

# Edge-light pupil cycle time

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**SUMMARY** A thin slit-lamp beam illuminating the pupil margin produces clearly visible pupil oscillations. These oscillations can be timed with a stopwatch, thus producing a measurement of the 'edge-light pupil cycle time'. The pupil cycle time is remarkably stable in various testing situations and is repeatable within about  $\pm 3\%$  over extended periods of time. Expected normal distribution and 95% confidence intervals are given in Table 3. When the iris muscles are normally innervated and responsive, the pupil cycle time is dependent on the speed of nerve conduction and the number and strength of optic nerve impulses. Only 5% of normal persons aged 12 to 50 years are expected to have a pupil cycle time in either eye longer than 954 ms or a difference in pupil cycle time between the two eyes longer than 70 ms.

A small beam or slit of light focused at the pupillary margin induces regular, persistent oscillations of the pupil. The period of these cycles can easily be measured and recorded in milliseconds. We call this period the 'edge-light pupil cycle time.' There are 2 other kinds of pupillary movements under stable lighting conditions. They are compared with edge-light oscillations in Table 1.

Lambert in 1760 described pupil movements when he illuminated the edge of the pupil with the focused image of a candle (Loewenfeld, 1966). Stern (1944) rediscovered this phenomenon at the slit lamp using a small spot of light. He gave an excellent description: 'If a fine pinpoint of light is projected on the eye with the slit lamp in such a way that it just enters the pupil near the margin of the iris a light reaction follows, the pupil contracts. That means that the iris margin moves towards the centre of the pupil and prevents the light pencil from entering the pupil. As no light now reaches the retina the stimulus for the contraction of the pupil is no longer present, the pupil dilates—and thus again allows the light pencil to reach the retina. The whole mechanism starts again, the pupil contracts, screens off the light pencil, dilates, allows the light pencil to pass, etc. This artificial 'hippus' continues regularly in a normal eye so long as the light pencil enters the pupil.'

Campbell and Whiteside (1950) and Wybar (1952) used a vertical slit to measure the pupil cycle time in normal subjects (Table 2). Sakuma (1965) used an apparatus which blocked light from the central

portion of the pupil to time edge-light pupillary oscillations and obtained similar results.

Stark (Stark and Cornsweet, 1958; Stark, 1960) pointed out that the pupil oscillations which occur with edge illumination are a property of the pupil reflex arc. If the eye is diffusely illuminated and the light intensity suddenly changed, the pupil will partially counteract the change in light intensity by constricting to block part of the entering light. But with a fine beam and edge illumination a small con-

Table 1 *There are 3 types of pupillary oscillations under stable lighting conditions. (1) Pupil unrest, often called hippus (Loewenfeld, 1966; Thompson, 1969; Thompson et al., 1971) is quite irregular. (2) Pupil oscillations in drowsy subjects (Lowenstein and Loewenfeld, 1952; Lowenstein et al., 1963; Yoss et al., 1969; Yoss et al., 1970a; Yoss et al., 1970b) are quite slow. (3) Edge-light pupil oscillations are fairly fast and quite regular*

	<i>Pupil unrest</i>	<i>Drowsy subject</i>	<i>Edge-light pupil cycle time</i>
Lighting	Diffuse-absent in dark	Diffuse-present in dark	Light at pupil margin
Cycling	Irregular	Episodically regular	Regular
Duration	Continuous	Stops with sleep or arousal	Continuous
Cycle time	667 ms or longer	5000 ms or longer	822 $\pm$ 69 ms
Amplitude	0-1 mm, variable	0-1.2 mm, variable	0-0.5 mm, uniform
Cause	Unknown	CNS depression and arousal	Property of light reflex loop

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Table 2 Pupil cycle time studies

	Stern (1944)	Campbell and Whiteside (1950)	Wybar (1952)	Results in this paper
Normal subjects	10	60	34	50
Mean $\pm$ SD	752 (ms)	870 $\pm$ 148	980 $\pm$ 97	822 $\pm$ 69

striction of the pupil will block the entire beam. The edge illumination makes the pupil much more effective in modifying the entering light. With edge illumination the pupil more than compensates for changes in light intensity. This situation of over-compensation is called the 'high gain' state. In such a state the system is inherently unstable and oscillates spontaneously.

Fig. 1 graphically demonstrates the edge-light oscillations from which the pupil cycle time is measured. A similar record was published by Zuber and Miller (1965) in describing their pupillometer.

### Methods

After reviewing the earlier techniques used to elicit edge-light pupillary oscillations we developed a

method which we feel gives more reliable stimulation at the pupil margin (Fig. 2). The patient is comfortably seated at the slit lamp in a dimly lit room. He removes his glasses or contact lenses and fixates an object near his far point. A horizontal slit beam of light of low to moderate intensity,  $\frac{1}{2}$  mm thick, is directed perpendicular to the plane of the iris at the inferior limbus. The beam is slowly elevated until it overlaps the margin of the pupil, which then constricts vigorously. The beam is held in this position so that the constricted iris blocks the light. The retina will now be in darkness and the pupil will dilate to overlap the edge of the light beam again, producing another pupil constriction, thus setting up a persistent oscillation.

We chose a line rather than a spot because the line gives a greater stimulus and better visibility of the pupil. The line was placed horizontally at the inferior margin of the pupil to avoid difficulty with horizontal fixation movements, which often disrupt the steady positioning of a vertical line at the lateral pupil border.

We chose coaxial stimulus and observation perpendicular to the iris plane because this position gives a symmetrical retinal stimulus and is easily

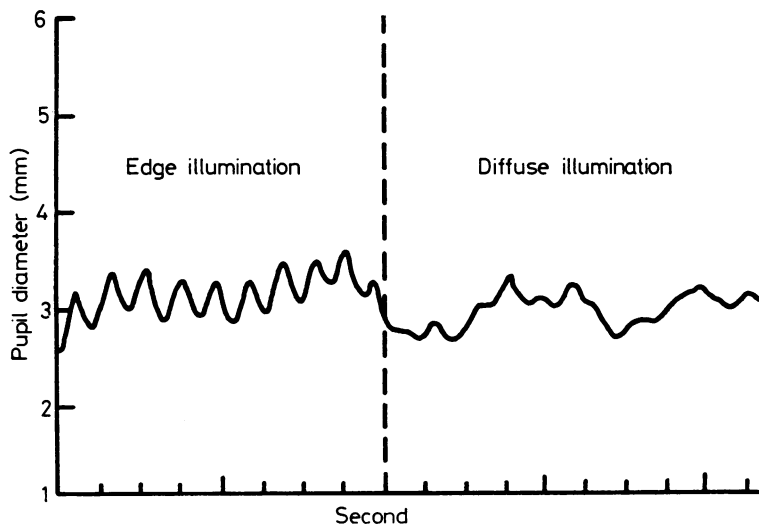
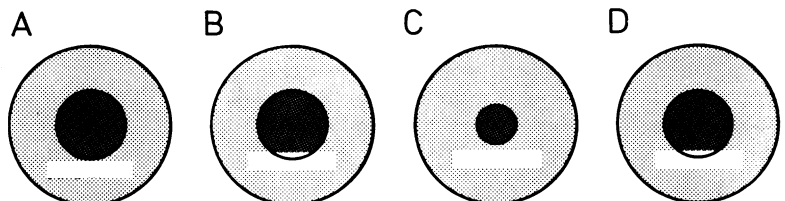


Fig. 1 Pupillographic tracing of high gain oscillations and pupil unrest, made with the electronic pupillograph of Lowenstein and Loewenfeld. During the first half of the tracing the right pupil was edge-lit with the slit beam of a streak retinoscope, causing high gain oscillations of both pupils. The movements of the left pupil were recorded in darkness. At the dashed line the beam was abruptly defocused to spread diffuse light over the entire pupil, and the oscillations immediately degenerated into disorganised pupillary unrest

Fig. 2 Examination technique. The focused beam is slowly elevated (A) until it overlaps the pupillary margin (B). The pupil then constricts vigorously (C), and the beam is held in this position so the pupillary margin is definitely out of the beam. The pupil will now be in darkness and will dilate to again overlap the edge of the light beam (D), then constrict (C), producing a persistent pupillary oscillation



reproduced. Noting a bright orange pupil reflex when the pupil grazes the beam assures consistent perpendicular positioning. For prolonged cycling it is important to be sure that the constricted pupil is out of the beam. As the basic pupil size varies with pupil unrest it may be necessary to make slight changes in beam elevation to keep the constricted pupil out of the beam.

Quick blinks do not interrupt the cycling but longer blinks do. So the patient must blink as little as possible.

After eliciting 2 or 3 regular cycles we measured the time for the pupil to constrict and dilate 150 times (five 30-cycle runs) to the nearest 0.1 second with a hand-held stopwatch. Normal pupils cycled steadily for as long as one would care to time them. Rarely they hesitated for 1 or 2 beats and then resumed oscillation in the previous rhythm. We assumed that these temporary suppressions were due to superimposed pupil unrest and allowed counting through 1 or 2 skips if the rhythm was preserved.

Previous workers described their results in terms of frequency—cycles per minute or second. But what actually is measured is the time for completion of a single loop of the pupil reflex arc. This time can be directly compared with visually evoked response latency times. Thus, we expressed our results in milliseconds per cycle—the 'edge-light pupil cycle time.' We divided the time for 150 cycles by 150 to obtain the edge-light pupil cycle time in milliseconds for each eye.

We studied 58 normal persons drawn from clinic staff and consecutive persons presenting for routine refraction. There were 21 males and 37 females,

ranging in age from 12 to 61 with an average age of 31.6 years. Both eyes were measured in each subject, giving a total of 116 normal eyes. All had normal visual acuity with correction, full confrontation fields, no afferent pupillary defect, and no known eye disease other than refractive error. Data on sex, age, iris colour, pupil size, acuity, refraction, pupil unrest, and amplitude and regularity of edge-light oscillations were collected on each subject. The effect of these variables was analysed by linear regression for continuous variables and by analysis of variance for categorical variables.

## Results

### EDGE-LIGHT PUPIL CYCLE TIME IN NORMAL SUBJECTS

In the entire normal group (Fig. 3) we found a significant ( $P=0.005$ ) but small ( $+2.4$  ms/year) trend of increasing cycle time with age. The normal groups above and below 50 years had significantly ( $P=0.03$ ) different means. Because of this difference and the small number of subjects over 50 years in our normal group we restricted our analysis of normal values to persons between 12 and 50 years. For the 50 normal subjects between 12 and 50 years there was no significant age trend. Their mean pupil cycle time was 822 ms with a standard deviation of 69 ms. The mean absolute difference in pupil cycle time between eyes was 30 ms with a standard deviation of 36 ms.

To establish normal criteria we analysed the slower cycle time of the two eyes in each normal patient. We used a normal distribution with a one-

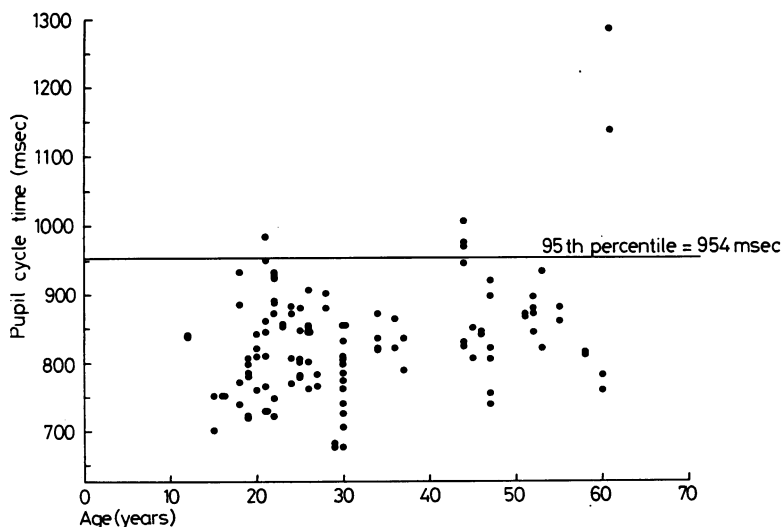


Fig. 3 Edge-light pupil cycle time in 116 normal eyes

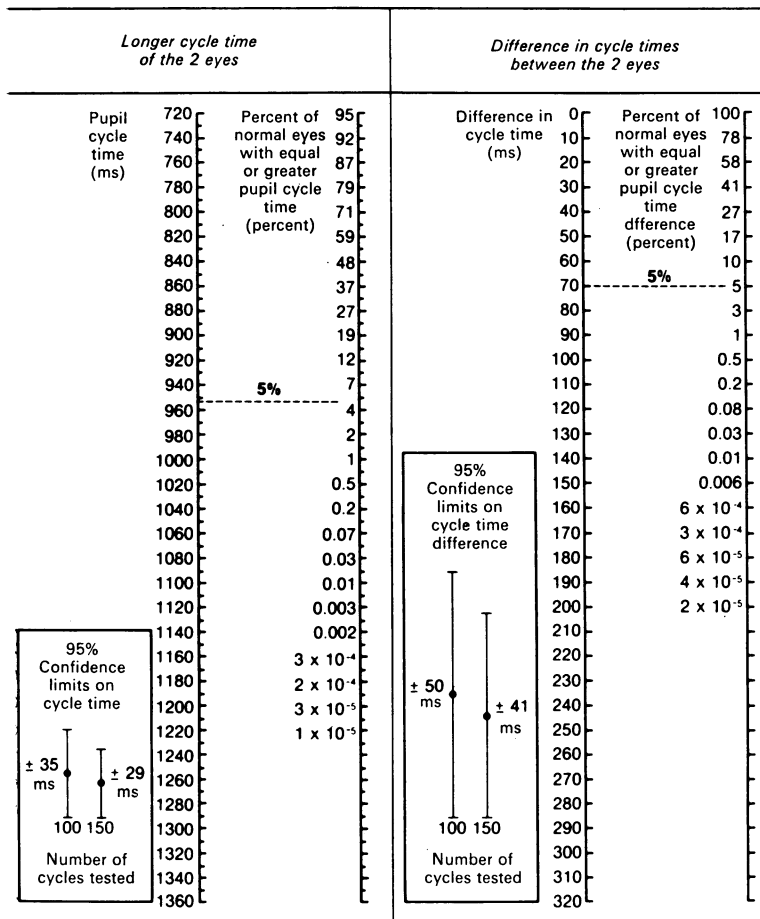


Table 3 Expected normal distribution of pupil cycle time based on 100 normal eyes under 50 years of age. Note that one can time 100 cycles and simply move the decimal to obtain the pupil cycle time (for example, if 100 cycles take 88.3 seconds the pupil cycle time is 883 ms). Cycle times and cycle time differences are given for values greater than the reasonable normal range because these extremely long times are often found in eyes with current or previous optic neuritis

sided limit, made a correction for the expected mean, and chose the 95th percentile as our cutoff (Table 3). Thus we expect only 5% of our normal population to have a pupil cycle time in either eye longer than 954 ms, or a difference in pupil cycle time between the 2 eyes longer than 70 ms. The 50th percentile of longer pupil cycle time (837 ms) is not the same as mean pupil cycle time (822 ms) because the percentiles are based on the eye with the longer cycle time. This is more appropriate than using the overall average when testing a new patient for unilateral abnormality.

VARIABLES AND PUPIL CYCLE TIME

Pupil cycle time was not significantly affected by sex, iris colour, visual acuity, refractive error, left eye or right eye, pupil size during the examination, amplitude of spontaneous pupil unrest, and the amplitude of the edge-light gain oscillations (Table 4).

Campbell and Whiteside (1950) found a tendency for the pupil cycle time to become prolonged as the

retina adapted to light. In our 50 normals we found no statistically significant trend in pupil cycle time over 5 30-cycle runs in each eye. Thus there was no significant effect of light adaptation during our testing.

We tested the effect of accommodation by neutralising the refractive error of the left eye in 6 normal subjects and adding a +5.00 dioptre lens to put the far point at an accommodative target 20 cm from the eye. We then measured the pupil cycle time in the right eye with the subject fixating at 20 cm, changing lenses so that increasing accommodation was required to bring the target into clear focus. The pupils were much smaller with the higher accommodation, but over a range of zero to 5 dioptres of accommodation there was no statistically significant change in the pupil cycle time.

Campbell and Whiteside (1950) reported an increase in pupil cycle time with a 94% decrease in stimulus intensity. We tested 5 subjects for variation in pupil cycle time over the range of intensity avail-

Table 4 Effect of variables on pupil cycle time

Variable	Subjects N	Significance P	Slope
Age 12-61*	58	0.005	+ 2.4 ms/year
Age 12-50	50	0.13	—
Sex	58	0.60	—
Iris colour	58	0.90	—
Visual acuity	58	0.20	—
Refraction	58	0.21	—
Left vs right	58	0.42	—
Pupil size	58	0.26	—
Pupil unrest	58	0.79	—
Oscillation amplitude	58	0.76	—
Oscillation regularity	50	0.38	—
Light adaptation (5 min exam.)	58	0.48	—
Accommodation	6	0.20	—
Stimulus intensity*	5	0.01	- 5 ms/log unit

\*Note that only two variables had a statistically significant effect. Age was significant only in persons over 50 years. Stimulus intensity was significant but negligibly small in the practical testing situation

able at the Zeiss slit lamp (0.5 log units). We found no significant trend by analysis of variance. With linear regression we found a slope of - 5 ms/log unit ( $P=0.01$ ). That is, over the entire range of illumination available at the Zeiss slit lamp there was only 2.5 ms change—a negligibly small effect on the pupil cycle time. Since reaching this conclusion we have done the examination at the lowest intensity setting because the patient is more comfortable and the readings are thus easier to obtain.

We calculated the standard deviations associated with doing only one 30-cycle measurement, 2 measurements, and so on up to 5 measurements. Most of the reduction in variability was obtained by the first 3 measurements; further measurements did not greatly decrease the standard deviation. So we believe it is necessary to count only a total of 100 cycles to obtain reasonable precision.

Table 3 shows the expected normal distribution and confidence limits for timings of 100 or 150 cycles. The confidence intervals are larger for cycle time difference because measurements of 2 eyes are needed, and each contributes variability. Only moderate improvement in confidence intervals is obtained by doing 150 cycles instead of 100.

WHAT DOES THE PUPIL CYCLE TIME MEASURE?  
Pupil cycle time is the time required for the con-

striction and redilatation of the pupil. Many factors could delay this pupillary light reflex arc—the speed, frequency, and intensity of the afferent nerve impulses reaching the mid-brain, the synaptic delays, the efferent nerve delays, and any structural slowness of the iris musculature itself.

Wybar (1952) observed a prolongation of the pupil cycle time in patients with multiple sclerosis. This may have been due to slowed conduction of the afferent impulses in the optic nerve from old optic neuritis.

#### STABILITY OF THE PUPIL CYCLE TIME

Of the various factors tested only 2 had a statistically significant effect—age over 50 years and variation of stimulus intensity. Patients over 50 years of age need further study. The intensity of the stimulus light in the useful range had a significant but negligibly small effect on the pupil cycle time.

Is the pupil cycle time constant over time or does it vary from day to day? Surprisingly little variation occurs. Six sets of observations over a 2 week period in the normal eye of 1 patient, varied only  $\pm 3\%$ . In another patient the range was  $\pm 2.5\%$  over 7 weeks. Thus, over extended periods of time the maximum variation in average pupil cycle time appears to be on the order of  $\pm 3\%$ .

#### Conclusion

Pupil cycle time is a fast, simple, and reliable clinic test of optic nerve function. It has the great advantage of being objective and quantitative for each eye individually. The use of pupil cycle time measurements in the clinical evaluation of demyelinating optic nerve disease is the subject of another paper (Miller and Thompson, 1978).

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