A Study Into the Effects of Types of Light on Children - A Case of Daylight Robbery

Warren E. Hathaway, Ph.D.
Hathaway Planning & Consulting Services
7607 - 183 St.
Edmonton, AB T5T 2A8

Abstract

Based on a review of the literature and a pilot study conducted from 1981 to 1985, a study was carried out that examined physical development and school performance effects of different lighting systems on elementary students. Students' dental health, growth and development, attendance, and academic achievement were examined under four different types of lighting: (a) full spectrum fluorescent lamps, (b) full spectrum fluorescent lamps with ultraviolet light enhancements, (c) cool white fluorescent lamps, and (d) high pressure sodium vapor lamps. Data on 327 students, in Grade 4 at the end of the 1986-87 school year, were collected at the start and at the conclusion of the study, which spanned two years. 7he results indicated that over the two year period, students under full spectrum fluorescent lamps with ultraviolet supplements developed fewer dental cavities and had better attendance, achievement, and growth and development than students under other lights. Students under the high pressure sodium vapor lamps had the slowest rates of growth and development as well as the poorest attendance and achievement. On the basis of the findings of this study it was concluded that lights have important non-visual effects on students who are exposed to them on a regular basis in classrooms.

This study was undertaken for two purposes: (a) to replicate the findings of studies conducted from 1981 to 1985 and reported by Wohlfarth (1986) and Hargreaves and Thompson (1989) into the non-visual effects of classroom lighting and (b) to test for physical development and school performance effects of four common types of classroom lighting on elementary students.

A search for ways to improve education is fueled by: (a) the general view that the learning environment is an important facet of the multi-faceted educational process (Helveston, E. M.,Weber, Miller, Robertson, Hohberger, Estes, Ellis, Pick, & Helveston, B. H., 1985, p. 346), and (b) the specific findings of research into the non-visual effects of types of lighting on people. Among the most surprising findings from the research into this domain, as reported by Wohlfarth (1986) and Hargreaves and Thompson (1989), were that those elementary students (Grades 5 and 6) who received trace amounts of ultraviolet (UV) light in their classrooms developed fewer dental caries and had better attendance than students in a comparison group. Even though the findings of these studies by Wohlfarth and Hargreaves and Thompson appeared to be highly significant, the conclusion was that further research was needed in order to confirm their findings—replication was required. At the same the literature on the non-visual effects of types of lighting on people is constantly expanding and from this there emerges a need to examine a variety of types of lighting for non-visual effects on people.

Although there has not been a great deal of research into the effects of light on students, a review of some of the more basic (and often animal-based) research that has been conducted provides a perspective for considering the human element in school facility design and construction. The following literature review centers on effects of natural light, incandescent light, fluorescent light, and other light sources including mercury vapor, metal halide, and high pressure sodium vapor on living organisms. It is also important to distinguish between discussions about types of lighting and discussions about well-designed lighting systems. Inasmuch as the latter is a well-documented science, it is not discussed here. Rather, attention is given to research related to sources and qualities of different types of lighting and their effects on living organisms.

Sunlight is by far the most important source of light and energy for living organisms and it may be experienced as direct light or as skylight (diffused light). Most people spend part of each day under the

influence of sunlight. However, as society becomes more urbanized, people spend much less time under sunlight and much more time under artificial lamps.

These environments in which we spend significant parts of each day are a far cry from the natural environments of our ancestors. We are surrounded by walls, floors and ceilings covered with colors seldom repeated on the same scale in nature and these colors are usually perceived under lighting systems designed more for efficiency than for their possible physiological or psychological effects on people. Indeed, our artificial lighting systems can only simulate twilight levels of illumination—light levels of 200 to 1500 lux in comparison to light in the natural environment at twilight of 2,800 to 8,200 lux and at noon up to 100,000 lux (Thorington, 1985).

Corth (1984) might argue about the significance of wide differences in light levels between natural settings and built environments. He contented that the natural environment of our earliest ancestors was the forest floor—and not the open plains. As a consequence the habitat noon-time light levels would have been much lower than the 8,200 to 100,000 lux found in open areas. Moreover, he further contended that the spectral quality of the light at the forest floor was greenish-yellow and represented the combined result of the solar radiation spectrum and the filtering effect of the forest canopy. He also advanced the view that our ancestors originally occupied the forest floor near the equator; only later did they move onto the open plains either north or south of the equator. Thus he concluded that heavy skin pigmentation was a matter of camouflage for survival more than it was a filter against UV light. As humans left the forest cover and moved into the more open country to the north (or south) of the equator and away from zones of intense UV light (and into zones where body covering was necessary to ward off the cold), the pigmentation decreased as a response to the need for increased vitamin D which is formed by the action of UV light on the skin.

Following Corth's logic, one might expect two effects. First, inasmuch as the light spectrum of cool-white fluorescent lamps approximates that of the greenish-yellow light reaching the forest floor, people may find these lights to be very satisfactory. Second, if skin pigmentation decreases as a response to an increased need for UV light highly pigmented people living in northern climates may have greater needs for UV stimulation (or vitamin D supplements) than do lightly pigmented people.

Sunlight contains all colors in relatively uniform amounts (i.e., there are neither sharps peaks nor discontinuities in the spectral distribution) and all colors are equally visible when illuminated by sunlight. For this reason natural light serves as the reference for comparing the color rendition characteristics of other light sources, with natural light having the maximum or reference Color Rendition Index (CRI) of 100. The color rendition index is a measure of the way colors look under specific light sources. It is important to note that equivalent CRI indices mean the same thing only when the light sources to which they relate have equivalent color temperatures. As a consequence, colored objects may appear different when viewed under lights with different color temperatures but equivalent CRI indices.

Not all artificial light sources accurately reproduce the full spectrum of sunlight. Incandescent lights are rich in red and yellow light, but radiate relatively little energy in the blue and green region of the spectrum. Cool-white fluorescent lights emit most of their radiant energy in the green and yellow bands of the spectrum, the range to which eyes are most sensitive. Indeed, as Thorington (1985) asserted, it is at the 555 nm (the yellow-green range) that the lumen or the standard unit of light is defined. Full spectrum lights emit a significant portion of their radiant energy in the blue area of the spectrum. A further small percentage of the radiant energy from fluorescent lamps may fall into the UV range. Since the eye is less sensitive to blue light than to green and yellow light, rooms lit with full spectrum fluorescent lights may be perceived as being somewhat dimly lit. Full spectrum lights do, however, have a relatively high Color Rendition Index and this may be very important to vision processes. In this regard, Aston and Bellchainbers (1969) compared high efficiency lamps (i.e., lamps such as cool-white fluorescent lamps) with lamps that provided a spectrum more closely balanced to natural light. In their report they said, "The results clearly show that the •Kolorite lamps [lamps simulating natural light in spectral distribution] not only provide better colour qualities but give a higher degree of visual clarity than do the high efficacy lamps at an equivalent illuminations [added by author].

By 1919 researchers had reached the conclusion that sunlight was the key to the cure of rickets. Later it was discovered that artificial light was also effective in curing rickets (Looniis, 1970). Today it is accepted that UV radiation derived from sunlight in the region of 290-315 nm triggers the development of vitamin D in the skin (Holick, 1985; Neer, 1985) and vitamin D formed in the skin or regular doses of vitamin D taken orally can prevent or cure rickets. Davies (1985) discussed links between calcium absorption and availability of vitamin D. The importance of vitamin D (the sunshine vitamin) has been recognized for a long time. Indeed, milk fortified with vitamin D is commonplace. Nevertheless, Wurtinan (1975) and Neer (1985) questioned whether or not dietary sources of vitamin D are biologically as effective as the vitamin D formed in the skin as a result of UV light stimulation.

Ozaki and Wurmm (1979) drew attention to the fact that light from high pressure sodium vapor lamps produced anomalies in the growth and development of animals. They presented evidence to the effect that the exposure of developing rats to high pressure sodium vapor (HPSV) lights caused characteristic changes in growth and development.

Hughes (1981) cited research to support the view that physiological disorders may occur in the human system if the human skin does not receive some exposure to solar radiation, either direct or diffused, for long periods of time. It is believed that there will be a vitamin D deficiency followed by weakened body defenses and an aggravation of chronic diseases. Wurtman and Neer (1970) suggested that non-visual retinal responses to light mediate a number of neuroendocrine hormonal functions which in turn regulate such mechanisms as pubescence, ovulation and a wide variety of daily rhythms. A national committee of physicists, chemists and physicians in the United States made it clear to the medical community that “photons must be considered a drug" (Lamola, 1985). Downing (1988) concluded: “There is no area of our mental and bodily functioning that the sun does not influence. Our bodies were designed to receive and use it in a wide range of ways. We were not designed to hide from it in houses, offices, factories and schools. Sunshine, reaching us through our eyes and our skin, exercises a subtle control over us from birth to death, from head to tail."

Thorington, L., Cunningham, L., & Parascondola, L. (1971), Hodr (1971), and Lucey (1972) cited numerous studies involving the use of phototherapy in treating hyperbilirubinemia. As an alternative to exchange transfusions, irradiation with light (especially blue light in the 440 to 470 nm range) was proven effective and is considered standard treatment in many hospitals. Wurtman (1975) suggested that full-spectrum light is as effective as blue light because full spectrum light sources have significant energy concentrated in the blue range. The added benefit provided by full spectrum lamps over monochromatic blue lamps is the improved color rendering characteristics of the former which permits nurses to readily perceive changes in an infant's skin color.

East (1939) reported a study which found a correlation between annual hours of sunlight and the incidence of dental caries in 94,337 boys (ages 12 - 14) in 24 American states. Sharon, Feller, and Burney (1971) found a relationship between artificial UV and development of dental caries. They reported that golden hamsters exposed to Vita-Lite fluorescent lamps with a measurable UV output (Vita-Lite is the registered trademark of Duro-Test Corporation, North Bergen, New Jersey) had one-fifth as many tooth caries as animals exposed to conventional fluorescent lights. As well, gonad, submandibular gland, and total body weights were greater for animals raised under the simulated natural light (i.e., full spectrum with measurable UV).

Zamkova and Krivitskaya (1966) augmented regular fluorescent light with UV suntan lamps in a controlled experiment involving school children and they reported that when compared to the control group, students who received exposure to UV light showed increased levels of working ability and resistance to fatigue, improved academic performance, improved stability of clear vision, and increased weight and growth. Volkova (1967) studied the effects of UV supplements to general lighting in a factory and found that when compared to a control group, an experimental group of adults demonstrated decreased permeability of skin capillaries, increased white cell activity, and reduced catarrhal infections and colds. Richard Wurtman (1968) concluded that light has biological effects that are important to health and that some of these effects may be easily reproduced and measured in the experimental laboratory. These effects were of two kinds: those which modify the individual's endocrine, hormone and metabolic state by means of light reaching the retina and those which

result from light on the skin (e.g., vitamin D production, skin tanning, and dissociation of bilirubin). Wurtman (1969) also linked light entering the eye with responses of the pineal gland and secretion of the hormone melatonin. This hormone in turn influences the functions of other glands, possibly as a result of direct action on specific areas of the brain. Wurtman and Weisel (1969) studied the effects of light from cool white lamps and full-spectrum Vita-Lite lamps on a group of rats. Their findings support the argument that environmental lighting has an effect on at least some neuroendocrine functions.

Himmelfarb, Scott and Thayer (1970) reported that light from Vita-Lite (full-spectrum) lamps was significantly more effective in killing bacteria than light from standard cool-white lamps. Downing (1988) offered evidence that small amounts of UV radiation destroys bacteria and moulds. At an irradiance level of 10 •W/cm^2 there is sufficient energy to kill in one minute a variety of bacteria and moulds—*alpha strep.* and *staph. aureus (100%), beta hemolytic strep.* and *E. coli* (85%), moulds (30-65%), and the AIDS virus (20%). Even though there appears to be some capability for the UVA and UVB components of full spectrum lamps to have a germicidal effect the greatest effect occurs in the UVC band—especially at 270±5 nanometers (Bickford, 1981). Emissions at that wavelength are about 100 times more effective than emissions in the UVA band.

Neer (1971) described a study which involved elderly male residents at the Chelsea Massachusetts Soldiers' Home who were exposed to full-spectrum fluorescent lighting which also emitted trace amounts of UV energy. The study's conclusion was that relatively small amounts of UV light can stimulate calcium absorption among elderly men who have no exposure to sunlight and who eat a diet containing little vitamin D.

Mass, Jayson and Kleiber (1974) reported that students studying under full-spectrum lights had the smallest decrease over time in critical flicker fusion (the frequency of intermittent stimulations of the eye at which flicker disappears) and an increase in visual acuity. Students studying under cool-white illumination demonstrated greater lethargy than those studying under full-spectrum lights.

Bickford (1981) reported that repeated treatments with a combination of psoralen and UVA (320 to 400 nm) was effective in controlling psoriasis. Davies (1985) undertook a study into the effects of UV light deprivation (wavelengths less than 380 nm) on nine young male volunteers who were enclosed in an isolation chamber for 10 weeks. The conclusion of the study was that: "In healthy young men on normal diets, lack of exposure to sunlight for only five or six weeks leads to depletion of vitamin D stores sufficient to cause inadequate intestinal absorption of calcium and increasingly negative calcium balance, though calcium absorption may begin failing after only three or four weeks."

Sydoriak (1984) found a correlation between types of lighting and wall coloring and blood pressure. In a similar study, Grangaard (1993) reported a significant correlation between color and light environments and student systolic blood pressure and off-task behaviors.

Wurtman (1985, p. *x*), one of the editors of the 453rd volume of the *Annals of the New York Academy of Sciences* which was devoted to the medical and biological effects of light, includes a summary of the broad range of light's actions on mammals (see Table 1).

This study was undertaken for two purposes: (a) to replicate the findings of studies reported by Wohlfarth (1986) and Hargreaves and Thompson (1989) into the non-visual effects of different types of lighting in classrooms and (b) to test for physiological development and school performance effects of four common classroom lighting types on elementary students. Specifically, this study was designed to answer the following questions as they pertain to students in Grades 4 to 6.

1. Does the type of lighting in classrooms have an effect on development of dental caries?

2. Does the type of lighting in classrooms have an effect on school attendance rates?

3. Does the type of lighting in classrooms have an effect on rates of achievement?

4. Does the type of lighting in classrooms have an effect on health and general development?

Table 1 Biologic and medical effects of light (Wurtman, 1985)

Effects	Direct	Indirect
Physiologic	Erythema Pigmentation Epidermal thickening Vitamin D synthesis Blood levels of amino acids Immune systems	Vision Entrainment of rhythms Reproductive activation Entrainment and suppression of melatonin synthesis
Pathologic	Photosensitization porphyrins drugs; toxins Ocular damage Carcinogenesis	(Poorly characterized behavioral and medical effects)
Therapeutic	Hyperbilirubinemia Rickets Light drug interactions (Psoriasis, Leukemia)	Depression: seasonal affective disorder (SAD) Jet lag

Study Method

In an attempt to answer the study questions, 327 students (located in five separate schools) were selected as subjects at the outset of the study. Four different types of lighting were involved in the study.

Study Sites

- Site 1 was a school lit with indirect high pressure sodium vapor (HPSV) lamps. High pressure sodium vapor lamps mounted in indirect fixtures were used throughout all classrooms. Natural light from windows modified the color characteristics of these lamps somewhat. A total of 71 students were involved at Site 1.
- Site 2 was a school lit with full spectrum fluorescent lamps mounted in conventional fixtures. The original cool-white fluorescent lamps in this school were replaced by Vita-Lites distributed by Duro-Test Canada, Inc. The white baked enamel fixtures and the Plexiglass lenses were unmodified. Thirty seven students were involved in the study at Site 2.
- Sites 3 and 5 were schools lit with full spectrum fluorescent lamps with UV supplements. The original cool-white fluorescent lamps in these schools were replaced with Vita-Lites manufactured by Duro-Test Corporation. The white baked enamel fixtures were modified by adding polished aluminum reflectors inasmuch as the reflectance of the white baked enamel fixtures is only 5 to 10 percent in the UV bands (Bickford, 1981). Because plastic lenses and diffusers also filter out UV radiation, several alternatives were followed to ensure that the maximum amount of UV was allowed to reach desk top level. Wraparound Plexiglass lenses in some fixtures were removed because suitable UV-transmitting substitutes were unavailable. Where lay-in Plexiglass lenses were in use, they were removed and replaced with aluminum grid diffusers. (The grid apertures were approximately one centimeter square.) Where open egg-crate style diffusers were available, they were left unaltered. Sites 3 and 5 included a combined total of 161 students.
- Site 4 was a school lit with cool-white fluorescent lamps. Cool-white fluorescent lamps mounted in white baked enamel fixtures equipped with Plexiglass lenses were used throughout the school. A total of 58 students were involved at Site 4.

These particular study sites were selected for a variety of reasons. One of the most important was economic—keeping project costs as low as possible. One way of keeping costs low was to use existing lighting systems wherever possible. Site 1 was selected because it was a new facility and it was fully equipped with high pressure sodium vapor lamps in all classrooms. Site 2 was selected as a result of an informal request to Alberta Education for full spectrum lamps to replace existing cool-white fluorescent lamps. Sites 3, 4 and 5 were selected because of the willingness of the district to permit three of its schools to be involved and further to permit the modification of the lighting systems in two of its schools to include new reflectors and diffusers in the fluorescent fixtures and replacement of existing cool-white lamps with full-spectrum lamps manufactured by Duro-Test Corporation. It was further agreed by all of the districts and schools that the selected schools would be a part of the study for two years and for that period students would remain in those classrooms equipped with modified lighting systems.

Sites 2, 3 and 5 were lamped with Vita-Lite fluorescent lamps for several reasons. First, the manufacturer's specifications indicate that these lamps simulate sunlight (they provide a balanced spectrum including controlled amounts of UV radiation in the mid- and near-UV range (280 - 400 nm). Second, these lamps are the same as those used in the studies reported by Wohlfarth (1986) and Hargreaves and Thompson (1989). Third, Duro-Test Canada, Inc. provided sufficient lamps at no cost to the study to relamp experimental areas at Sites 2, 3 and 5 (approximately 2,000 lamps).

Lighting Environments

Table 2 serves to summarize the illumination and UV levels at each site.

Table 2 Measured Light in Classrooms

Site and Type of Lighting	UVA 315-400 nm ($\mu w/CM^2$)	UVB 280-315 nm ($\mu W/CM^2$)	UVC 100-280 nm (nW/cm^2)	Illumination Photometric Range (Lux[a])
Site 1 High Pressure Sodium Vapor Lamps	0.21	0.00	0.00	250-540
Site 2 Full Spectrum Fluorescent (UV inhibited)	1.01	0.00	0.00	300-900
Site 3 Full Spectrum Fluorescent (UV supplemented)	7.20	0.30	0.00	280-450
Site 4 Cool-white Fluorescent	0.87	0.07	0.00	250-540
Site 5 Full Spectrum Fluorescent (UV supplemented)	5.18	0.18	0.00	220-450

Note. Averages of several participating classrooms were taken in each school. Measures were taken at the end of the study and reflect the minimum levels of UV exposure during the study.

[a] Variations in readings at the upper end of the range are the result of substantial amounts of natural light entering the classrooms. The lower end of the range reflects the minimum amount of light available in the classrooms and may be most representative of the emissions from the classroom lighting systems.

Measurements of the lighting environments reported in Table 2 were measured as follows.

A UVX-36 broadband ultraviolet meter manufactured by Ultraviolet Products Ltd. was used to perform broadband UV measurements over various areas of each room to assess the uniformity of the ultraviolet levels throughout the classroom. A series of measurements was performed at selected locations. Direction of measurements included: (i) horizontally directed towards windows (sunlight contribution); (ii) horizontally directed away from windows (UV classroom lighting-ambient); and (iii) vertically directed towards the classroom lighting (maximum UV lighting contribution).

An EL-791 Spectroradiometer System manufactured by International Light (a NBS traceable calibrated system) was used to conduct narrow-band (5 nm bandwidth) measurements of ultraviolet wave band from 200 to 400 manometers. A location in the classroom corresponding to an average UV exposure level was chosen. At this location, measurements were taken horizontally in a direction perpendicular to the sunlight flux entering the classroom. Another set of measurements was performed vertically towards the lighting system. The first set of data correspond to the average ambient classroom UV levels, while the second set are useful for comparisons of the different light/lens/reflector combinations.

A Model 4OX Optometer manufactured by United Detector Technology Inc. was used to measure visible light illuminance. Visible light illuminance was assessed at the chosen average UV position in the classroom. A range of illuminance was found via a 360° horizontal scan about the chosen position.

A comparison of measured UV levels in all classrooms indicates the following:

- Aluminized reflectors enhance ambient UV emission levels from four to six times over conventional white-painted fixtures.
- Fixtures without lenses or diffusers create significant UV "hot-spots" which are about 1.3 times greater than average ambient levels.
- The Vita-Lite full-spectrum lamps emit UV levels approximately 10 times higher than that of high pressure sodium vapor lamps and approximately four times higher than cool-white fluorescent lamps.
- The aluminum grid diffusers create the most uniform UV levels throughout the classroom.
- High pressure sodium vapor lighting systems emit insignificant quantities of UV.

The question of excessive ultraviolet light exposures was a matter of on-going concern to the study team. As a guideline, the following UV radiation safety limits for an eight (8) hour period (Phillips, 1983) were followed.

- UVA (315-400 nm): 1000 $\mu W/cm^2$
- UVB + UVC (100-315 nm): 0.1 $\mu W/cm^2$

Subjects

The study included all of the Grade 4 students enrolled in each of the schools at the end of the 1986-87 school year (71 at Site 1; 37 at Site 2; 48 at Site 3; 59 at Site 4; and 113 at Site 5). With the exception of students leaving the school, these students remained in the study to the end of the 1988-89 school year.

Grade 4 students were selected in the 1986-87 school year for three reasons. First, this is the age group that was involved in the studies reported by Wohlfarth (1986) and Hargreaves and Thompson (1989). Second, elementary students usually remain in homerooms for most of the school day and for that reason it is easier to retain them under the selected lighting system for the duration of a study. Third, students at this age are on the brink of, or already undergoing, significant physical development (including the eruption of permanent teeth). Only those students remaining at their respective study sites for the duration of the study were examined in the final data collection phase. The intent was that by starting with all of the students in Grade 4 in June 1987 at each school, at least 20 students would remain in each school to the conclusion of the study.

Though some students missed specific tests and measurements at the end of the study, a total of 233 students remained at the end of the study (43 at Site 1, 34 st Site 2, 42 at Site 3, 46 at Site 4, and 68 at Site 5).

A number of different kinds of data were collected from the students including: age, sex, nutrition histories, fluorine levels in the community water supply, dental histories, attendance histories, general health and growth and development histories, and scholastic achievement histories.

Physical Development and Health

Information about general health and the growth and development of students was collected by a Registered Nurse and included the following: age at onset of menarche, height, weight (measured with a Seca personal scale accurate to 0.5 kilograms), body fat (measured with a Lange Skinfold Caliper calibrated in millimeters), other health data, and general data.

Nutrition histories were collected on two occasions during the study by means of the *Three-Day Personal Daily Menu Diary.* On each occasion a nutritionist instructed the students with respect to maintaining an accurate diary. When the diaries were completed, a nutritionist discussed them with students individually and added any details that had been overlooked.

Dental

Procedures for collecting dental histories developed during the earlier study (Hargreaves & Thompson, 1989) were used in this study and were carried out by the same researchers involved in the earlier study.

Each child's teeth were examined twice during the study, first at the end of the 1986-87 school year (as students were preparing to leave Grade 4), and again at the end of the 1988-89 school year as the students were leaving Grade 6. For each child all erupted teeth (i.e., all teeth where the crown was visible in the mouth) were examined and both decayed, extracted and filled teeth (DEFT) and decayed, extracted and filled surfaces (DEFS) were recorded. The examination assessed degrees of caries as follows: *Sound*-no clinically detectable defect in the tooth surface; *Caries* 1-(a) minimal enamel defect, detected by a "catch" with a sickle probe, or (b) a decalcification without enamel penetration; *Caries* 2-(a) marked involvement of enamel and/or dentine with detection by a "sticking" sickle probe, or (b) obvious tooth loss from caries; and *Caries* 3-severe tooth loss from caries with probable pulpal death.

Attendance

To develop attendance histories for each student, monthly attendance was recorded in half-day increments and compared to the maximum number of days the schools were open.

Achievement

Scholastic achievement histories were developed by administering the complete *Canadian Test of Basic Skills:* Form 5 (Level 10 for Grade 4 and Level 12 for Grade 6). The completed data set included 15 measures: vocabulary, reading, language (four tests and a subscore), work study (two tests and a subscore), mathematics (three tests and a subscore), and a total score.

Controlling for Contaminating Variables

Inasmuch as the study sites were selected on the basis of either existing lighting systems or the ease of converting to new lighting systems, the ability to randomly select schools and subjects was lost. It is recognized that failure to randomly select subjects substantially weakens the study. Nevertheless, several things were done to compensate and to reduce the risk of contaminating variables in the study.

- The lighting systems were changed during July and August so that they were in place when children returned to school in September, 1987.
- The students as well as the health, nutrition and dental researchers were not made aware of the school lighting types. Experience suggests that unless one is very knowledgeable about lighting systems, they

would not have discerned the type of lighting present in the different schools just by a visual inspection. Indeed, in some of the schools the test lamps were only in classroom areas and would not have been visible to researchers examining or testing students in specially assigned rooms.

- The nature of the study and the potential outcomes were not discussed with anyone in the schools. In view of the rather limited research in circulation on the subject of non-visual effects of light on people, the probability is low that teachers and students could have guessed the nature of the anticipated study outcomes.
- Administering achievement tests and maintaining attendance records were tasks completed by teachers and no external researchers intervened. To students, it would have been difficult to discern that some of the ordinary information collected by teachers during the two years of the study was also earmarked for study purposes.
- Some data were collected in order to assess the comparability of the student groups and all of the pre-test data collection was useful in this regard. The nutrition data was collected and examined in conjunction with the dental data but it was also used as a proxy for socioeconomic and cultural data. It was believed that differences in total daily caloric intake or differences in protein and sugar intake could point to socioeconomic and cultural differences in the groups.
- Statistical routines designed to overcome the inability to randomly assign subjects to study groups were used in the analysis of achievement test results.

Study Participants

Participants in the design of the study and in the collection, analysis, and interpretation of data included personnel from the Faculty of Dentistry, University of Alberta; Alberta Occupational Health and Safety; Duro-Test Canada, Inc.; and Alberta Education. The study was funded by Alberta Education and Vita-Lite lamps for three schools were provided by Duro-Test Canada, Inc.

Results

The students involved in this study (a total of 327) were located in five different schools. In order to determine the comparability of students and sites, information about students' ages, sex, nutrition, and fluorine levels in water were collected and analyzed.

The average age of all of the students involved in the study was 12.02 years as of June 30, 1989. No significant age differences were found among the study populations. With respect to gender, females made up 47.7 percent of the study population and males made up 53.3 percent.
Nutritional data were collected for three purposes: (a) to serve as a proxy measure in establishing the comparability of student populations at the five sites, (b) to determine if nutrition deficiencies might have an impact on development of dental caries, and (c) to determine if nutrition deficiencies might have an impact on overall health.

Findings with respect to daily calorie, protein and sugar intake are presented in Table 3 on a site-by-site basis and for combined sites receiving UV supplements and those not receiving UV supplements. No significant differences were found in the daily nutrition of students at the five sites or between the UV-supplemented group and the UV-inhibited group.

Inasmuch as no significant differences were found in the sex, ages or daily nutrition of students at the different sites, the conclusion is supported that the students at the five sites are comparable. The argument is that substantial differences in culture or socioeconomic factors might have been reflected in either the global daily calorie intake or the composition of the diet (e.g., differences in protein or sugar intake).

There is abundant evidence that the addition of small quantities of fluorine to drinking water or the local application of fluorine to the teeth of growing children greatly reduces the incidence of caries. The most common practice is to add fluorine to the drinking water to bring the fluorine content up to 0.5 - 1.0 parts per

million. Public water supplies at all of the study sites were adjusted to the range of 1.0 to 1. I parts per million of fluorine.

Dental

Those students receiving trace amounts of UV emitted from Vita-Lites (Sites 3 and 5) developed significantly fewer dental caries than students under other lighting environments (Sites 1 and 2). Students at Site 4 (lamped with cool white fluorescent lamps) were dropped from the dental component of the study when it was found that a high percentage of these students had fissure sealants applied to their teeth during the course of the study. Because fewer students at the other sites received fissure sealants (fissure sealants were readily detectable by the dental examiners), the results are reported with students receiving fissure sealants both included and excluded. As may be expected, the beneficial effects of UV radiation are understated when the students with fissure sealants are included.

These results are presented in Table 4 together with summarized findings obtained by comparing the sites receiving UV supplements with these sites that did not receive the UV supplements.

When students receiving fissure sealants are included in the analysis, students in the Control Group had an average of 0.59 decayed teeth (or 0.95 decayed surfaces) more than the UV Treatment Group. When students receiving fissure sealants are excluded from the analysis, the Control Group had an average

Table 3 Daily Nutrition Intake

Site	Calories	Protein (grams)	Sugar (grams)
Specific Sites			
Site 1	1772.0	59.4	107.2
Site 2	1697.4	67.4	102.9
Site 3	1642.6	61.7	101.3
Site 4	1577.3	60.7	102.9
Site 5	1736.2	63.4	106.6
Combined Sites			
UV Supplemented Sites (3 & 5)	1689.4	62.7	103.9
UV Inhibited Sites (1, 2 & 4)	1662.4	62.6	104.0

of 0.79 decayed teeth (or 1.36 decayed surfaces) more than the UV Treatment Group. Complete reversals (clinical signs of early caries at the initial examination not being detectable at the final examination) were observed for some tooth surfaces, specifically in the Treatment Group receiving the UV supplements.

The findings from site to site with respect to reductions in dental caries development as a result of UV radiation are apparently not influenced by diet based on macro-nutrient assessment or by fluoride levels of the drinking water. As well, all children involved in the study had equal access to over-the-counter preventive dental health products and more than 95 percent of dentifrices available in the marketplace have a fluoride component of 1,000 to 1,250 ppmF.

An analysis of dental records for the children located in the different lighting environments examined in this study supports the conclusion that exposure to low levels of UV light does prevent or reduce the development of dental caries.

Attendance

The results of an analysis of the attendance data are presented in Table 5.

A number of significant differences in attendance are to be noted. Site 2 (full spectrum) and Sites 3 and 5 (full spectrum with UV supplement) had significantly better attendance than Site 1. The difference amounts to approximately 3.2 days per year. It might be concluded that an absence of 3.2 days is about the length of time that it would take to recover from a severe cold.

Table 4 Effects of Supplemental Ultraviolet Light on the Development of Dental Caries

Site	Incremental Increase in Caries 1987-89 (Students with Fissure Sealants Included in Analysis)		Incremental Increase in Caries 1987-89 (Students with Fissure Sealants Excluded from Analysis)	
	DEFT[a]	DEFS[b]	DEFT[a]	DEFS[b]
By Site				
Site 1 High Pressure Sodium Vapor Lamps	1.13	1.45	1.30	1.72
Site 2 Full Spectrum Fluorescent (UV inhibited)	0.68	1.18	0.70	1.33
Site 3 Full Spectrum Fluorescent (UVsupplemented)	0.42	0.40	0.22	0.14
Site 5 Full Spectrum Fluorescent (UVsupplemented)	0.21	0.34	0.19	0.19
By Exposure to Ultraviolet Light				
Non-UV Control Group Average	0.91	1.32	1.00	1.53
UV Treatment Group Average	0.32	0.37	0.21	0.17

Note. Students at Site 4 (cool-white lamps without UV) were eliminated from the data analysis when it was discovered that a very high percentage of these students had received applications of fissure sealants during the study period. Results are reported for students at all other sites both with and without fissure sealants. Including students with fissure sealants tends to mask the effect of UV supplements on untreated teeth.

[a] DEFTmeans decayed, extracted, or filled teeth

[b] DEFS means decayed, extracted, or filled surfaces.

Based on an analysis of attendance records for the children located in the different lighting environments examined in this study, it may be concluded that the type of lighting does have an effect on attendance rates.

Achievement

Scholastic achievement histories were developed by administering the complete *Canadian Test of Basic Skills:* Form 5 (Level 10 for Grade 4 and Level 12 for Grade 6) which included 15 measures: vocabulary, reading, language (four tests and a subscore), work study (two tests and a subscore), mathematics (three tests and a subscore), and a total score.

As is the case with many research projects, it is often necessary to study groups as they are—the subjects cannot be matched or assigned at random. Such was the case with this study. In cases like this Kerlinger (1964) is of the view that Analysis of Covariance is a preferred statistical procedure—"it tests the significance of differences between means of the final experimental data by taking into account and adjusting initial differences in data." Ferguson (1971) describes the Analysis of Covariance as a "statistical, rather than an experimental,

method [that] may be used to 'control' or 'adjust for' the effects of one or more uncontrolled variables [added by author] "—in this case differences in achievement pretest scores.

Table 5 Effects of Types of Lighting on Average Attendance, Achievement, and Development

Site	Attendance Rate (%)	Achievement Gain[a]	Height Gain[b]	Weight Gain[c]	Body Fat Gain[d]
Site 1	94.3*	1.61	10.2*	10.2	3.4
Site 2	96.2	2.25	12.0	10.9	7.6
Sites 3/5	95.9	1.96	12.3	11.2	3.9
Site 4	95.9	1.88	11.9	9.6*	0.4*

Note. [a] Gain measured in grades (i.e., 1.8 means a gain of 1.8 grades during the period of the study).
[b] Gain measured in centimetres.
[c] Gain measured in kilograms.
[d] Gain measured in millimetres.
*Statistically significant differences, $p > 0.05$ based on two-tailed *t* test.

When Analysis of Covariance was applied to the data collected by administering the *Canadian Test of Basic Skills* in this study, significant differences beyond the 0.05 level were found between the four groups formed on the basis of classroom lighting in total achievement gains (p=0.000, F= 1 1.423) and in gains in language (p=0.003, F--4.877), work study (p=0.040, F=2.826), and mathematics (p=-O.001, F=5.912).

Site specific data with respect to total gains on the *Canadian Test of Basic Skills* are summarized in Table 5. The lowest achievement gains are to be found at Site 1 while the greatest gains are found at Site 2 and Sites 3 and 5.

Based on an analysis of achievement records for the children located in the different lighting environments examined in this study, it may be concluded that light does have an effect on rates of achievement.

Physical Development

It may be noted in Table 5 that the smallest gains in height were made at Site I (high pressure sodium vapor) while the greatest gains were made at Sites 3 and 5 (full spectrum with UV supplement). Indeed, the gains at Site 1 were significantly less than gains at Sites 3 and 5 (full spectrum with UV supplement) and Site 4 (cool-white).

The greatest average weight gain occurred at Sites 3 and 5 (full spectrum with UV supplement) and these gains were significantly greater than those at Site 4 (cool-white). Arguably, light could be a clear factor in this instance inasmuch as both sites are located in the same community and other factors are more or less equal.

Increases in body fat during the period of the study were lowest at Site 4 and highest at Site 2. Differences are displayed in Table 5.

Based on an analysis of health and general development records for the children located in the different lighting environments examined in this study, the conclusion is supported that light does have an effect on health and general development. Specifically, significant differences were found to include; height gains, weight gains, and gains in body fat.

Menarche

A relatively small percentage of the overall female study population reached menarche during the course of the study (17.8 percent), however the distribution was not entirely uniform. To establish an expectation of the number of girls that should have reached the onset of menarche, the results of a completed study of 1829 girls was provided by the Edmonton Board of Health. Table 6 presents the data collected in this study as compared to the study of 1829 girls. Statistically significant differences were determined by means of Chi Square tests. The higher than predicted incidence of onset of menarche at Sites 2 (full spectrum) and Sites 3 and 5 (full spectrum with UV supplement) and the lower than predicted incidence of the onset of menarche at Site 1 is difficult to explain. One factor common to all of these sites is light—the higher incidence of menarche occurred in schools lit by Vita-Lite full spectrum lamps (rich in blue light) and the lower incidence was in the school lit by high pressure sodium vapor lamps (deficient of blue light).

Based on an analysis of health and general development records for the girls exposed to the different lighting environments examined in this study, significant differences were found in the age for the onset of menarche.

Discussion

This study set out to examine for non-visual effects of different types of lighting on students over a two-year period.

A number of significant findings were found in this study and they are summarized in tabular form in Table 7. Without placing a value judgement on the findings (i.e., good or bad) two symbols are used to describe the findings in Table 7—a negative sign (-) is used to indicate the lowest or smallest significant measures, a positive sign (+) is used to indicate the highest or greatest significant measures, and a blank is left when the findings were insignificant. This non-evaluative view must be kept in mind, especially when viewing the findings with respect to the onset of menarche and gains in body fat. Sites 3 and 5 (full spectrum with UV enhancement) and Site 2 (full spectrum) appear to contain the preferred lighting systems inasmuch as students at these sites were significantly better than other sites on the greatest number of measures. At the same time it must be noted that students at Site 1 (high pressure sodium vapor) rated significantly poorer on most measures.

From evidence summarized in Table 7 it may be concluded that different types of lighting do have differential effects on students' dental histories, growth and development histories, scholastic achievement histories, and attendance histories when examined over a two-year period.

When it comes to the findings summarized in Table 7, it seems clear that UV supplements may account for differences in the rates at which dental caries developed and this may be linked to the stimulation of vitamin D production in the skin as a result of UVB irradiation. Improved attendance (perhaps a reflection of good health) may also be linked to Vitamin D as well as to the bacteria-killing effects of UV light. A number of the other significant findings may be more related to color or the visible light spectra than anything else. The onset of menarche seems to fit this case. The higher than expected incidence occurred at schools with full spectrum light (i.e., enhanced blue). The lower than expected incidence occurred at the site with the yellow-orange (near monochromatic) light. Indeed, gains in height and achievement and attendance ratios all fit into this same pattern—students under conventional or blue-enhanced lighting scored the largest gains and those students under HPSV lighting scored lowest.

Every study tries to answer some questions and to provide some new information but it is also often the case that the new information identifies still other areas which need to be studied. Such is the case with this study.

Table 6 Incidence of Girls Reaching the Onset of Menarche

Site	Number of Girls	Number Reaching Menarche	Average Age at Onset of Menarche	Predicted Probability[a] (Percent)	Actual Percent Reaching Menarche
Site 1	17	2	11.763	21.8	11.8*
Site 2	15	7	11.729	21.0	46.7*
Sites 3 and 5	73	12	11.069	9.5	16.4*
Site 4	30	3	11.238	11.8	10.0
Totals	135	24	11.340	13.5	17.8

Note. [a] Probability based on a study of l,829 girls reported by the Edmonton Board of Health.
* Statistically significant differences, $p > 0.05$ based on Chi Square test.

On the basis of this study, and other research reported in the literature, we know that trace amounts of UV in the classroom have the effect of reducing the incidence of dental caries in children in Grades 5 and 6. We also suspect that the color of visible light in classrooms may have an effect on the growth and development rates of children. For example, the poor Color Rendering Index and the monochromatic light at Site I may explain the lower academic achievement rates for those students. Similarly**,** the blue-enriched full spectrum lamps may account for some of the significant differences measured with respect to Site 2 and Sites 3 and 5. Unfortunately, we still do not know enough about the risks associated with different lighting systems. Most importantly, we do not know where the boundary lies between risks and benefits of exposure to UV light.

Lighting systems are most often designed with efficiency in mind—the objective being to obtain the highest possible lumens/watt ratio. Seemingly little attention is paid to any non-visual effects lights may have on the occupants using the lighting systems. Clearly, this study points to the single conclusion that—no matter how efficient—lighting systems are not neutral with respect to their effects on people. Indeed, it appears to be the case that there are a number of non-visual effects associated with different types of lighting. This study has identified a number of such effects—differences in the rate of dental caries development, differences in rates of attendance, differences in the age of the onset of menarche, differences in height, weight, and body fat gains, and differences in scholastic achievement. One might conclude from these findings that natural light is important to the development and well-being of people and to imprison people in spaces lit only with artificial lights designed solely for efficiency amounts to a clear case of daylight robbery.

Wurtman (1985: p. *xi*) very articulately argues the need for clear policy-making guidelines and better understanding of light and its effects on people by first posing a question, Should limits be placed, based on health considerations, on the artificially illuminated lighting environments under which people may live and work?

Table 7 A Summary of Significant Findings Compared to Different

Types of Lighting

Factor Examined	Site 1 HPSV	Site 4 CW	Site 2 FS	Sites 3/5 FS + UV
Lighting System Characteristics				
Dominant color characteristic of light source	Golden (yellow-	Yellow-green	Daylight (bluish)	Daylight (bluish + UV)

	orange)			
Color temperature (K)[a] (Daylight-sun and sky >5000)	2100	4250	5500	5500
Color rendering index[a] (100 = natural daylight)	21	62	91	91
Non-Visual Effects on Students				
Reductions in the development of dental caries.	-	na[b]	-	+
Attendance ratio.	-		+	+
Onset of menarche.	-		+	+
Gains in height.	-	+		+
Gains in weight.		-		+
Gains in body fat.	+	-	+	+
Academic achievement[c]	-	+	+	+

Note. [a] Thorington (1985)
[b] Students at Site 4 were dropped from the dental component of the study when it was found that many students had received applications of fissure sealants.
[c] Site 2 had significantly greater achievement gains than all other sites while Sites 3 and 5 and Site 4 were only better than Site 1.

To more fully answer Wurtman's questions, and in spite of the positive findings of this study, several areas need to be explored further. For example:

1. At what ages are UV supplements most beneficial?

This study has focused on students in Grades 5 and 6 and they were chosen because students in this age range (10 to 12 years of age) are undergoing a number of changes in their bodies. On the basis of this narrow age range, it is impossible to generalize to other age groups. Further research should be carried out to examine non-visual effects of light on children in play school, kindergarten, and in the primary grades. Similar research should also be carried out on students in the junior and senior high school age group. Though not the mandate of education, similar research could also be carried out on all age groups in our society.

2. What are the most efficient ways of providing UV supplements?

Vita-Lites manufactured by Duro-Test Corporation were used in this study for three reasons. First, the manufacturer claims that the lamp spectrum contains UV radiation in approximately the same proportion as that found in natural daylight. Second, research using animals (i.e., Sharon, Feller & Burney, 1971) pointed to beneficial effects derived through use of Vita-Lites. Third, Vita-Lites were used in the earlier studies reported by Wohlfarth (1986) and Hargreaves and Thompson (1989). The measured UVA emitted by these lamps in classroom settings, when mounted in modified fixtures, amounts to about 8 to 10 IIW/CM2 at desk top height and this translates to about 0.6 percent of the recommended maximum eighthour dosage of 1,000 •W/cm^2. However, the measured effective UVB (important to synthesis of vitamin D) amounted to less than 0.01 •W/cm^2 and this equates to about seven percent of the recommended, maximum daily dosage.

Other sources could include use of high energy UV sources, special UV fluorescent lamps (black lights) mounted adjacent to conventional fluorescent lamps, or exposure to sunlight for a period of time between 10:00 AM and 2:00 PM.

3. Are there any concerns about supplementary UV radiation?

Yes there are concerns. People are warned by radio and television to exercise caution when it comes to unnecessary exposure to UV light. Patronizing tanning studios and sunbathing are now both considered to be unwise. At the same time exposure to sunlight is still a satisfactory way of controlling the incidence of rickets. The question of risk probably has to do with the intensity of UV light to which people are exposed. None of the lighting systems used in this study emitted UV energy in the UVA band at a level exceeding about 0.6 percent of the recommended maximum exposure for an eight hour period (i.e., 1,000 •w/cm^2 in the UVA band per eight hours). UVB levels encountered in the classroom were about 16 percent of the amount encountered while on a one-hour walk in the noontime summer sun in Edmonton, Alberta in June and approximately 41 percent of the exposure gained in a similar walk in October. Based on these standards, the UV levels in the classrooms involved in this study give no great cause for concern. Nevertheless, the extent of the concern can only be considered in terms of exposure to natural light. For example, two hours of exposure to the noon-time summer sun also exceeds the allowable occupational exposure limit to UVB. It is important to note that the equivalent of a 15-minute exposure to noon-time summer sun (at 36º N. Latitude) is considered sufficient for developing a person's daily requirement of vitamin D (Neer, 1975).

Though UVB radiation exposures in this study were at acceptable levels (by current standards), continuing research in this area may change presently held views about the risks of UV exposure. Should that happen, lighting systems should be re-evaluated to take into consideration any new information.

4. Are dietary vitamin D and vitamin D synthesized in the skin exactly equivalent?

One logical hypothesis to be drawn from analysis of the dental data collected in this study is that reductions in the development of dental caries is explained by the better use of dietary calcium brought about by small amounts of vitamin D synthesized in the skin as a result of exposure to low levels of UV radiation. Testing of this hypothesis is beyond the sorts of research that can be carried out in classrooms by non-medical researchers. Nevertheless, the processes associated with reduction of dental caries development under UV radiation is interesting.

Wurtman (1975) and Holick (1985) question the biological efficiency of dietary vitamin D relative to vitamin D synthesized in the skin. An analysis of the nutrition of students in this study indicates normal levels of vitamin D in their diets. Accordingly, it might be expected that any vitamin D synthesized in the skin as a result of the low levels of UV radiation in classrooms involved in this study would be insignificant. The results of this study, however, suggest that such may not be the case. Small amounts of vitamin D synthesized in the skin may be very important. Clearly, this study supports the view that the relative efficiencies of dietary and synthesized vitamin D should be assessed in future research.

5. At what geographical locations (i.e., latitudes) are UV supplements most beneficial?

All of the light-related research conducted in Alberta has been conducted at sites located between 49º and 54º North Latitude. This region is noted for its relatively short periods of daylight and long periods of darkness from September to March. Students spend most of the daylight hours in school and have little opportunity for exposure to sunlight and natural UV radiation. Perhaps it is this lack of exposure to natural UV that explains why relatively small but prolonged exposures to UV radiation have such beneficial effects on students. That being the case, it is important that the effects of exposure to small amounts of UV radiation should be explored at other latitudes and in regions where fog or cloud cover minimizes exposure to natural sunlight and UV radiation.

6. What are the implications of this research on the workplace? On health facilities? On facilities for the aged? On osteoporosis?

This study has focused on children from ten to 12 years of age. Accordingly, the findings cannot be generalized beyond this age group without some degree of risk. Nevertheless, the research findings reported in

this study suggest that similar effects should be looked for in other segments of the population. Obvious targets for future research should be in, (a) offices where people spend most of their daylight hours, (b) in health facilities, and (c) in facilities for the aged. It is a well-established that the aged lose their ability to absorb calcium with the result that they tend to suffer from osteoporosis and increased bone porosity and fragility. This segment of the population may especially benefit from light therapy.

References

Aston, S. M. & Bellchambers, H. E. (1969). Illumination, colour rendering and visual clarity. *Lighting Research and Technology, (1),* 259-261.

Bickford, E. W. (1981). Nonvisual effects of radiant energy. *IES Lighting Handbook: 1981 Applications Volume.* 19.1-19.40.

Corth, R. (1984, January 19). What is "natural" light? A paper presented at the Conference on the Photobiological Health Effects of Artificial Light Sources conducted by the Puget Sound Section of the Illuminating Engineering Society, Seattle, Washington.

Davies, D. M. (1985). Calcium metabolism in healthy men deprived of sunlight. In R. J. Wurtman, M. J. Baum & J.T. Potts, Jr. (eds), *The Medical Effects of Light (Annals of the New York Academy of Sciences, Volume 453).* New York: The New York Academy of Sciences.

Downing, D. (1988). *Day Light Robbery.* London: Arrow Books Limited.

East, B. R. (1939, July). Mean annual hours of sunshine and the incidence of dental caries. *American Journal of*

Public Health and The Nation's Health, 29, 777-780.

Ferguson, G. A. (1971). *Statistical Analysis in Psychology & Education (Third Edition).* Toronto: McGraw-Hill Book Company.

Grangaard, E. (1993). *Effects of Color and Light on Selected Elementary Students.* Unpublished doctoral dissertation, University of Nevada—Las Vegas, Las Vegas, Nevada.

Hargreaves, J. A. & Thompson, G. W. (1989). Ultraviolet light and dental caries in children. *Caries Research, 23,* 389-392.

Helveston, E. M., Weber, J. C., Miller, C. O., Robertson, K., Hohberger, G., Estes, R., Ellis, F. D., Pick, N., & Helveston, B. H. (1985, March). Visual function and academic performance. *American Journal of Ophthalmology, 99* (3), 346-355.

Himmelfarb, P., Scott, A., & Thayer, P. S. (1970). Bacterial activity of a broad-spectrum illumination source. *Applied Microbiology, 1013-1014.*

Hodr, R. (1971). Phototherapy of hyperbilirubinemia in premature infants. *Ceskoclovenska Pediatrie, 26.*

Holick, M. F. (1985). The photobiology of vitamin D and its consequences for humans. In R. 1. Wurtman, M. J. Baum & J. T. Potts, Jr. (eds), *The Medical Effects of Light (Annals of the New York Academy of Sciences, Volume 453).* New York: The New York Academy of Sciences, 1-13.

Holick, M. F., McNeill, S. C., MacLaughlin, J. A., Holick, S. A., Clark, M. B., & Potts, J. T. Jr. (1971). Physiologic implications of the formation of previtamin D3 in skin. *Transactions of the Association of American Physicians, 92.*

Hughes, P. C. (1981, March-April). School lighting for the total person: a psychobiolgical approach. CEFP *Journal, 19* (2), 4-7.

Kerlinger, F. N. *(1964). Foundations of Behavioral Research.* Toronto: Holt, Rinehart and Winston, Inc.

Lamola, A. A. (1985). A history of organizations interested in biological effects of light. In R. J. Wurtman, M. J. Baum & J. T. Potts, Jr. (eds), *The Medical Effects of Light (Annals of the New York Academy of Sciences, Volume 453).* New York: The New York Academy of Sciences, 121-122.

Loomis, W. F. (1970, December). Rickets. *Scientific American, 223* (6), 77-91.

Lucey, J. F. (1972, November). Neonatal jaundice and phototherapy. *Pediatric Clinics of North America, 19* (4), 1-7.

Maas, J. B., Jayson, J. K. & Kleiber, D. A. (1974). 'Quality" of light is important—not just quantity. *American School and University, 46* (12), 31.

Neer, R. M. (1971, August). A paper presented at the National Technical Conference of the Illuminating Engineering Society.

Neer, R. M. (1975). The evolutionary significance of vitamin D, skin pigment, and ultraviolet light. *American Journal of Physical Anthropology, 43* (3), 409-416.

Neer, R. M. (1985). Environmental light: Effects on vitamin D synthesis and calcium metabolism in humans. In R. J. Wurtman, M. J. Baum & J. T. Potts, Jr. (eds), *7he Medical Effects of Light (Annals of the New York Academy of Sciences, Volume 453).* New York: The New York Academy of Sciences, 14-20.

Neer, R. M., Davis, T. R. A., Walcott, A., Koski, S., Schepis, P., Taylor, I., Thorington, L. & Wurtman, R. J. (1971, January 22). Stimulation by artificial lighting of calcium absorption in elderly human subjects. *Nature,* 229.

Ozaki, Y. & Wurtman, R. J. (1979). Spectral power distribution of light sources affects growth and development of rats. *Photochemistry and Photobiology, 29,* 339-341.

Phillips, D. G. (1983, May 3-5). Ultraviolet radiation and fluorescent lighting. A paper presented at the 4th Annual Conference of the Canadian Radiation Protection Association, Toronto, Ontario.

Sharon, I. M., Feller, R. P., & Burney, S. W. (1971). The effects of lights of different spectra on caries incidence in the golden hamster. *Archives of Oral Biology, 15* (12), 1427-1431.

Sydoriak, D. E. (1984). *An experiment to determine the effects of light and color in the learning environment.* Unpublished doctoral dissertation, University of Arkansas, Little Rock, Arkansas.

Thorington, L. (1985). Spectral, irradiance, and temporal aspects of natural and artificial light. In R. J. Wurtman, M. J. Baum & J. T. Potts, Jr. (eds), *The Medical Effects of Light (Annals of the New York Academy of Sciences, Volume 453).* New York: The New York Academy of Sciences.

Thorington, L., Cunningham, L. & Parascondola, L. (1971, April). Visual and biologic aspects of an artificial sunlight illuminant. *Illuminating Engineering, 240-250.*

Thorington, L., Parascondola, L. & Cunningham, L. (1971, October). Visual and biologic aspects of an artificial sunlight illuminant. *Journal of the Illuminating Engineering Society, 33-41.*

Volkova, N. V. (1967). Experience in the use of erythemic ultraviolet radiation in the general lighting system of a machine shop. Translated by Duro-Test Electric from original Russian in *Gigiena in Sanitariia, 32,* 109-111.

Wohlfarth, H. (1986). *Color and Light Effects on Students' Achievement, Behavior and Physiology.* Edmonton, Alberta: Planning Services Branch, Alberta Education.

Wurtman, R. J. & Neer, R. M. (1970, February 12). Good light and bad. *The New England Journal of Medicine, 282* (7).

Wurtman, R. J. (1968, September 9-12). Biological implications of artificial illumination. A paper presented at the National Technical Conference of the Illuminating Engineering Society, Phoenix, Arizona.

Wurtman, R. J. (1969, January). The pineal and endocrine function. *Hospital Practice, 4* (1), 32-37.

Wurtman, R. J. (1975). The effects of light on man and other mammals. *Annual Review of Physiology, Volume* 37.

Wurtman, R. J. (1985). Introductory remarks. In R. J. Wurtman, M. J. Baum & J. T. Potts, Jr. (eds), *The Medical Effects of Light (Annals of the New York Academy of Sciences, Volume 453).* New York: The New York Academy of Sciences.

Wurtman, R. J. & Weisel, J. (1969, December). Environmental lighting and neuroendocrine function: relationship between spectrum of light source and gonadal growth. *Endocrinology, 85* (6), 1218-1221.

Zamkova, M. A. & Krivitskaya, E. 1. (1966, April). Effect of irradiation by ultraviolet erythema lamps on the working ability of school children. Translated by Duro-Test Electric from original Russian in *Gigiena in Sanitariia, 31,* 41-44.