.p.h., and that a large dinner plate (10″) flying in excess of 510 m.p.h. could not be seen. In terms of the present simplified analysis it may be further observed that the mere use of optical magnification, otherwise unaided, could not be beneficial and, because of vibration, decrease of field and other factors, would be detrimental. Similar considerations apply to mere magnification by electronic means. A magnification of size without loss of contrast and without increase in angular velocity would be helpful.

Let us define the degree of visibility as the ratio of the angle available for recognition, θ, to the angle necessary for recognition, β. Then visibility $= \frac{\theta}{\beta}$, and for a flight at constant value of y, setting $\frac{\partial\frac{\theta}{\beta}}{\partial x} = 0$, we obtain $x = \pm\sqrt{\frac{(2)(57.3)b}{a}vy - y^2}$; therefore, as v increases, x increases, and the point of maximum visibility recedes from the observer.

It now becomes apparent that, as the linear velocity of an object increases, the point of maximum visibility recedes farther and farther from the point of nearest approach of the object to the observer until the object is no longer visible, simply because it is too far away. This, then, explains the large number of cases of inability to recognize moving objects when they are moving slowly enough so that they can actually be seen. Similar reasoning will apply in practical problems where one wishes to determine the conditions necessary for maximum visibility, e.g. the optimal altitude and velocity of flight for the identification of life rafts, downed planes, etc., and in the design of instruments intended to be employed for the identification of aircraft, missiles, etc.

References

1. LOW, FRANK N. *Amer. J. Physiol.*, 1947, **148**, 124–133.
2. LUDVIGH, ELEK. Unpublished observations.
3. LUDVIGH, ELEK. *Science*, 1947, **105**, 176.
4. ————. *Handbuch der normalen und pathologischen Physiologie.* (XII/2.) Berlin: J. Springer, 1931. Pp. 759 ff.