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Methodology

Pupillometry: A Survey of Sources of Variation

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ABSTRACT

The purpose of this article was to discuss sources of pupillary variation not mentioned by either Hess (1972) or Goldwater (1972) and suggest experimental procedures to control for the effects of these variables when they are not themselves the object of study.

DESCRIPTORS: Pupillometry, Pupil size, Methodology.

The pupillary response has long been of interest to physicians and has increasingly become of interest of psychologists. Goldwater (1972) has recently reviewed much of the literature concerning the psychological significance of changes in pupil size. As in most articles, the author discussed methodological problems to some extent but usually in the limited context of interpreting a particular finding by a particular investigator. In 1966 Woodmansee published a brief article in which he discussed four sources of pupillary variation which investigators should consider in designing experiments in this area. Recently, Hess (1972) published an article which considered questions of methodology and psychological significance. Hess discussed approximately 17 sources of pupillary variation which represents a considerable expansion of the work of Woodmansee (1966). Table 1 contains in tabular form 23 sources of pupillary variation. Only those sources of variation which Hess did not discuss or mentioned only in passing will be discussed in this paper.

The basic purpose of this paper is to further acquaint the researcher with sources of variation regarding the pupillary response. It is obvious that when studying one source of variation, all others become possible sources of error and need to be considered when interpreting experimental findings. It is the author's belief that the more an investigator understands what variables can influence the dependent variable which he is studying the more able he is to design better experiments and more carefully he can interpret the results of previous experiments.

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Sources of Variation

A relatively obscure pupillary reflex is the darkness reflex which refers to the momentary dilation observed when a constant adapting light stimulus is briefly interrupted. Pupillographic recordings have shown reliable differences in the exact form and duration of various phases of the reflexive response. Lowenstein & Loewenfeld (1964) explicitly state that the dark reflex should not be confused with the redilation observed when a constant adapting light stimulus is terminated while investigating the light reflex. The physiological mechanisms underlying the two dilatory responses are different.

Lowenstein & Loewenfeld (1952a, 1952b) have reported that the pupillary response to light changes in several ways with repeated stimulation. These fatigue and habituation changes can be negated in normal people by presenting a loud noise which increases sympathetic activity which in turn increases pupil diameter. Pupillographic recording shows that the next light stimulus will elicit a contraction reflex which is similar to the first observation prior to the onset of the fatigue and habituation factors. This includes lowering the threshold of the light reflex such that a previously shown light of low intensity now elicits constriction where it did not before. Psychosensory restitution is not dependent upon pupil size. The authors concluded that

TABLE 1

Sources, descriptions, and documentation regarding variation in pupil size

Sources	Descriptions	Selected Documentation
1. Light Reflex	Pupil constricts with increased intensity of illumination and dilates with decreased intensity of illumination.	Dennison (1968); Young & Biersdorf (1954)
2. Darkness Reflex	Momentary dilation due to interrupting a constant adapting light. Different from the light reflex.	Lowenstein & Loewenfeld (1964)
3. Consensual Reflex	Stimulation of one eye affects both eyes equally. Failure called dynamic anisocoria.	Lowenstein & Loewenfeld (1964)
4. Near Reflex	Constriction due to decreasing the point of focus.	Lowenstein & Loewenfeld (1964)
5. Lid-closure Reflex	Momentary contraction followed by redilation.	DeLaunay (1949)
6. Pupillary Unrest (Hippus)	Continuous changes in pupil diameter.	Duke-Elder (1971)
7. Psychosensory Reflex	Restoration of diminished reflexes due to external stimulation.	Lowenstein & Loewenfeld (1952a, 1952b)
8. Age	Decreased diameter and increased variability with age.	Kumnick (1954, 1956); Birren, Casperson, & Botwinick (1950)
9. Habituation	Pupil diameter decreases, speed of contraction increases, magnitude of reflex decreases.	Lowenstein & Loewenfeld (1952a); Lehr & Bergum (1966)
10. Fatigue	Diameter decreases, amplitude and frequency of hippus increases. Age amplifies these effects.	Lowenstein & Loewenfeld (1951, 1964)
11. Alertness & Relaxation	Alertness suggestions decrease and relaxation suggestions increase pupil size.	Barlett, Faw, & Leibert (1967)
12. Binocular Summation	Constriction is greater when both eyes are stimulated.	Thompson (1947)
13. Wavelength (Pupillomotor Purkinje phenomena)	Larger dilation to chromatic than achromatic stimuli. As intensity of illumination is increased proportionately more constriction is elicited by shorter wavelengths.	Miller (1966); Bouma (1962)
14. Alcohol	Dilates the pupil in proportion to the percentage of alcohol in the blood.	Skoglund (1943)
15. Sexual Preference	Dilation to sexually stimulating material.	Hess (1965)
16. Psychiatric Diagnosis	Abnormal pupillary responses in schizophrenics, and neurotics.	Duke-Elder (1971); Rubin (1964)
17. Pupil Size	Stimuli involving larger pupils elicit more dilation.	Hess (1965)
18. Political Attitude	Dilation for preferred political figures.	Hess (1965)
19. Semantic Stimuli	Small pupil diameters are associated with high recognition thresholds.	Hutt & Anderson (1967)
20. Taste	Pleasant taste elicits dilation.	Hess (1965)
21. Information Processing Load	Increasing dilation to increasingly difficult problems.	Simpson & Hale (1969); Beatty & Kahneman (1966); Kahneman & Beatty (1966)
22. Task Relevant Response	Having to make a motor response augments pupillary responses.	Simpson (1969); Kahneman Peavler, & Onuska (1968)
23. Incentive	Increases diameter on easy problems only.	Kahneman et al. (1968); Kahneman & Peavler (1969)

the psychosensory reflex is a brain reflex since bilateral lesions to the posterior hypothalamus abolish psychosensory restitution but not the dilation response.

The consensual reflex describes the fact that the visual threshold is lower when the light stimulus is viewed binocularly than when it is viewed monocularly and this effect is greater with peripheral than with foveal vision. Thompson (1947) found that the degree of pupillary constriction was greater when both eyes were stimulated than when only one eye was stimulated. To achieve the same degree of contraction in the monocular as was obtained in the binocular mode, the area of the stimulating flash had to be increased between two and four times.

Another obscure source of pupillary variation is that of wavelength. Miller (1966) obtained significantly larger pupil diameters to chromatic than to achromatic stimuli in 30 normal males. Bouma (1962) measured the pupil diameter elicited by 6 monochromatic sources of different wavelength at 10 different intensities of illumination and found that as intensity of illumination was increased, proportionately more constriction was elicited by the shorter wavelengths. This difference was both significant and substantial as differences in pupil diameter of up to 3 mm were reported at a fixed intensity of illumination.

As the eye becomes increasingly dark adapted, the spectral point appearing brightest shifts from yellow toward greenish yellow. This is called the Purkinje phenomenon. Similarly, as dark adaptation increases, the point requiring the least energy for a constant change in pupil area shifts from the yellow to the greenish yellow portion of the spectrum. This has been labelled as the pupillomotor Purkinje phenomenon and demonstrates that changes in wavelength as well as energy level are important in determining the pupillary response (Duke-Elder, 1971).

Kahn and Clynes (1969) found that by shifting from red to green light of the same intensity, or vice versa, a temporary contraction and redilation response occurred which was similar to that found when the eye was stimulated by a flash of white light. A feedback system was arranged to change color, while keeping the intensity constant, when the pupil redilated from the color contraction reflex. This system induced a 1 cycle per second oscillation between dilation and contraction. Furthermore, it was found that subtracting any one of the primary colors from a beam of white light caused pupillary contraction to occur. This color contraction reflex has the same latency as the light contraction reflex and the amplitude of the reflex increases as stimulus intensity increases.

Design Considerations

Regarding the design of experiments involving pupillometry, the factors of age, absence of alcoholic intake, absence of a psychiatric diagnosis, sexual abnormality, and minimal hippus can all be rather easily determined and controlled for through subject selection. Regulating binocular or monocular viewing is also easy. A fixed point on which the *S* continually focuses will control for the near reflex and specifying when the *S* is to blink will control for the lid-closure reflex. Modern technology allows *E* to monitor where *S* is looking and thus verify that he has complied with *E*'s directions.

All *Ss* should be tested at the same time of day and the number of hours sleep received on the previous night equated for as well as the type of daily activity to control for fatigue effects. Each individual trial and thus the total experimental session should be conducted as rapidly as possible in order to minimize the habituation effect. It may also be possible to separate blocks of trials with a loud noise or some abrupt stimulation that is sufficient to elicit the psychosensory reflex which restores the pupillary reflexes to normal (in persons without neurological damage). Alertness, sympathetic arousal, of the *S* can be independently assessed by taking concomitant physiological measures such as heart rate, respiration rate, and blood pressure. If the level of arousal cannot be held constant across trials and among conditions then at least statistical procedures can be utilized to minimize the effects of such uncontrolled sources of variation.

The light reflex can be controlled by constructing one's stimuli such that they reflect the same amount of light and by using a light source that is constant in its intensity. To be doubly safe from the effects of altered illumination, the pupil size associated with systematically varied levels of illumination can be independently determined for each *S* in addition to measuring his rate of pupillary dilation and constriction under standard changes in illumination. By then monitoring the amount of light coming from the point where *S* is focusing, *E* can adjust his readings of pupil size for any detected but unplanned changes in illumination. A similar procedure could be used to control for changes in wavelength. Achromatic materials could be used thus eliminating the problem altogether. Alternately, *E* could measure the amount of change in pupil size to standardized changes in wavelength for each *S* and then partial out of his record changes in wavelength associated with the different points of focus or stimuli focused upon by *S*.

The amount of incentive, the presence, absence, and nature of a manual response as well as the informational load caused by the instructions need to be held constant across trials and among conditions or their effects should be independently assessed for each *S* and his data corrected accordingly. Such variables as political and sexual preference, use of semantic or taste stimuli, etc. are more easily controlled since the presence or absence of such eliciting stimuli is more determined by *E* than inherent in the measurement of pupil size.

The above comments are not intended to represent an exhaustive list of possible corrections for controlling unwanted sources of variation nor is it implied that these are necessarily the best methods for correcting experimental errors. It is only hoped that these suggestions will further stimulate attempts to consider variables that could confound the findings stemming from research in the area of pupillometry.

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