AN EVALUATION OF OPTICAL RADIATION HAZARDS ASSOCIATED WITH INFRARED CORNEAL - REFLECTION EYE TRACKERS

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INTRODUCTION

Most corneal-reflection eye tracking systems employ infrared radiation (1). Several of these have been developed at the Institute of Biomedical Engineering (IBME) since 1960 (2-4). Current IBME eye trackers (5,6) include both desk and helmet mounted versions which were designed, for reasons of long-term safety, to irradiate the eye with less than 1 mW/cm^2 of infrared optical radiation. This irradiance level was chosen on the basis of recommendations for safe chronic ocular exposure published as long as 20 years ago (7-8). This presentation will briefly evaluate chronic exposure standards in light of more recent evidence (9-14).

IR RADIATION AND THE EYE

The absence of an extensive heat-dissipation mechanism and the strong focusing ability of the eye make it the most critical organ for damage by low-level IR radiation. Transmission and absorption studies indicate that the *cornea*, *iris*, *lens* and *retina* are the ocular structures most likely to be damaged. The action spectrum for IR-induced eye hazard seems to be confined predominantly to the near IR region. Peak transmittance is about 1.1 um for the cornea. A strong absorption of IR energy by the *aqueous humor*, *iris*, *lens*, and *vitreous humor* occurs at wavelength bands of 900-1100 nm and 1200-1400 nm. The *cornea* is essentially opaque beyond 2000 nm.

It will be important to define exactly what one means by *damage* to specific ocular structures. This will be done in terms of grossly observable structural change, ultra-fine changes at a sub-cellular level, and through alterations in psychophysical tests.

CURRENT EXPOSURE STANDARDS

At the present time there are no generally accepted standards for the prevention of ocular damage from *broadband*, *low-level*, *non-coherent* IR sources. However, in the case of IR radiation as it is relevant to eye-tracking devices there will be no particular need to consider wavelengths other than in the IR-A region of 760-1400 nm.

There are at least three reasons for this: (1) The motive for using IR in the first instance is to render the source *invisible* to the subject; (2) Available detectors which are most useful in the IR tend to have peak spectral sensitivities well below 1000 nm; and, (3) The existence of a variety of ocular IR absorption bands makes it potentially more dangerous to use the functionally *non-contributing* longer wavelengths.

In practice, it is relatively easy to filter out those components of the IR spectrum which are of no special utility - thus reducing the overall ocular heat load, while maintaining peak energy at the wavelengths most relevant to modern detector technology. While eye trackers which use infrared radiation have been used for more than 20 years, there are few critical, quantitative analyses of the risk associated with their chronic use. Indeed, the definition of *chronic exposure* is itself somewhat arbitrary.

CHRONIC OCULAR EXPOSURE

The World Health Organization (12) suggests that *chronic exposure* might be considered the maximum duration of exposure which is to be expected in an average working day. In a laboratory setting this might be 1 to 2 hours; in the case of an eye tracking device incorporated in an aircraft simulator this might be 4, to as many as 8, hours per day. Under conditions of real flight experience where an eye tracker might be used as a control element in aircraft or weapons control this might reach 12 hours per day during peacetime.

THE QUESTION OF RISK

In defining *meaningful risk*, it will be appropriate to consider other risks which are taken as a matter of routine by a given population of eye tracker users. In the field of medical diagnosis (where the risk of serious disease is apprehended) more invasive or potentially dangerous tests are justified. In wartime, risks are accepted which cannot be justified in a non-combat situation. The relative risk of IR exposure for peacetime training should be equal to or less than any other of the necessary risks associated with training. In the opinion of the authors, the minimal relevant risk is probably that of using the eye to see under normal daylight conditions (at ground level).

IR irradiance from modern eye tracking devices falls well below ambient ground-level daylight environmental IR exposure levels. However, one must be sensitive to such variables as geographical location and time of day (both irradiance and spectral distribution), angle of illumination, and limiting aperture. In this discussion, for the retinal hazard region of 400-1400 nm, a pupil size of 7 mm will be taken to be the relevant sampling aperture. The spectral dependence of exposure limits has been taken into account by the American National Standards Institute (ANSI) in Standard ANSI Z-136.1 (1980) for IR-A wavelengths between 1050-1400 nm.

AVAILABLE EYE TRACKERS

Young and Sheena (1) in their comprehensive review of available eye trackers provide estimates of subjective discomfort and

subject awareness but do not give quantitative data for irradiance (dose rate) or for radiant exposure (dose). Sliney and Wolbarsht (10) have presented a brief evaluation of an older Honeywell Remote Oculometer, and a Stanford Research Institute (SRI) Eyetracker. The Honeywell instrument had a projected source area of 4.9 cm^2 and a projected source radiance of 4.5 $W/(cm^2/sr)$. The irradiance at the subject's eye was 2.5 mW/cm^2. The SRI instrument used an IR-emitting diode (930 nm; unstated spectral full width, half maximum). Its corneal irradiance could be as high as 4 mW/cm^2, but the projected angle of the source is 7.5° and the average projected radiance is 300 $mW/(cm^2/sr)$. These authors conclude that no hazard was presented by either instruments. Modern eye trackers generate lower corneal irradiances (more typically in the range of 0.5-1.5 mW/cm^2). Current University of Toronto eye trackers (5, 6) with full angle beam divergences of 2° to 8°, present corneal irradiances of 0.6-1.2 mW/cm^2.

Sliney and Freasier (7) presented a detailed and rigorous method for retinal hazard evaluation, which has been adopted in a simplified manner into the hazard criteria of the American Conference of Governmental Industrial Hygienists (ACGIH), and later into those of the National Institute of Occupational Safety and Health (NIOSH). A detailed discussion of protection standards for non-laser sources is presented by Sliney and Wolbarsht (10).

CONCLUSION

The most relevant standard for the IR-A spectral band appears to be the 1980 ANSI Standard Z-136.1 for *intrabeam viewing of laser sources* which takes into account both wavelength and exposure time.

This stringent intrabeam laser standard represents a conservative approach to setting threshold limits for safe ocular exposure to IR radiation. In the case of the full IR-A spectral band (700-1400 nm the standard suggests that irradiance at or below 0.96 mW/cm^2 is safe for continuous exposure of a duration slightly greater than 8 hours. Through an analysis of this standard the authors will argue that the frequently cited corneal irradiance of 1 mW/cm^2 should continue to be recognized as a safe level of chronic ocular exposure to IR-A.

In supporting such a conclusion this presentation will consider **additivity** and **synergism** of different spectral bands, the existence of **concurrent visual hazard**, the use of **laser light**, the validity of assuming continuous **ocular movement**, the possibility of **antecedent ocular pathology**, and **measurement errors** in determining actual radiant exposure.

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