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AUTHOR	Hathaway, Warren E.; And Others
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ABSTRACT

This report describes a 2-year study of the effects of various lighting systems on elementary school students' dental health, attendance, growth and development, vision, and academic achievement. The four light types used were: (1) full spectrum fluorescent; (2) full spectrum fluorescent with ultraviolet light supplements; (3) cool white fluorescent; and (4) high pressure sodium vapor. A review of the literature reveals physiological and psychological effects of light and color. Participants were upper elementary students from five schools. Each school had one of the four lighting types; two schools had the same type. Data on students were collected before and after the study. Results indicated that over a 2-year period, students who received ultraviolet light supplements had fewer dental caries, better attendance, greater gains in height and weight, and better academic performance than did students who did not receive the supplements. Students under the high pressure sodium vapor lighting had the slowest rates of growth in height and academic achievement and the lowest attendance. It was concluded that lighting systems have important nonvisual effects on students who are exposed to them over long periods of time. Implications for facility planning are considered and recommendations regarding lighting for classrooms are offered. Appended are 44 references. (GLR)

A Study Into the Effects of Light on Children of Elementary School Age —A Case of Daylight Robbery

Planning and Information Services

Alberta
EDUCATION

A Study Into the Effects of Light on Children of Elementary School Age —A Case of Daylight Robbery

by

Warren E. Hathaway

John A. Hargreaves

Gordon W. Thompson

Dennis Novitsky

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Steering Committee

Dr. J. A. Hargreaves
Director, School of Dentistry
Faculty of Medical Sciences
The University of the West Indies
Eric Williams Medical Sciences Complex
Champs Fleurs
Trinidad and Tobago, W.I.

Dr. Gordon W. Thompson
Faculty of Dentistry, University of Alberta
Rm. 1043, Dentistry-Pharmacy Building
Edmonton, Alberta T6G 2N8

Mr. Dennis Novitsky
Radiation Health Services
Alberta Occupational Health and Safety
4th Floor, Donsdale Place
10709 Jasper Avenue
Edmonton, Alberta T5J 3N3

Mr. Robert Grant
Duro-Test Canada Inc.
1840, 10123 - 99 Street
Edmonton, Alberta T5J 3H1

Mr. Hoang Le
School Buildings Services Branch
Alberta Education
11160 - Jasper Avenue
Edmonton, Alberta T5K 0L2

Dr. Warren E. Hathaway
Research and Educational Technology
Policy and Planning Branch
Alberta Education
11160 - Jasper Avenue
Edmonton, Alberta T5K 0L2

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Information about students' nutrition was collected by nutritionists Marie Slusar and Heather Brown. Health and general development information were collected by Dana Fitzpatrick, a Registered Nurse. Dennis Novitsky, Radiation Health Services, Alberta Occupational Health and Safety, performed light spectrum measurements in all of the schools as well as performing a number of measurements on test lamps in his laboratory. Andrew Folkins, a systems analyst at the University of Alberta, provided support in assembling and analyzing the study's data base.

Dr. John Burger, Policy Consultant, Policy and Planning Branch, Alberta Education, provided considerable assistance with respect to specifying and interpreting a number of analyses on the achievement and health data.

The Vita-Lite[1] lamps (i.e., full-spectrum lamps which produce ultraviolet light supplements) used in this study were provided by Duro-Test Canada, Inc. with head offices at 419 Attwell Drive, Rexdale, Ontario, M9W 5W5. The initiatives of Robert Grant of the Edmonton office of Duro-Test Canada, Inc. in obtaining a supply of these lamps for this study is very much appreciated.

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[1] Vita-Lite is the registered trademark of Duro-Test Corporation, North Bergen, New Jersey.

Executive Summary

Yes! Light affects people in some surprising ways. Some would even go so far as to say that light is nutritious. In order to get a firmer grasp on some of these effects of light on people, a study of the effects of light on children of elementary school age was undertaken by Alberta Education between June 1987 and June 1989. This is the study report.

This study was intended to replicate the 1981-1985 study wherein it was found that trace amounts of ultraviolet light served to reduce the development of dental caries. Five schools were involved in this study (the specific schools have not been named in order to protect the students from undue notoriety). The study has been guided by a Steering Committee with representatives from Alberta Occupational Health and Safety (Radiation Health Services); the Faculty of Dentistry, University of Alberta; Duro-Test Canada, Inc.; and Alberta Education (School Buildings Services and Policy and Planning Branches).

The study was designed to test the null hypothesis—different light types (full spectrum fluorescent, full spectrum fluorescent with ultraviolet light supplements, cool-white fluorescent, and high pressure sodium vapor) have no differential effects on Division II students' dental histories, growth and development histories, vision histories, scholastic achievement histories, or attendance histories when compared over a two-year period.

Upper elementary students were selected for the study for three reasons: upper elementary students were involved in the first study completed by Alberta Education, elementary students tend to remain in home rooms most of the time which makes it easier to ensure that they remain under selected lighting types, and upper elementary students are going through significant body changes (including eruption of permanent teeth).

Schools were chosen either because they had unusual lighting systems (the case with high pressure sodium vapor site) or they were willing to have their lighting systems modified through Alberta Education's Building Quality Restoration Program and with Vita-Lite full spectrum lamps provided by Duro-Test Canada, Inc. at no cost to the project.

Dental and nutrition data were collected by the Faculty of Dentistry, University of Alberta as a part of a contract with Alberta Education. Health-related data were collected by a Registered Nurse under contract to Alberta Education. Attendance and achievement data were collected and analyzed within the Policy and Planning Branch of Alberta Education. Tests of the spectral quality of the lights in schools involved in the study were completed by Radiation Health Services of Alberta Community and Occupational Health.

Major findings of the study include:

- over a two year period students receiving ultraviolet light supplements developed 0.17 decayed surfaces while the non-UV group developed 1.53 decayed surfaces. Those students receiving ultraviolet light supplements also demonstrated the best attendance, the greatest gains in height and weight, and the best academic achievement.

- over a two year period students under high pressure sodium vapor lighting had the slowest rates of growth in height (2.1 cm less than students receiving a ultraviolet light supplement), and achievement (a gain of 1.6 years in comparison to the 2.0 years which was the average of all other sites). They also had the lowest percentage of attendance (94.3 percent) while the other sites had attendance patterns of 95.9 percent, 95.9 percent and 96.2 percent. The difference of 1.6 percent between the poorest and next best site translates into 3.2 days per year (about the time needed to recover from a major cold).

These findings support the conclusion that lighting systems are not neutral—they have non-visual effects on people who are exposed to them over long periods of time.

This report concludes with a section devoted to a discussion of the ways by which the findings of this study might be used.

Three recommendations are supported by the findings of this study. First, continued research should be carried out into the non-visual effects of light. Second, the impact of the completed studies should be examined with a view to providing the best and safest lighting systems for existing classrooms and new or redesigned classrooms. Third, a clearing house of information should be created with respect to the non-visual effects of light—and perhaps color—and related implications for schools and school design.

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Chapter 1

Purpose of Study

Education is a multifaceted process which includes opportunity, environment, curriculum, teaching effectiveness, parental support, innate ability, and physical factors. If deficiencies exist in any of these areas, a child's education may be compromised (Helveston, et al, 1985: 346).

This study was undertaken in response to two issues: (a) the view that environment is an important facet of the multi-faceted educational process (Helveston, et al, cited above), and (b) the findings of earlier research carried out in Alberta. The most surprising findings from the earlier research supported by Alberta Education from 1981 to 1985 (Wohlfarth, 1986; Hargreaves & Thompson, 1989) were that those elementary students (Grades 5 and 6) who received trace amounts of ultraviolet light in their classrooms developed fewer dental caries and had better attendance than students in a comparison group.

Based on the 1981 to 1985 research it was concluded that there could be significant benefits for education in several areas. On the basis of the daily per pupil educational expenditure in 1984-85 (i.e., $21.42 per pupil space per day) and a with difference of 9.49 days of absence per year for students under different lighting systems, the cost of having these spaces vacant because of these absences amounts to $203.28 per pupil per year (i.e., an average expenditure of $203.28 is made to provide a pupil space which is not used). On the basis of the reduced dental caries, a further saving was calculated at $116.75 per pupil per year. Combined, these benefits total $320.03 per pupil per year. Inasmuch as the cost of providing trace amounts of ultraviolet in classrooms amounts to no more than $30.00 per student per year, there is a net social benefit of $290.03 per pupil per year. It was further concluded that if these benefits could be generalized to all students in Alberta (approximately 430,000) the net social benefit would approach $125,000,000 per year. Moreover, these findings may be generalizable to other regions of Canada, the northern United States, areas frequently shrouded in fog, and other geographical locations where the daily availability of natural ultraviolet light is minimal for extended periods of time.

Even though the findings of the original studies by Wohlfarth (1986) and Hargreaves and Thompson (1989) were highly significant, the bottom line was that further research was needed in order to confirm the original findings.

At the same time the literature on the non-visual effects of light on people is constantly expanding. Research at the Massachusetts Institute of Technology (Ozaki & Wurtman, 1979: 339-341) drew attention to the fact that light from high pressure sodium vapor lamps produced anomalies in the growth and development of animals. In addition to high pressure sodium vapor lamps, schools in Alberta and elsewhere are presently lit with a variety of other lamp types: incandescent lamps; cool-white, warm-white, full spectrum, and UV-enhanced full-spectrum fluorescent lamps; and mercury vapor lamps.

This study was undertaken in order to (a) replicate the findings of the initial study undertaken by Alberta Education into the effects of classroom lighting and (b) to test the differential effects of other lighting types on students. It was planned around a pretest-posttest, multiple-group design and attempted to test the following null hypothesis:

Different light types (full spectrum fluorescent, full spectrum fluorescent with UV enhancement, cool-white fluorescent, and high pressure sodium vapor) have no differential effects on Division II students' dental histories, growth and development histories, vision histories, scholastic achievement histories, or attendance histories when compared over a two-year period.

Chapter 2

Literature Review

The environments in which we spend significant parts of each day are a far cry from the natural environments of our ancestors. We find ourselves 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 (i.e., light levels of 200 to 1500 lux in comparison to natural light at twilight of 2,800 to 8,200 lux and at noon up to 100,000 lux (Thorington, 1985: 44)).

Corth (1984) might argue with some of these views. His contention is 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 contends that the spectral quality of the light at the forest floor was the combined result of the solar radiation spectrum and the filtering effect of the forest canopy. He says:

> *Field measurements of the spectral distribution of the light under a number of forest canopies have been made by Federer and Tanner. Although there is some variation with species, all show a similar structure since chlorophyll is the primary component in the foliage which determines the spectral absorption. Regardless of the variation in the spectral characteristics of the foliage and in the density of the forest canopy, the light that comprises the forest illumination is markedly different from that which enters the top of the canopy. A more dense canopy would sharpen the curve around the maximum near 550 nm and a more sparse canopy would flatten it. Nevertheless, all reasonable proportions of transmitted, reflected, and unaltered daylight lead to similar results, namely, a 'greenish-yellow' light with a maximum, in the visible, near the peak of the photopic spectral sensitive function of the diurnal primate, including man.*

Corth (1984) further argues 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 concludes that heavy skin pigmentation was a matter of camouflage for survival more than it was a filter against ultraviolet light. As humans left the forest cover and moved into the more open country to the north (or south) and away from zones of intense ultraviolet 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 ultraviolet 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 light reaching the forest floor, people may find these lights to be very comfortable. Second, if skin pigmentation decreases as a response to an increased need for ultraviolet light, highly pigmented people living in northern climates may have greater needs for ultraviolet stimulation (or vitamin D supplements) than do lightly pigmented people.

For people, sunlight is by far the most important source of light and energy 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.

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 research that has been conducted provides a perspective for considering the human element in school facility design and construction. Consequently, the following discussions will center on natural light, incandescent light, fluorescent light, and other sources including mercury vapor, metal halide, and high pressure sodium vapor. It is also important to distinguish between discussions about lighting sources and discussions about well-designed lighting systems. As the latter is a well-documented science, it is not discussed here. Rather, attention is given to sources and qualities of different light types.

Danzig, Lazarev, and Sokolov, cited by Hughes (1981: 5), captured the essence of much research into the non-visual effects of light. They contend 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. They believe there will be a vitamin D deficiency followed by weakened body defenses and an aggravation of chronic diseases. Wurtman and Neer (1970) suggest 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. At about this same time (i.e., in the early '70s), 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: 122). Faber Birren has been quoted as saying that ultraviolet radiation intensifies the enzymatic processes of metabolisms, increases hormone system activity, and improves the tone of the central nervous and muscular systems (Faily, Bursor, & Musemeche, 1979: 16). More recently Downing (1988) argues:

> *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.*

There is wide consensus that sunlight nurtures most living things and some light-related processes are well understood. Photosynthesis (the ability of plants to use sunlight in manufacturing food), phototropism (the tendency of plants to grow towards light), and the effects of light on vision, are examples. The non-visual effects of light on people are not so well understood.

Since sunlight contains all colors in relatively uniform amounts (i.e., there are neither sharps peaks nor discontinuities in the spectral distribution), 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 and eyes are most sensitive to light in this range. Indeed, as Thorington (1985: 50-51) points out, 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 ultraviolet range. Since the eye is less sensitive to blue light than to green and yellow light, rooms lit with full spectrum fluorescent lights are often perceived as being 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 Bellchambers (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 say, "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 illumination [added by author].

Light-Related Studies

Aside from enabling vision, there are some interesting non-visual effects of light on animals and people; some of these effects are physiological and some may be psychological.

By 1919 researchers had reached the conclusion that sunlight was the key to the cure of rickets. It was later discovered that artificial light was also effective in curing rickets (Loomis, 1970: 77-91). Today it is accepted that ultraviolet radiation derived from sunlight in the region of 290-315 nm triggers the development of vitamin D in the skin (Neer, 1985: 15; Holick, 1985: 4) and vitamin D formed in the skin or regular doses of vitamin D taken orally can prevent or cure rickets. Other studies point to different effects of light on animals and people.

Zamkova and Krivitskaya (1966: 41-44) augmented regular fluorescent light with ultraviolet suntan lamps in a controlled experiment involving school children. They reported interesting findings. When compared to the control group, students who received exposure to ultraviolet 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: 109-111) studied the effects of ultraviolet supplements to general lighting in a factory. 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 could 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: 32-37) 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: 1218-1221) studied the effects of light from cool white lamps and full-spectrum Vita-Lite[1] 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: 1218-1221) reported that light from Vita-Lite (full-spectrum) lamps was significantly more effective in killing bacteria than light from standard cool-white lamps. They say:

> *In conclusion, it may be stated that Vita-Lite lamps used at intensities recommended for illumination produced significant killing of S. Aureus over protracted periods of exposure. High levels of such artificial daylight, including the small amount of UV normally present, could thus be of value in controlling air contamination with this and presumably other organisms where danger to personnel precludes the use of standard bactericidal lamps.*

Downing (1988: 84) offers evidence that small amounts of UV radiation destroys bacteria and moulds. At an irradiance level 10 $\mu W/cm^2$ 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 UV component of full spectrum lamps to have a germicidal effect, the greatest effect occurs in the UVC band—especially at 270±5 nanometers (Bickford, 1981: 19-14). Emissions at that wavelength are about 100 times more effective than emissions in the UVA band.

East (1939) reported 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: 1427-1431) 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) 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).

Neer and others (1971) described a study which involved elderly male residents at the Chelsea Massachusetts Soldiers' Home who were exposed to full-spectrum fluorescent lighting. These lights delivered about five percent of their total radiant energy in the ultraviolet range from 290 to 380 nm. The study's conclusion was that relatively small amounts of ultraviolet light can stimulate calcium absorption among elderly men who have no exposure to sunlight and who eat a diet containing little vitamin D. It is important to note that during the course of the study the experimental group was exposed to 500 foot-candles (5,500 lux) of illumination from Vita-Lites for eight hours a day while the control group was exposed to 30-50 foot-candles (330-540 lux) of illumination from cool-white lamps.

Bilirubin is formed by the breakdown of hemoglobin and is normally excreted after undergoing a chemical change in the liver. Many newborns suffer jaundice from a

1 Vita-Lite is the registered trademark of Duro-Test Corporation, North Bergen, New Jersey.

combination of two factors; an immature bilirubin oxidation capacity in the liver and/or a storm of bilirubin in the body subsequent to birth due to higher than normal red blood cell counts. In either case, the bilirubin excretion system is temporarily overburdened and bilirubin levels tend to rise. A rise in the level of bilirubin can lead to jaundice and if untreated, the excessive bilirubin can result in brain damage and permanent neurological impairment. Thorington, and others (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: 476) suggested that full-spectrum light is as effective as blue light. (Full spectrum light sources have significant energy concentrated in the blue range.) The benefit of 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.

Mass, Jayson and Kleiber (1974: 31) reported studies comparing the effects of full-spectrum and cool-white light on a group of students at Cornell University. The findings indicated 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.

Holick (1985: 1-13) and Neer (1985: 14-20) describe the processes whereby vitamin D is synthesized in the skin as a result of stimulation by ultraviolet light in the 290-315 nanometer range (i.e., UVB). Davies (1985: 21-27) discusses 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, Wurtman (1975:474) and Neer (1985: 14) question whether or not dietary sources of vitamin D are biologically as effective as the vitamin D formed in the skin as a result of ultraviolet light stimulation.

Painter (1976: 181-184) described a small-scale study that compared the effects of incandescent and fluorescent lighting. When a class of nine children, who were variously described as autistic or emotionally disturbed, was exposed to incandescent lighting, the hyperactive behavior of the class decreased. When standard fluorescent lights were replaced, hyperactive behavior returned to normal levels.

A study by Ozaki and Wurtman (1979: 339-341) presents evidence to the effect that exposure of developing rats to high pressure sodium vapor (HPSV) lights caused characteristic changes in growth and development. They say:

> *Exposure of rats to the highly unnatural spectrum emitted by HPSV bulbs causes significant changes in growth and development, as indicated by increased body weights at days 26-28 for males and day 48 for females, and increased weight of the adrenal gland. The latter change might be a manifestation of a stress response to the light spectrum; if so, the decreased splenic weight sometimes associated with it is to be expected.*

Bickford (1981: 19.13) reported that repeated treatments with a combination of psoralen and UVA (320 to 400 nm) was effective in controlling psoriasis.

Davies (1985: 26) undertook a study into the effects of ultraviolet 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.*

Wurtman (1985: *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 whole range of light's actions on mammals (see Table 2.1).

Alberta's Light/Color Study (1981-1985)

A project designed to test a number of variables identified in the literature was conducted under the auspices of Alberta Education between 1981 and 1985 (Wohlfarth, 1986). The study explored how classroom settings affect the well-being and performance of elementary school children and provides information that can be used to enhance the physical conditions in which teaching and learning take place. The study: (a) examined the effects of lighting, selected colors, and color/light combinations on students' achievement, attitudes towards school subjects, misbehaviors, absences due to illness, refractive eye problems, blood pressure, and mood variations; (b) determined changes in the off-task behaviors of Grade 5 students caused by eliminating the electromagnetic (and possibly) stray ionizing radiation associated with fluorescent lighting; (c) measured the effects of color/light combinations on the levels of noise in libraries; (d) assessed the effect of supplemental ultraviolet light on the incidence of dental caries and absences due to illness of Grade 5 students; and (e) provided suggestions on cost effective changes which can be made to classroom settings for the benefit of teachers and students.

Seven hundred students in Grades 1 to 6 from four elementary schools participated in the study. The control school used cool-white fluorescent lighting and traditional school colors such as dark brown, grey, off-white, putty, and bright orange accents. The color school followed a psychodynamic color scheme and used a soft yellow (stimulating) on the walls within the students' vision field—front and side walls of the classrooms—and a soft blue (relaxing) on the walls in the teachers' vision field—rear walls of the classrooms. Accents were bold yellow and blue. Chalkboards and desks were also blue. The color/light school used the psychodynamic color scheme and Vita-Lite fluorescent lamps distributed by Duro-Test Canada Inc. The light school used the Vita-Lites and traditional colors. The Grade 5 classes in the light-only school and the color/light school were exposed to ultraviolet supplements averaging about 8 $\mu W/cm^2$ (7 mW/ft^2). To obtain sufficient UV output from the fixtures, aluminum reflectors were placed in the fixtures and the UV absorbing Plexiglass lenses were replaced with aluminum grid diffusers (approximately one centimeter grid). The aluminum reflectors were necessary because the original enamel fixtures have very low reflectance in the UV range of the spectrum. Bickford (1981: 19-17) reports on the reflectance of various materials (see Table 2.2). The Control Group was under fluorescent illumination emanating from white enamel fixtures with Plexiglass lenses. Ultraviolet radiation from the fixtures was negligible.

During the 1981-82 school year standardized tests were administered at various grade levels in all four schools to pretest student ability and achievement. Post-testing was completed after the students had progressed a grade and had been exposed to the effects of

Table 2.1. Biologic and medical effects of light (from Wurtman, 1985: *x*).

	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

Table 2.2. Reflectance of various materials for energy of wavelengths in the region of 253.7 nanometers (from Bickford, 1981: 19-17).

Material	Reflectance (percent)
Aluminum	
Untreated surface	40-60
Treated surface	60-89
Sputtered on glass	75-85
Paints	55-75
Stainless steel	25-30
Tin plate	25-30
Magnesium oxide	75-88
Calcium carbonate	70-80
New plaster	55-60
White baked enamels	5-10
White oil paints	5-10
White water paints	10-35
Zinc oxide paints	4-5

light, color, and color/light combinations for ten months. Students in the dental study were assessed over a two-year period (to June 1983). Analysis of Covariance and Repeated Measures Analysis of Variance were used to adjust averages and to determine significant differences.

Public health nurses tested students' vision twice during the project year and took blood pressure readings two days per month (both mornings and afternoons) from a sample of ten students from each of grades 2, 4, 5 and 6.

During the study period, student behavior requiring disciplinary actions and absences due to illness were recorded by school staff. Preadolescent Mood Scales were used to assess students from Grades 1 through 6. The School Subjects Attitudes Scales were administered to students in Grades 5 and 6.

Findings

Major findings of the study included:

1. Grade 5 students exposed to supplemental ultraviolet light developed fewer dental caries (Hargreaves & Thompson, 1989: 389-392), and had fewer days of absence from school, than students in the Control Group. The researchers found that the Control Group had 1.05 more decayed, missing and filled teeth than the Treatment Group receiving supplemental ultraviolet light. By using an alternate measure, the researchers found that Control Group had 1.58 more decayed, missing and filled surfaces than the Treatment Group. They also found what appears to be healing of some Type 1 caries (i.e., minimal enamel defect) under supplemental ultraviolet light. They measured a decline in the number of Type 1 caries in the Treatment Group while over the same period noting an increase in the incidence of Type 1 caries in the Control Group.

   With respect to absences from school, the researchers found the average absences during one school year to be 6.9 for the Treatment Group and 16.39 for the Control Group. The difference represents almost ten extra days of schooling for the Treatment Group in comparison to the Control Group.

2. There were significantly lower levels of noise in the color/light school library than in the control school library. (These two schools had identical floor plans and approximately the same number and ages of students.)

3. Warm colors induced slight but significant elevations in students' blood pressure. This finding is supported by Sydoriak's (1984) study wherein she found a small but significant drop in both systolic and diastolic blood pressures among students in blue rooms.

4. Full-spectrum lighting induced significantly more positive moods in students than did the conventional cool-white lighting.

5. Light, color, and color/light combinations had no significant effects on student mental abilities and achievement levels; attitudes towards subjects; misbehaviors warranting disciplinary actions; absences due to illness; and refractive eye problems.

6. Ingraham (1983) examined for effects of electromagnetic radiation and suspected soft X-rays on children. For a heterogeneous class of students, he observed that the elimination of suspected soft X-rays and electromagnetic radiation (through

appropriate shielding) had a measurable effect on behavior. He found that under shielded lights the students engaged in significantly fewer off-task behaviors.

Summary

Research points to a number of non-visual effects of light on people. Of these effects the suntan effect and the control of rickets are two that are quite well understood. Other important (but perhaps less well known) effects include: seasonal affective disorder (SAD), synchronization of a number of physiological rhythms, and the control of infantile jaundice. Though artificial lighting systems provide illumination equivalent to on'y one or two percent of the intensity of daylight, research also suggests that variations in the quality of artificial light in classrooms can have an effect on students.

The photobiologic action spectra of greatest importance to humans ranges from 290 to 770 nm. Skin reddening and vitamin D synthesis occurs in the range of 290 to 315 nm. Tanning or pigmentation of the skin and reduction of dental caries occurs in response to light in the band from 280 to 400 nm. Vision is most sensitive to light in the 500 to 650 nm range (yellow-green light). Bilirubin degradation occurs in response to light in the 400 to 500 nm range (blue light). Natural light provides the spectral energy distribution necessary for all of these biological functions. Full-spectrum fluorescent illumination also provides substantially all of the spectral energy distribution although light levels are much lower than daylight levels. The spectra of incandescent, cool-white fluorescent, and high pressure sodium vapor light sources appear to fall short of covering the entire photobiologic action spectra of importance to human beings.

For people who are outdoors for a significant part of each day, the quality of indoor lighting to which they are exposed may be of little consequence. Their needs for natural light stimulation may be adequately met.

But for people who spend almost all of their time indoors, and with outdoor exposure limited to morning and evening light, there may be a need for artificial lighting that is supplemented with light stimulation in the spectrum areas of energy deficiency—especially blue (440 to 440 nm) and ultraviolet in the 290 to 400 nm range (UVA and UVB).

Building on this background of research, a classroom-based study conducted in Alberta from 1981 to 1985 identified what appears to be the very significant finding that elementary students receiving trace amounts of ultraviolet light developed fewer dental caries than those students of a similar age and background that did not receive ultraviolet light exposure. The research reported in the literature also suggests that exposure to different lighting systems may lead to differences in the way children develop—light may also have an effect on the overall growth and development of children.

Chapter 3

Study Design

The current study was designed around a pretest-posttest, multiple-group model and intended to prove that:

> Different light types (full spectrum fluorescent, full spectrum fluorescent with UV enhancement, cool-white fluorescent, and high pressure sodium vapor) have no differential effects on Division II students' dental histories, growth and development histories, vision histories, scholastic achievement histories, or attendance histories when compared over a two-year period.

Study Sites

Five study sites were selected and included:

- Site 1 (high pressure sodium vapor lighting): a school lit with indirect high pressure sodium vapor (HPSV) lamps. High pressure sodium vapor lamps mounted in indirect fixtures were used throughout the classrooms in this school. Natural light from windows modified the color characteristics of these lamps somewhat.

- Site 2 (full spectrum fluorescent lighting without UV enhancement): 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.

- Sites 3 and 5 (full spectrum fluorescent lighting with UV enhancement): two schools lit with full spectrum fluorescent lamps with UV enhancement and mounted in fixtures that contained aluminum reflectors and aluminum grid diffusers or open egg-crate diffusers. 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: 19-17). 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. Wrap-around Plexiglass lenses in some fixtures were removed because suitable 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 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 ultraviolet radiation in the mid and near UV range (280 - 400 nm). Second, these lamps are the same as those used in the first study 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).

- Site 4 (cool-white fluorescent lighting): 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.

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 it's schools to be involved and further to permit the modification of the lighting systems in two of it's 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.

Table 3.1 serves to summarize the illumination and UV levels at each site.

A preliminary comparison of all classroom UV levels measured to date indicates the following:

1. Aluminized reflectors enhance ambient UV emission levels from four to six times over conventional white-painted fixtures. (A comparison of the UV reflective characteristics of a number of surfaces is presented in Table 2.2.)

2. Fixtures without lenses or diffusers create significant UV "hot-spots" which are about 1.3 times greater than average ambient levels.

3. 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 that of cool-white fluorescent lamps.

4. The aluminum grid diffusers create the most uniform UV levels throughout the classroom.

5. High pressure sodium vapor lighting systems emit insignificant quantities of UV.

Study Population

The study included all of the Grade 4 students enrolled in each of the schools at the end of the 1986-87 school year. 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 first study completed in Alberta from 1981 to 1985 which looked at the effects of light on development of dental caries. 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 the study. Third, students at this age are on the brink of, or already undergoing, significant physiological 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 (40 - 50 students), at least 20 students would remain in each group to the conclusion of the study.

Table 3.1. Measured light in classrooms. (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.)

Site (Light Type)	**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*
Site 1 High Pressure Sodium Vapor Lamps	**0.21** Ave (0.19, 0.23)	**0.00** Ave (0.0, 0.0)	**0.00**	**250-540**
Site 2 Full Spectrum Fluorescent (UV inhibited)	**1.01** Ave (1.54, 0.48)	**0.00** Ave (0.0, 0.0)	**0.00**	**300-900**
Site 3 Full Spectrum Fluorescent (UV enhanced)	**7.20** Single measure	**0.30** Single measure	**0.00**	**280-450**
Site 4 Cool-white Fluorescent	**0.87** Ave (0.60, 1.15)	**0.07** Ave (0.0, 0.13)	**0.00**	**250-540**
Site 5 Full Spectrum Fluorescent (UV enhanced)	**5.18** Ave (3.52, 5.63, 6.40)	**0.18** Ave (0.11, 0.19, 0.24)	**0.00**	**220-450**

* 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.

Ultraviolet (UV) Safety Limits

UV radiation safety limits for an eight (8) hour period are as follows: (Phillips, 1983:4):

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

Measuring Equipment

1. UVX-36 broadband ultraviolet meter manufactured by Ultraviolet Products Ltd. This meter 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).

2. IL-791 Spectroradiometer System manufactured by International Light. This NBS traceable calibrated system was used to conduct narrow-band (5 nm bandwidth) measurements of ultraviolet wave band from 200 to 400 nanometers. 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.

3. Model 40X Optometer manufactureed by United Detector Technology Inc. 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.

Data Collection

A number of different kinds of data were collected from the students including:

- age,
- sex,
- nutrition histories,
- fluorine levels,
- dental histories,
- attendance histories,
- general health and growth and development histories,
- scholastic achievement histories,
- skin types, and
- vision histories.

Controlling for Bias and 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. Nevertheless, several things were done to reduce the risk of contaminating variables in the study.

1. The lighting systems were changed during July and August so that they were in place when children returned to school in September, 1987.

2. 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.

3. 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 information collected by teachers during the two years of the study was earmarked for study purposes.

4. 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 socio-economic and cultural data. It was believed that differences in total daily caloric intake or differences in protein and sugar intake could point to socio-economic and cultural differences in the groups.

5. 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.

6. Statistical routines designed to overcome the inability to randomly assign subjects to study groups were used in some of the data analyses.

Dental Histories

Procedures developed during the 1981 to 1985 study (Hargreaves & Thompson, 1989) were used in this study and were carried out by the same researchers involved in the earlier study. The procedures used in that first study (and repeated in this study) are as follows.

> *The diagnostic standards were based on criteria similar to previous surveys undertaken by the authors [Hargreaves and Chester, 1973]. Portable dental chairs were used, and illumination was achieved by Anglepoise lamps with 100 watt bulbs and natural daylight, by placing the dental chair in well-lit conditions. Disposable mirrors and replaceable sickle-shaped probes were used. Examinations were carried out at the respective schools without precleaning the teeth: however, the teeth were air-dried with a chip syringe before examination. Caries were assessed as previously described by the authors [Hargreaves and Chester, 1973] which fulfilled WHO standards [1977]. Teeth and tooth surfaces were recorded to complete DEFT and DEMS scores. The caries experience in the primary dentition was not measured because of the subjects' age, most primary teeth having exfoliated. Degrees of caries were assessed based on a modification of the criteria by Møller [1966]; 'sound': no clinically detectable defect detected in the tooth surface; 'caries 1': minimal enamel defect, detected by a 'catch' with a sickle probe or a decalcification without enamel penetration; 'caries 2': marked involvement of enamel and/or dentine with detection by a 'sticking' sickle probe or obvious tooth loss from caries; 'caries 3': severe tooth loss from caries with probable pulpal death. A tooth was considered erupted if any part of the crown was observed in the mouth [Hargreaves, 1958]. No radiographs were used in order to avoid excessive use or duplication of radiographs with this age group. Oral hygiene was assessed by the modified debris index of Löe and Silness [1964]...Inter- and intra-examiner reliability was maintained at a level of Kappa 0.8 [Cleaton-Jones, et al., in press].*

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.

Caries 3 — severe tooth loss from caries with probable pulpal death.

General Health and Growth and Development Histories

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),
- vision,
- skin types, and
- other health data.

Vision Histories

Vision histories included:

- uncorrected distance vision (left eye, right eye, both eyes together) which was measured by means of a standard 20-Foot Snellen Chart based on a visual angle of one minute (supplied by Avenue Medical Supply Ltd.) and illuminated to normal classroom lighting levels, and

- use of glasses.

The Snellen Chart was calibrated from 20/200 (poorest vision) to 20/10 (best vision). The denominator in the ratio was recorded and included in the data analysis. Based on Helveston, et al (1985: 346-355), normal distance vision was taken to be 20/30 or better and abnormal vision taken to be 20/40 or worse.

Attendance Histories

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.

Scholastic Achievement Histories

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.

Nutrition Histories

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.

Skin Types

With the notion in mind that skin pigmentation may lead to differential effects of ultraviolet light on students, student skin types were noted and recorded. The classification of skin types was based on a system reported by Pathak (1985: 328) and includes the following six types:

Skin type I. These individuals have very fair skin, red or blond hair, blue eyes, and are often freckled. They burn easily, develop painful sunburn, often peel, and do not tan. They are most often of Celtic background (e.g., Irish, Scottish, Welsh).

Skin type II. These individuals have fair skin, blue or hazel eyes, red or blond hair, and are often freckled. They do not tan well, but upon repeated exposures, "harden" their skin and acquire a slight tan. The freckled skin becomes darker, and the non-freckled skin remains red.

Skin type III. These individuals have a light tan or medium color skin with blond, brunette, or light pigmented hair. They burn moderately, then tan moderately and uniformly. They acquire an average or good delayed tanning reaction with two or three exposures and do not burn intensely on subsequent sun exposures.

Skin type IV. These individuals are lightly tanned and can tolerate the sun a little better than skin types I and II. Unexposed skin is light brown or olive. Eyes and hair are most likely to be dark. The group includes pigmented Caucasoids, Red Indians, Chinese, Japanese, and people from the Mediterranean (Italians, Greeks, Spaniards). In the summer the facial skin color changes from light brown to olive or medium brown.

Skin type V. These are brown-skinned people who can tolerate the sun quite well. The eyes and hair are deep brown or black. This group included Mexicans, East Indians, Egyptians, Malaysians, Puerto Ricans, and other Spanish-speaking people.

Skin type VI. These are markedly pigmented individuals. The skin is brown to black in color. These individuals generally never burn, but become profusely dark skinned after exposure to the sun. This group includes African and American Blacks and Australian Aborigines.

Data Processing

The collected data were translated into electronic form, checked for accuracy, and transferred to the computer at the University of Alberta. Data summary and statistical analyses were performed under the direction of Dr. Gordon Thompson, Faculty of Dentistry, University of Alberta. Analysis of attendance, achievement and health-related data were completed by researchers within Alberta Education.

Chapter 4

Study Findings

This current study was designed as a replication of a study carried out from 1981 to 1985 wherein it was found that trace amounts of ultraviolet light in classrooms were linked to: (a) reductions in the development of dental caries, and (b) improved attendance. Inasmuch as findings from other research projects seemed to point to the conclusion that different lighting systems may have differential effects on people, a number of different kinds of data were collected from the students in this study, including:

- age,
- sex,
- nutrition histories,
- fluorine levels,
- dental histories,
- attendance histories,
- general health and growth and development histories,
- scholastic achievement histories,
- skin types, and
- vision histories.

For the most part the data sets that were collected were intended for use in interpreting the findings of the dental and attendance components of the study. Accordingly, the dental and attendance components of the study will be reported and discussed first and then followed by the remaining data sets.

A Description of the Study Population

The students involved in this study 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.

Age

The average age of all of the students involved in the study was 12.02 years as of June 30, 1989. Table 4.1 describes the range of ages of the students at the five study sites. No significant age differences were found among the study populations.

Sex

The composition, by sex, of the study group is described in Table 4.2.

Nutrition

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.

Nutrition histories were collected by means of a *Three-Day Personal Daily Menu Diary*. Site specific data with respect to daily calorie, protein and sugar intake are presented in

Table 4.1. A two-tailed *t* test comparison of the age of study participants as of June 30, 1989. Levels of significance beyond the 0.05 level are in bold faced italics.

Site	Mean	St Dev	N	Site 1 11.97 0.23 38	Site 2 12.04 0.52 35	Site 3 12.02 0.36 44	Site 4 11.98 0.27 43	Site 5 12.06 0.36 56
Site 1 (HPSV)	11.97	0.23	38	—	0.723	0.750	0.178	1.463
Site 2 (FS)	12.04	0.52	35		—	0.191	0.610	0.197
Site 3 (FS + UV)	12.02	0.36	44			—	0.580	0.546
Site 4 (CW)	11.98	0.27	43				—	1.251
Site 5 (FS + UV)	12.06	0.36	56					—

Table 4.2. Sex of study participants.

Site	Total	Number of Males	Percent of Total	Number of Females	Percent of Total
Site 1 (HPSV)	41	24	0.585	17	0.415
Site 2 (FS)	37	22	0.595	15	0.405
Sites 3 and 5 (FS + UV)	147	74	0.503	73	0.497
Site 4 (CW)	58	28	0.483	30	0.517
Total	283	148	0.523	135	0.477

Table 4.3. Table 4.4 reports data for the 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 group and the non-UV group.

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

Fluorine Levels

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 1.1 parts per million of fluorine.

Study Findings

The purpose of this study was to test the null hypothesis that light does not have non-visual effects on students in classrooms with different lighting environments. This section serves to test the null hypothesis in a number of ways.

Dental Effects

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). These results are presented in Table 4.5. Table 4.6 summarizes the findings by comparing the sites receiving ultraviolet supplements with the sites that did not receive the UV supplements.

Students at Site 4 (lamped with cool white fluorescent lamps) were dropped from 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.

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 Treatment Group. When students receiving fissure sealants are excluded from the analysis, the Control Group had an average of 0.79 decayed teeth (or 1.36 decayed surfaces) more than the 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 ultraviolet radiation are apparently not influenced by diet based on macro-nutrient

Table 4.3. A two-tailed *t* test comparison of daily nutrition levels—calorie, protein, and sugar intake. Levels of significance beyond the 0.05 level are in bold faced italics.

Daily Calorie Intake

Site	Mean	St Dev	N	Site 1 1772.0 658.3 19	Site 2 1697.4 527.8 28	Site 3 1642.6 450.1 37	Site 4 1577.3 406.8 36	Site 5 1736.2 497.1 37
Site 1	1772.0	658.3	19	—	0.402	0.751	1.147	0.204
Site 2	1697.4	527.8	28		—	0.434	0.979	0.296
Site 3	1642.6	450.1	37			—	0.642	0.837
Site 4	1577.3	406.8	36				—	1.475
Site 5	1736.2	497.1	37					—

Daily Protein Intake in Grams

Site	Mean	St Dev	N	Site 1 59.4 24.6 19	Site 2 67.4 24.4 28	Site 3 61.7 18.0 37	Site 4 60.7 17.0 36	Site 5 63.4 21.5 37
Site 1	59.4	24.6	19	—	1.071	0.343	0.189	0.586
Site 2	67.4	24.4	28		—	1.031	1.228	0.677
Site 3	61.7	18.0	37			—	0.245	0.375
Site 4	60.7	17.0	36				—	0.603
Site 5	63.4	21.5	37					—

Daily Sugar Intake in Grams

Site	Mean	St Dev	N	Site 1 107.2 51.0 19	Site 2 102.9 39.9 28	Site 3 101.3 50.9 37	Site 4 102.9 41.6 36	Site 5 106.6 36.5 37
Site 1	107.2	51.0	19	—	0.302	0.404	0.312	0.045
Site 2	102.9	39.9	28		—	0.142	0.004	0.378
Site 3	101.3	50.9	37			—	0.144	0.511
Site 4	102.9	41.6	36				—	0.403
Site 5	106.6	36.5	37					—

Table 4.4. A two-tailed *t* test comparison of daily nutrition levels—calorie, protein, and sugar intake—for UV enhanced sites and non-UV enhanced sites. Levels of significance beyond the 0.05 level are in bold faced italics.

Daily Calorie Intake

Site	Mean	St Dev	N	Non-UV Sites 1662.4 513.7 83
UV Supplement Sites	1689.4	473.3	74	0.341

Daily Protein Intake in Grams

Site	Mean	St Dev	N	Non-UV Sites 62.7 21.6 83
UV Supplement Sites	62.6	19.7	74	0.030

Daily Sugar Intake in Grams

Site	Mean	St Dev	N	Non-UV Sites 103.9 42.8 83
UV Supplement Sites	104.0	44.1	74	0.010

Table 4.5. Effects of supplemental ultraviolet light in classrooms on the development of dental caries in elementary students in Grades 4, 5 and 6.

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*	DEFS*	DEFT	DEFS
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 (UV released)	0.42	0.40	0.22	0.14
Site 5 Full Spectrum Fluorescent (UV released)	0.21	0.34	0.19	0.19

* DEFT means decayed, extracted, or filled *teeth*. DEFS means decayed, extracted, or filled *surfaces*.

Students at Site 4 (Cool white lamps without UV) were eliminated from the data analysis when it was discovered that a high percentage of these students had received applications of fissure sealants during the study period.

Table 4.6. **Summarized effects of supplemental ultraviolet light in classrooms on the development of dental caries in elementary students in Grades 4, 5 and 6.**

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*	DEFS*	DEFT	DEFS
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
Differences (fewer cavities)	0.59	0.95	0.79	1.36

* DEFT means decayed, extracted, or filled *teeth*. DEFS means decayed, extracted, or filled *surfaces*.

Site 4 (Cool white lamps without UV) was eliminated from the data analysis when it was discovered that a high percentage of the students had received applications of fissure sealants during the study period.

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.

These findings support the view that the ultraviolet light component of the classroom lighting systems may best explain the differences in caries increments found among students at different sites.

> *Conclusion. On the basis of an analysis of dental records for the children located in the different lighting environments examined in this study, the null hypothesis was rejected—light does have an effect on the development of dental caries.*

Attendance Effects

To develop attendance histories, monthly attendance was recorded for each student in half-day increments and then divided by the maximum number of days the schools were open in order to derive the percentage of attendance. The findings are presented in Table 4.7.

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. One might conclude that an absence of 3.2 days is about the length of time that it would take to recover from a severe cold.

> *Conclusion. On the basis of an analysis of attendance records for the children located in the different lighting environments examined in this study, the null hypothesis was rejected—light does have an effect on attendance rates.*

General Health and Growth and Development Effects

A number of pieces of information pertaining to the general health and to the growth and development of the students in the study groups were collected by a Registered Nurse with the expectation that these data may be of use in interpreting findings with respect to effects of light on students. An analysis of the information provides the following findings.

Age at onset of 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 4.8 presents the data collected in this study. When compared to the study of 1829 girls, 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 occurred in schools lit by Vita-Lite full spectrum lamps and the lower incidence was in the school lit by high pressure sodium vapor lamps.

Table 4.7. A two-tailed *t* test comparison of rates of attendance (attendance rates represent the actual attendance divided by possible days for the period September 1987 to June 1989). Levels of significance beyond the 0.05 level are in bold faced italics.

Site	Mean	St Dev	N	Site 1 0.943 0.051 67	Site 2 0.962 0.016 36	Sites 3/5 0.959 0.038 136	Site 4 0.959 0.040 56
Site 1 (HPSV)	0.943	0.051	67	—	***2.780***	***2.260***	1.933
Site 2 (FS)	0.962	0.016	36		—	0.707	0.497
Sites 3 and 5 (FS + UV)	0.959	0.038	136			—	0.000
Site 4 (CW)	0.959	0.040	56				—

Table 4.8. Incidence of girls reaching the onset of menarche. Statistically significant differences beyond the 0.05 level, as determined by means of Chi Square tests, are shown in bold faced italics.

Site	Total Number of Girls	Number Reaching Menarche	Average Age at Onset of Menarche	Predicted Probability*	Actual Percent Reaching Menarche
Site 1 (HPSV)	17	2	11.763	0.218	***0.118***
Site 2 (FS)	15	7	11.729	0.210	***0.467***
Sites 3 and 5 (FS + UV)	73	12	11.069	0.095	***0.164***
Site 4 (CW)	30	3	11.238	0.118	0.100
Totals	135	24	11.340	0.135	0.178

* Probability based on a study of 1,829 girls reported by the Edmonton Board of Health.

Height Gains

One measure of general health which was collected at the study sites was gains in height (measured in centimeters). This information is displayed in Table 4.9.

The smallest gains in height were made at Site 1 (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).

Weight Gains

Weight gains were recorded for students at all sites with the weight gains measured in kilograms. These data are summarized in Table 4.10.

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.

Body Fat Gains

Body fat was measured with a Lange Skinfold Caliper calibrated in millimeters. Changes in body fat were calculated by subtracting the pre-test results from the post-test results.

Increases in body fat during the period of the study were lowest at Site 4 and highest at Site 2. Differences that are statistically different beyond the 0.05 level are displayed in Table 4.11.

> *Conclusion. On the basis of an analysis of health and general development records for the children located in the different lighting environments examined in this study, the null hypothesis was rejected—light does have an effect on health and general development. Specifically, significant differences were found to include; age at the onset of menarche, height gains, weight gains, and gains in body fat.*

Scholastic Achievement Effects

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.

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: 347-348) 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, 288) 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 pretest scores.

Table 4.9. A two-tailed *t* test comparison of height gains measured in centimeters between June 1987 and June 1989. Levels of significance beyond the 0.05 level are in bold faced italics.

Site	Mean	St Dev	N	Site 1 10.2 3.6 29	Site 2 12.0 3.9 34	Sites 3/5 12.3 2.9 110	Site 4 11.9 2.7 46
Site 1 (HPSV)	10.2	3.6	29	—	1.873	***2.827***	***2.151***
Site 2 (FS)	12.0	3.9	34		—	0.378	0.127
Sites 3 and 5 (FS + UV)	12.3	2.9	110			—	0.772
Site 4 (CW)	11.9	2.7	46				—

Table 4.10. A two-tailed *t* test comparison of weight gains measured in kilograms between June 1987 and June 1989. Levels of significance beyond the 0.05 level are in bold faced italics.

Site	Mean	St Dev	N	Site 1 10.2 4.5 29	Site 2 10.9 5.3 34	Sites 3/5 11.2 4.9 42	Site 4 9.6 3.5 47
Site 1 (HPSV)	10.2	4.5	29	—	0.558	1.063	0.603
Site 2 (FS)	10.9	5.3	34		—	-0.323	1.230
Sites 3 and 5 (FS + UV)	11.2	4.9	110			—	***2.335***
Site 4 (CW)	9.6	3.5	47				—

Table 4.11. A two-tailed *t* test comparison of gains in body fat measured in millimeters between June 1987 and June 1989. Levels of significance beyond the 0.05 level are in bold faced italics.

Site	Mean	St Dev	N	Site 1 3.4 5.9 29	Site 2 7.6 6.2 33	Sites 3/5 3.9 6.1 110	Site 4 0.4 4.8 46
Site 1 (HPSV)	3.4	5.9	29	—	***2.686***	0.398	***2.264***
Site 2 (FS)	7.6	6.2	33		—	***2.984***	***5.501***
Sites 3 and 5 (FS + UV)	3.9	6.1	110			—	***3.801***
Site 4 (CW)	0.4	4.8	46				—

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 in total achievement gains ($p=0.000$, $F=11.423$) and in gains in language ($p=0.003$, $F=4.877$), work study ($p=0.040$, $F=2.826$), and mathematics ($p=0.001$, $F=5.912$) between the four groups formed on the basis of classroom lighting (i.e., high pressure sodium vapor, full spectrum fluorescent, full spectrum fluorescent with UV supplements, and cool-white fluorescent).

Site specific data with respect to total gains on the *Canadian Test of Basic Skills* are summarized in Table 4.12. 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.

> *Conclusion. On the basis of an analysis of achievement records for the children located in the different lighting environments examined in this study, the null hypothesis was rejected—light does have an effect on rates of achievement.*

Skin Type Effects

Corth (1984) suggested that skin pigmentation may influence the extent to which ultraviolet light is absorbed by the skin. Skin types were recorded so that any relationships between skin pigmentation and development of dental caries could be explored at those sites receiving UV supplements. The results which were non-significant are reported in Table 4.13.

> *Conclusion. On the basis of an analysis of skin types for the children located in the different lighting environments examined in this study, tit was concluded that skin type does not modify the light effect on the development of dental caries.*

Vision Effects

Vision histories included data with respect to:

- uncorrected distance vision (left eye, right eye, both eyes together) was measured by means of a standard 20-foot Snellen chart based on a visual angle of one minute and illuminated to normal classroom lighting levels, and
- use of glasses.

Based on Helveston, et al (1985: 346-355), normal distance vision was taken to be 20/30 or better and abnormal vision taken to be 20/40 or worse.

Baseline data collected with respect to uncorrected distance vision at the beginning and end of the study are displayed in Table 4.14. Though no statistically significant changes in uncorrected distance vision were detected, some interesting patterns may be seen in Figure 4.1.

The changes in uncorrected distance vision at Site 2 (from 20/37 to 20/38.7) and Site 4 (from 20/47.3 to 20/48.9) parallel each other. Changes at both Site 1 (from 20/39.1 to 20/44.7) and Sites 3 and 5 (from 20/39.6 to 20/51.1) appear to be taking place at faster rate than at Sites 2 and 4. There is no easy explanation for the more pronounced changes at Site 1. At Sites 3 and 5, however, the more pronounced changes may be linked to the nature of the fixtures which contained the full spectrum lamps.

Table 4.12. A two-tailed *t* test comparison of total achievement gains (combined subscores on *Canadian Test of Basic Skills*) measured in grades between June 1987 and June 1989. Levels of significance beyond the 0.05 level are in bold faced italics

Site	Mean	St Dev	N	Site 1 1.61 0.70 43	Site 2 2.25 0.37 34	Sites 3/5 1.96 0.45 109	Site 4 1.88 0.4 34
Site 1 (HPSV)	1.61	0.70	43	—	***5.089***	***3.008***	***2.101***
Site 2 (FS)	2.25	0.37	34		—	***3.737***	***3.901***
Sites 3 and 5 (FS + UV)	1.96	0.45	109			—	0.976
Site 4 (CW)	1.88	0.40	34				—

Table 4.13. A two-tailed *t* test comparison of skin types in relation to the incidence of dental caries. Levels of significance beyond the 0.05 level are in bold faced italics.

Incremental Decayed, Filled Teeth (DEFT)

Skin Type	Mean	St Dev	N	Skin Type 1	Skin Type 2	Skin Type 3	Skin Type 4
				0.60	0.29	0.18	0.57
				1.17	0.61	1.04	1.36
				10	14	38	21
Type 1	0.60	1.17	10	—	0.729	0.986	0.061
Type 2	0.29	0.61	14		—	0.457	0.805
Type 3	0.18	1.04	38			—	1.118
Type 4	0.57	1.36	21				—

Incremental Decayed, Filled Surfaces (DEFS)

Skin Type	Mean	St Dev	N	Skin Type 1	Skin Type 2	Skin Type 3	Skin Type 4
				[illegible]	0.43	0.08	0.52
				2.56	1.34	1.55	1.78
				10	14	38	21
Type 1	1.10	2.56	10	—	0.720	1.145	0.616
Type 2	0.43	1.34	14		—	0.777	0.165
Type 3	0.08	1.55	38			—	0.931
Type 4	0.52	1.78	21				—

Table 4.14. A two-tailed *t* test comparison of pretest vs posttest changes in uncorrected distance vision—both eyes together. Levels of significance beyond the 0.05 level are in bold faced italics.

	Pre-Test			Post-Test			
Site	**Mean**	**St Dev**	**N**	**Mean**	**St Dev**	**N**	***t* Value**
Site 1	39.1	40.4	41	44.7	47.9	29	0.505
Site 2	37.0	42.6	37	38.7	44.7	34	0.161
Sites 3 and 5	39.6	46.2	147	51.1	63.1	111	1.613
Site 4	47.3	58.7	58	48.9	60.5	47	0.135

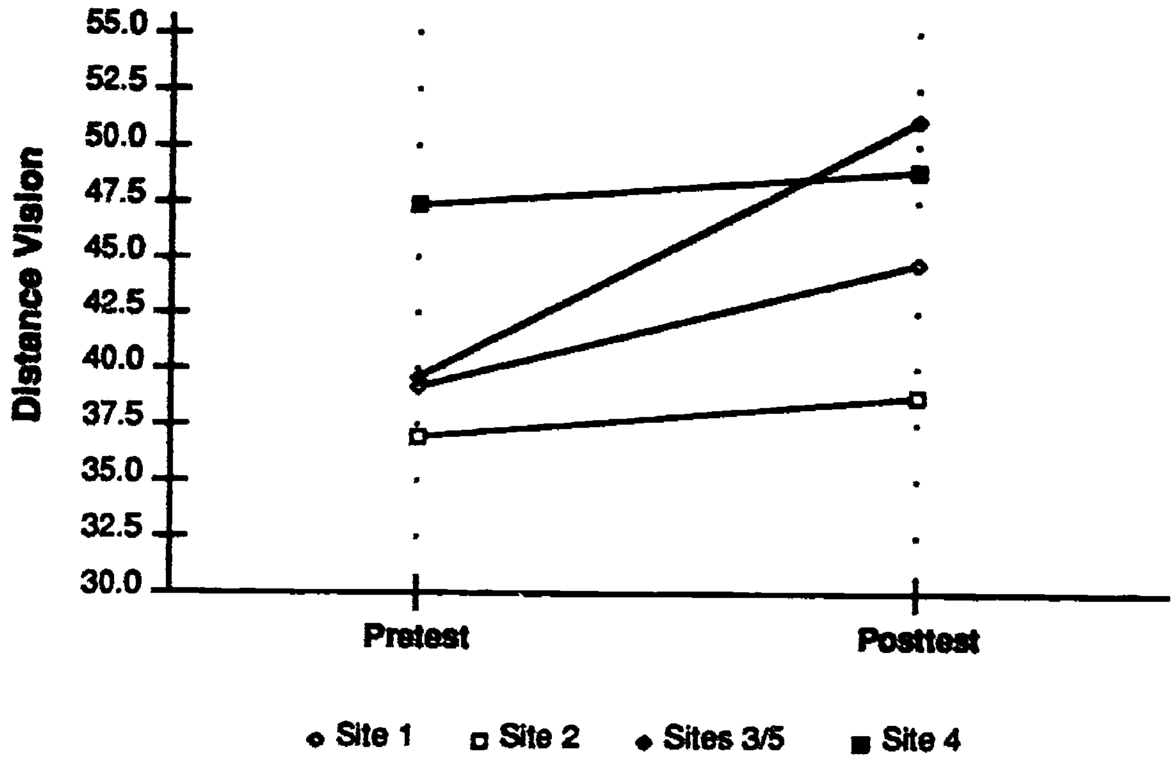

Figure 4.1. Changes in distance vision (both eyes) as measured by a standard 20-Foot Snellen Eye Chart. Normal vision is taken to be 20/30 or better and abnormal vision taken to be 20/40 or worse (Helveson, et al, 1985: 346-355).

In order to maximize the UV output from lamps at these two sites two things were done. First, polished reflectors were placed behind the lamps. Second, where they were obtainable, special aluminum grid diffusers were used to replace the Plexiglass lenses. One school has older fixtures with egg-crate diffusers and these were not changed. At the second school, many of the fixtures were of the surface mounted type with wrap-round Plexiglass lenses. Because replacements could not be found, these lamps were left without lenses or diffusers. Moreover, the ceilings were lower than in the other schools. The result in both schools was that the combined effect of reflectors and unshielded bulbs (i.e., no lenses or diffusers) produced a very high contrast in the room. This may have resulted in students experiencing some degree of eye strain.

Table 4.15 records the percentage of students never wearing glasses. Here it may be noted that the greatest increase in the regular use of glasses by students occurred at Site 1—from 75.6 percent of students never wearing glasses at the beginning of the study to 65.5 percent at the end of the study. Blackwell (1985: 340-353) identifies two factors which may serve to explain the higher need for glasses. First, the spectral effectiveness of HPSV lamps is such that 7.5 times as much illuminance is required from them in order to match a light source with a relatively uniform spectral power distribution. Second, the monochromatic HPSV lights (560 to 610 nm) may result in higher degrees of chromatic aberration and inappropriate focusing than the more balanced lights.

> *Conclusion. On the basis of an analysis of vision records for the children located in the different lighting environments examined in this study, the null hypothesis was supported—light does not have an effect on changes in vision. Nevertheless, it must be underscored that anomalies in the rate of change in uncorrected vision at two of the sites point to the conclusion that the quality of lighting systems may be critical. Lighting systems should produce comfortable light and without high contrast levels.*

Fluorescent Lamps as Ultraviolet Sources

The choice of Vita-Lites for use in this study has already been discussed. Nevertheless, the question remains. Are there other fluorescent lamps that emit ultraviolet radiation? The answer is, Yes. All fluorescent lamps emit some ultraviolet radiation but this radiation is probably little more than that which is common and characteristic of this type of lamp. The manufacturers of Vita-Lites do, however, claim to provide ultraviolet radiation in somewhat the same ratio that ultraviolet radiation is present in daylight. A comparison of a random selection of a number of readily available fluorescent lamps is presented in Table 4.16. In the UVA band which is of interest to this study, the Vita-Lites radiate almost 60 percent more energy than the nearest competitor. In the UVB band which is also of interest to this study, but more of a concern from the point of view of safety, three of the lamp types emit more energy than Vita-Lites.

Table 4.17 provides data about the life or longevity of the phosphors used in Vita-Lites. At the end of 50 months of use, a sample of Vita-Lite lamps retained 61 percent of the UVA output and 79 percent of the visible light output. Stated another way, the UVA-emitting phosphors appear to fall off at about the same rate as the light-emitting phosphors. Levels of UVB and UVC emitted by the lamps appears to fall off much more quickly with use.

Risk of Exposure to Supplemental Ultraviolet Light in Classrooms

Stepping outside into the sunlight means that we are at the same time exposed to ultraviolet light and ultraviolet light is of three types. Two of these types are of significance to this

Table 4.15. A pre-test/post-test comparison of the percentage change in the number of students *never* using glasses.

	Pre-Test (%)	Post-Test (%)	Increment (%)
Site 1	75.6	65.5	-10.1
Site 2	83.8	79.4	-4.4
Sites 3 and 5	68.0	66.4	-1.6
Site 4	58.6	55.4	-3.2

Table 4.16. Measured radiant energy from a sample of different fluorescent lamps. All measurements were made at a distance of 163±1 cm from the surface of the lamp. All lamps were new and were given a three to five minute warm-up before testing.

	Spectroradiometer Measurements[1]			Illumination[2]
Lamp Type	UVA 320-400 nm $\mu W/cm^2$	UVB 280-320 nm $\mu W/cm^2$	UVC 200-280 nm nW/cm^2	Photometric range Lux
Vita-Lite 40W Duro-Test Canada, Inc.	29.4	1.02	0.00	200
F40D Daylight GE Canada	18.6	0.00	0.00	245
GTE F40CW Cool White Sylvania	17.7	1.70	0.00	320
GE F40-C50 Chroma 50 GE Canada	13.7	1.70	0.00	210
GE F40WW Warm White GE Canada	11.1	2.00	0.00	270

Ultraviolet (UV) Safety Limits

UV radiation safety limits for an eight (8) hour period are as follows: (Phillips, 1983:4):

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

Measuring Equipment

1. IL-791 Spectroradiometer System manufactured by International Light was used for UV measurements in the narrow bands (UVA, UVB, UVC). This NBS traceable calibrated system was used to conduct narrow-band (5 nm bandwidth) measurements of ultraviolet wave band from 200 to 400 nanometers.

2. Model 40 Optometer manufactureed by United Detector Technology Inc. was used to measure the illuminance of the test lamps.

Table 4.17. A comparison of new lamps and lamps that have been in use for fifty (50) months at study sites. All measurements were made at a distance of 170±0.5 cm from the surface of the lamp. All lamps were given a three to five minute warm-up before testing.

	Spectroradiometer Measurements[1]			Illumination[2]
Lamp Type	**UVA** 320-400 nm µW/cm²	**UVB** 280-320 nm µW/cm²	**UVC** 200-280 nm nW/cm²	Photometric range Lux
Vita-Lite 40W Duro-Test Canada, Inc. (Sample of 3 new lamps)	30.0	0.78	0.05	201
Vita-Lite 40W Duro-Test Canada, Inc. (Sample of 7 lamps used for 50 months)	18.3	0.24	0.01	158
Percent of output remaining in lamps after 50 months of use	**0.61**	**0.31**	**0.20**	**0.79**

Measuring Equipment

1. IL-791 Spectroradiometer System manufactured by International Light was used for UV measurements in the narrow bands (UVA, UVB, UVC). This NBS traceable calibrated system was used to conduct narrow-band (10 nm bandwidth) measurements of ultraviolet wave band from 200 to 400 nanometers.

2. Model 40 Optometer manufactureed by United Detector Technology Inc. was used to measure the illuminance of the test lamps.

study. Ultraviolet light in the region nearest to visible light (i.e., 320-400 nanometers) is referred to as the UVA band. Next to the UVA band is the UVB band with wavelengths from 280 to 320 nanometers. UVC represents the third band and includes all wavelengths shorter than 280 nanometers. UVC irradiance emitted from the lighting systems used in this study was nil (see Table 3.1) and therefore of no consequence.

Sunlight reaching the earth's surface contains energy in both the UVA and UVB bands. Energy in sunlight in the UVC band (potentially the most dangerous form of ultraviolet light) is completely filtered out by the atmosphere before it reaches the earth and is of little consequence. Indeed, Thorington (1985: 36) presents evidence of an absolute cutoff at 295 nanometers as a result of atmospheric absorption.

The amount of UVA and UVB energy contained in sunlight is presented in Table 4.18. At noon on a sunny day in June the UVA irradiance in Edmonton may reach 4,885 $\mu W/cm^2$. At the same time the effective UVB irradiance may approach 0.44 $\mu W/cm^2$. UVA exposures in October are approximately 60 percent of the June levels while the UVB levels are down to the range of 40 percent of the June levels. Exposure to ultraviolet light is cumulative and may be converted to annual exposures measured in joules per square centimeter (J/cm^2). Table 4.18 includes recommended maximum doses of ultraviolet light for an eight-hour period and these cumulative exposures have been worked out based on 200 days of exposure per year. Two hundred days instead of 365 was chosen since students are in school only 200 days per year. Following this approach reduces the risk of using the students' entire annual UV quota in the classroom. One might conclude from Table 4.18 that 5,760 J/cm^2 of UVA and 0.6 J/cm^2 of UVB are the maximum recommended dosages for an eight hour daily exposure for a 200 day period.

Exposure levels encountered as a result of UV supplements provided at Sites 3 and 5 are also presented in Table 4.18. There it may be seen that the cumulative classroom dosage of UVA was 36 J/cm^2 and of UVB it was 0.04 J/cm^2. The exposure to UVA amounts to 0.6 percent of the maximum recommended exposure. On the other hand, the exposure to UVB amounted to about seven percent of the recommended maximum exposure.

To put the UVB exposure at Sites 3 and 5 into perspective, it is important to make some comparisons. First, the UVB emitted by the Vita-Lite full spectrum lamps is greater than that emitted by other lighting systems involved in the study (see Table 3.1). Second it is also important to compare the cumulative effect of five hours of exposure per day in the UV supplemented classrooms with the cumulative exposure that might be encountered by a 15 minute exposure to the noontime sun in October or June in Edmonton. The cumulative classroom UVB exposure levels were approximately 33 percent greater than a 15 minute exposure to the noontime sun in October and about 50 percent of the exposure gained during a 15 minute exposure to the sun at noon in June.

Clearly, it can be seen from Table 4.18 that the UVA exposure levels in the schools receiving UV supplements were in the range of one percent of the maximum recommended dosage. The UVB exposure levels were about seven percent of the recommended exposure levels.

Because of the introduction of UV radiation into the classrooms at Sites 3 and 5 it is important to understand some of the concerns that lie behind the recommended standards for UV exposures. One of the concerns is that skin cancer rates in Alberta (and elsewhere) are on the increase. The rates in Alberta have more than tripled since 1971, with an average increase of 7.5 percent per year. This may be due to changes in ultraviolet levels as a function of ozone layer depletion or it may represent the fact that the population spends

Table 4.18. Relative safety of UV supplements in classrooms.

Nature of UV Exposure	UVA $\mu W/cm^2$	UVA Annual Dose[2] J/cm^2	UVB (Effective[1]) $\mu W/cm^2$	UVB (Effective[1]) Annual Dose[2] J/cm^2
Daylight Exposure Levels				
Edmonton exposure October noontime	2925		0.1[illegible]	
Edmonton exposure June noontime	4885		0.44	
Recommended maximum eight-hour dosage (200 days/yr)	**1000**	**5760**	**0.1**	**0.6**
Exposure Comparisons				
Sites 3 and 5 Average exposures[3]	<10	<36	<0.01	<0.04
Fifteen minute outdoor exposure[4] October noontime	2925	526.5	0.18	0.03
Fifteen minute outdoor exposure[4] June noontime	4885	879.3	0.44	0.08

1 The efficacy of ultraviolet radiation is not uniform across the spectrum. Maximum efficacy occurs in the 260 to 280 nanometer range. In order to permit comparisons, the measured UVB irradiance (shown in Table 3.1) has been converted to effective irradiance in this table.

2 Exposure to ultraviolet radiation is cumulative. The average annual dose represents the cumulative amount of exposure for a year expressed as joules per square centimeter (J/cm^2). A watt of energy equals one joule per second. Cumulative exposure is calculated as follows:

$$\text{Exposure } (J/cm^2) = \text{Effective UV irradiance in watts/cm}^2 \times \text{exposure time in seconds}$$

3 Inasmuch as students are in school for only 200 days per year, all calculations are based on 200 days instead of 365. Students are exposed to ultraviolet radiation for approximately five (5) hours per day for 200 days per year.

4 Exposure equivalent to 15 minutes per day for 200 days per year.

more time outdoors now than in 1971. It may also be that there are other factors at work. For example, it may be the case that fewer of the people working indoors full time have "hardened" to sunlight. As a consequence they may experience more frequent burning than those with "hardened" skin when they do venture outside. Nevertheless, one thing is clear—ultraviolet radiation is considered to be carcinogenic and exposure elevates the risk of skin cancer.

Though it is clear that ultraviolet radiation in the UVB band is beneficial in the production of vitamin D in the skin, and vitamin D formed in the skin seems to be of a different quality than that which is taken orally, there remains the problem of establishing an optimum amount of UVB exposure. Until that optimum level is established (perhaps on the basis of some risk-benefit ratio), caution would suggest that any unnecessary exposure to UVB is unwise. The debate is similar to that of milk and eggs versus cholesterol. How much is good? How much is too much?

There is also a concern about the relative UVA:UVB imbalance when compared to natural light which has a ratio in excess of 10,000:1. At Sites 3 and 5 the ratio was about 1000:1. Tanning occurs in response to irradiation in the range of 290 to 340 nanometers (Pathak, 1985: 331). UVB irradiance (280 to 320 nm) stimulates vitamin D production, skin reddening and it initiates the tanning process. UVA irradiance (320 to 400 nm) darkens skin pigmentation and this tanning acts to block out excessive UV exposure. In this study the classrooms UVB levels may have been sufficiently high to actually trigger a tanning response. The unbalanced UV radiation emitted by the test lamps was too weak, however, to effectively produce tanning. Consequently, students could be exposed to UVB levels in classrooms, which under natural light could trigger a normal tanning response, but because of the relatively low levels of UVA the normal tanning response may not be completed. If this is the process leading to pigmentation and UV blockage or protection by the skin to further UV irradiance, then it may be risky to expose students to therapeutic doses of UVB without the availability of sufficient UVA energy to enable the skin to develop pigmentation as a control for excessive UV exposure.

A further word of caution must be introduced in this section. Three of the fluorescent lamps tested in Table 4.16 had higher levels of UVB and lower levels of UVA than the Vita-Lites used in this study. For these lamps, the UVA:UVB balance is inferior to Vita-Lites and for that reason care and caution should be exercised, especially if these lamps are to be used in fixtures modified to release UV radiation.

Summary

This study set out to test the null hypothesis—different light types (full spectrum fluorescent, full spectrum fluorescent with UV enhancement, cool-white fluorescent, and high pressure sodium vapor) have no differential effects on Division II students' dental histories, growth and development histories, vision histories, scholastic achievement histories, or attendance histories when compared over a two-year period.

The significant findings of the study are summarized in tabular form in Table 4.19. Without placing a value judgement on the findings (i.e., good or bad) two symbols are used to describe the findings in Table 4.19—a negative sign (–) is used to indicate the lowest or smallest measure while a positive sign (+) is used to indicate the highest or greatest measure. 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 they are significantly better than other sites on the greatest

Table 4.19. A summary of significant findings of the study together with a description of lighting system characteristics. Significant differences ($p<0.05$) were found to occur between negatives (–) and positives (+).

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-orange)	Yellow-green	Daylight (bluish)	Daylight (bluish + UV)
Color temperature (K)[1] (Daylight—sun and sky ≥ 5000)	2100	4250	5500	5500
Color rendering index[1] (100 = natural daylight)	21	62	91	91
Non-Visual Effects on Students				
Reductions in the development of dental caries.	–	na*	–	+
Attendance ratio.	–		+	+
Onset of menarche	–		+	+
Gains in height.	–	+		+
Gains in weight.		–		+
Gains in body fat.	+	–	+	+
Academic achievement**	–	+	+	+

* Site 4 was dropped from the dental component of the study when it was found that many students had received applications of fissure sealants.

** 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.

[1] Thorington (1985: 50).

number of measures. At the same time it must be noted that Site 1 (high pressure sodium vapor) rated significantly poorer on most measures.

From Table 4.19 it may be concluded that the null hypothesis (set forth above) was rejected. Different light types do have differential effects on Division II students' dental histories, growth and development histories, vision histories, scholastic achievement histories, or attendance histories when examined over a two-year period.

The findings of this study point to the clear conclusion that light has important non-visual effects on people. Just how these effects occur is still uncertain.

When it comes to the findings in Table 4.19, 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. 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.

Chapter 5

Conclusions and Recommendations

Conclusions

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

What Do We Now Know About Light and It's Effects on Students?

On the basis of this current 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.

What Don't We Now Know About Light and It's Effects on Students?

We 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 ultraviolet light.

Putting the Study Findings Into Perspective

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 lighting systems. 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: *xi*) very articulately describes 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?

> *The question is important for all of us, but especially so for people who cannot readily walk outside for some fresh air and sunshine—like school children in very cold climates, or residents of nursing homes, hospitals, submarines, or spacecraft. How much evidence, and based on which specific tests, ought to be required before a given light source is adjudged safe, when that source may be used to provide people with all of their light for many hours at a time, on many days? For years now companies that make artificial foods have labored under the burden of fortifying their products with the vitamins or minerals that people would otherwise have*

consumed had they instead eaten the "real" food that the artificial one replaces. (For example, Vitamin C is added to Tang and to other orange juice substitutes.) If the design of a light source is such that it omits a spectral band that can be shown to contribute to good health, should exposure to that source be limited? Whose job should it be to decide? If future medical research should demonstrate that people who spend the daylight hours working indoors need to be exposed to greater light intensities than those now recommended by the Department of Energy, should energy policy or health policy be the victor? Again, which of society's institutions should be charged with deciding?

To fully answer Wurtman's questions, and in spite of the positive findings of this study, two areas need to be explored. The first area has to do with the scope and extent of non-visual effects. The second area focuses on how the results of the already-completed studies might be used.

The first set of questions seeks to explore the scope and extent of non-visual effects of light.

1. At what ages are UV supplements most beneficial?

This study has focused on students in Grades 4, 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 (and in the 1981-1985 study) for two reasons. First, the manufacturer claims that the lamp spectrum contains ultraviolet 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. The measured UVA emitted by these lamps in classroom settings, when mounted in modified fixtures, amounts to about 8 to 10 $\mu W/cm^2$ at desk top height and this translates to about 0.6 percent of the recommended maximum eight-hour dosage of 1,000 $\mu W/cm^2$. However, the measured effective UVB (important to synthesis of vitamin D) amounted to less than 0.01 $\mu W/cm^2$ and this equates to about seven percent of the recommended maximum daily dosage.

Other sources could include use of high energy ultraviolet sources, special ultraviolet 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 to exercise caution when it comes to unnecessary exposure to ultraviolet 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 ultraviolet light to which people are exposed. None of the lighting systems used in this study emitted ultraviolet 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 $\mu W/cm^2$ in the UVA band per eight hours). UVB levels encountered in the classroom were about 12.5 percent of the amount encountered while on a one-hour walk in the noontime summer sun in Edmonton in June and approximately 33 percent of the exposure gained in a similar walk in October. Based on these standards, the ultraviolet 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 36° N. Latitude) is considered sufficient for developing a person's daily requirement of vitamin D (Neer, 1975:413).

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 ultraviolet 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 ultraviolet 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 ultraviolet radiation is interesting.

Wurtman (1975: 474) and Holick (1985:4) 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 ultraviolet 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 (i.e., the 1981 to 1985 study and this study) has been conducted at sites located between 49° and 54° 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 ultraviolet radiation. Perhaps it is this lack of exposure to natural ultraviolet that explains why relatively small prolonged exposures to ultraviolet radiation has such a beneficial effect on students. That being the case, it is important that the effects of exposure to small amounts of ultraviolet radiation should be explored at other latitudes and in regions where fog or cloud cover minimizes exposure to natural sunlight and ultraviolet 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.

The second set of questions pertains to ways of using the findings of this study.

1. How should the schools be modified to capitalize on findings of completed research?

Clearly, the selection of classroom lighting and colors should be based on something more than economics and energy conservation. The big question asks, What can facility planners do, based on the available research, to improve learning environments? The answer is several things.

For people who are outdoors for a significant part of each day, the quality of indoor lighting to which they are exposed may be of little consequence. Their needs for natural light stimulation may be adequately met. But for people who spend almost all of their time indoors, and with outdoor exposure limited to morning and evening light, there may be a need for artificial lighting that is supplemented with light stimulation in the spectrum areas of energy deficiency—especially ultraviolet in the 290 to 400 nm range (UVA and UVB).

Using windows to obtain the required ultraviolet light supplements is of marginal effect because some ultraviolet light, especially UVB, the most significant missing component in artificial light, is almost completely filtered out by ordinary window glass. Allen (1971: 33) reports that glass attenuates UV transmission below 325-350 nanometers while acrylic and styrene have sharp cutoffs in the range of 375-400 nanometers. Moreover, natural UV within classrooms would be available only in full sunlight and near a window. Much of any UV passing through the window glass and diffused throughout the classroom would be lost due to absorption by surfaces in the classroom. (Many materials absorb UV radiation [see Table 2.2]). To create a truly balanced lighting in classrooms, perhaps controlled amounts of ultraviolet radiation should be introduced into classrooms as a part of the overall classroom lighting system.

Color may also be used to advantage. A rule of thumb suggests that cool colors foster relaxation and warm colors foster stimulation. With this in mind, planners might try to determine the sorts of activities to take place in the learning spaces and to plan colors accordingly. Active spaces like gymnasiums might benefit from extensive use of warm colors. Libraries might be suitable candidates for the cool colors. The same may be true for washrooms, showers, and corridors. Spaces for over-active children or children with behavioral problems might be decorated with cool colors. Students who are slow and unmotivated might benefit from warm colors.

Finally, on the basis of the sparse research into the effects of light from high pressure sodium vapor lamps on people, it is probably unwise to use these lamps in regular classrooms. Their use should be limited to gymnasiums, corridors, and other spaces used only occasionally by students.

2. In what ways can trace amounts of UV be introduced into classrooms?

If it was decided that UV radiation should be introduced into classrooms, there are several ways by which controlled amounts might be introduced. One way might be to provide banks of sunlamps in some rooms or areas frequented by all building occupants—areas such as lounges, cafeterias, showers, washrooms, and gyms. A second way might be to replace existing classroom lights with UV emitting full-spectrum fluorescent lamps. However, without reflectors and special UV transmitting diffusers or lenses the UV energy is absorbed by the fixture and thus serves no useful purpose. A third way might be to explore the use of ultraviolet fluorescent lamps (black lights) mounted in special fixtures in the classrooms. If these lamps emit ultraviolet in the appropriate band and at desired levels, they could be used as an alternative to the use of the more costly full spectrum lamps and the modified fixtures that they require when used as ultraviolet sources.

An alternative to changing lighting systems might be to supplement diets with suitable doses of vitamin D (for example, by drinking two to four glasses of fortified milk daily). Wurtman (1975: 474) does, however, question whether dietary sources of vitamin D are biologically as effective as the vitamin D formed in the skin and the studies reported by Alberta Education tend to strengthen Wurtman's concerns. (Most of those students involved in the Alberta studies received reasonable levels of Vitamin D through their diets—especially through milk which is fortified with Vitamin D.) A second alternative might be to provide some outdoor activity between roughly 10:00 AM and 2:00 PM (especially during the winter months).

It is important to remember that unless reflectors and UV transmitting lenses are installed in conjunction with installation of UV emitting full-spectrum fluorescent lamps, the only advantage to be obtained from full spectrum lighting is improved color rendition. In this regard, full spectrum lamps may be used to provide high quality lighting in paint shops, art studios, and other places where correct color rendering is important.

3. Who are the principal benefactors of the beneficial effects of improved lighting systems? Who should pay?

One of the clear benefits that could derive from applications of this research into the learning environments children occupy could be reductions in the development of dental caries. The benefits of this action would accrue to parents in the form of reduced dental bills.

The second clear benefit derives from the fact that under improved lighting conditions students seem to learn better (i.e., demonstrate better academic achievement) and their attendance improves—students are occupying the spaces provided for them (i.e., improved attendance) and they are learning more. The combined effects of these two benefits clearly accrues to the educational institution.

Recommendations

This study was undertaken for the purpose of exploring the effects on elementary school children (Grades 4, 5 and 6) of different lighting systems. The findings of the study affirm the findings of an earlier study (Wohlfarth, 1986; Hargreaves & Thompson, 1989) and point to the conclusion that light—far from being neutral with respect to effects on children—has significant non-visual effects on children. The study points to differences in development of dental caries, the age at the onset of menarche, gains in height, gains in weight, gains in body fat, gains in achievement, and improvements in attendance as being related to classroom lighting types.

Several recommendations flow logically from this study.

1. When it comes to lighting sources, this study suggests that there are clear differences in quality. Full spectrum lamps (i.e., Vita-Lites) mounted in ultraviolet transmitting fixtures provide light with demonstrable beneficial effects. Full spectrum lamps in conventional fixtures also appear to contribute to differences in growth and development patterns. Cool-white fluorescent lamps mounted in conventional fixtures appear to be neutral with respect to many of these non-visual effects. High pressure sodium vapor lamps appear to have negative effects on children.

   Inasmuch as cool-white lamps or full spectrum lamps mounted in conventional fixtures emit insignificant amounts of UV radiation and because have no identifiable drawbacks, they should continue to be used.

   High pressure sodium vapor lamps should not be used in classrooms until further tests prove that they have no effects on children or the way they behave.

2. Ultraviolet levels within the UVB band should be checked in all schools equipped with fluorescent lamps (any brand) mounted in lighting fixtures that have UV-transmitting diffusers. Included in this category are the rather common egg-crate diffusers. When mounted in these fixtures, any fluorescent lamp can emit some ultraviolet radiation.

3. Schools and school districts should be cautious when it comes to changing lighting systems to match the UV-emitting systems used in this study. There needs to be a better understanding of the relative risks and benefits of UV in the classroom.

4. When the more expensive full spectrum fluorescent lamps are to be used as a source of controlled ultraviolet light, care must be taken to ensure that the chosen lamps emit reasonable levels of ultraviolet radiation at desk top heights (probably in the range of 8 to 10 $\mu W/cm^2$ as a minimum). Reflectors should be selected which have no ultraviolet-inhibiting coatings on the front surface. Laboratory tests can be used to verify that reflectors operate in the ultraviolet range. Finally, lenses should be capable of transmitting ultraviolet radiation. Again, laboratory tests can be used to determine the ultraviolet transmission efficiency.

5. When fluorescent lighting fixtures are modified with reflectors and ultraviolet transmitting lenses for the purpose of obtaining an output of ultraviolet radiation, care must be taken to ensure that the overall quality of the lighting system is not degraded. The addition of reflectors, in particular, has the effect of increasing the contrast ratio of the lighting system and it is suspected that this may contribute to significant eye fatigue.

6. Three of the fluorescent lamps tested in Table 4.16 had higher levels of UVB and lower levels of UVA than the Vita-Lites used in this study. For these lamps, the UVA:UVB balance is inferior to Vita-Lites (and much worse than natural light) and for that reason these lamps should not be used in classroom lighting fixtures which have been modified to release UV radiation—at least not until additional studies have been carried out.

7. Further research should be undertaken into the non-visual effects of light in at least three areas.

   Research should be undertaken in order to explore optimum lighting systems (i.e., person lighting and not just task lighting) and optimum levels of ultraviolet light to be introduced into classrooms. The ideal might be to conduct a controlled study in an urban district where half the schools could be used as experimental sites and half as control sites. The ability to control for a number of factors (especially socio-economic factors) could be easier than in this study and it's 1981-1985 predecessor.

   Research should be undertaken to determine the most efficient and cost-effective ways of introducing controlled amounts of ultraviolet radiation into classrooms.

   Research should be undertaken in order to explore the generalizability of the findings of this study to other populations (pre-school, the primary grades, and junior and senior high school) and other geographic locations and climates.

8. In the field of lighting and lighting effects (which is rapidly expanding) there is a need for a clearinghouse of information and ideas for implementation. A clearinghouse of research into the non-visual effects of light and color and implications for school facilities should be established. Funding of future studies should be integrated with other facility-related research and synthesized to yield clear school facility design guidelines.

Bibliography

Allen, C. J. (1971, January). Color temperatures. *Illuminating Engineering*, 31-36.

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.

Blackwell, H. R. (1985). Effects of light source spectral distribution upon visual functions. 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.

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.

Faily, A., Bursor, D. E. & Musemeche, R. A. (1979, September-October). The impact of color and lighting in schools. *CEFP Journal, 17* (5), 16-18.

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

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. 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, 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 D^3 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.

Ingraham, L. (1983). *Electromagnetic Radiation and Student Off-Task Behavior.* Edmonton, Alberta: Planning Services Branch, Alberta Education.

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., 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.

Painter, M. (1976). Fluorescent lights and hyperactivity in children: an experiment. *Academic Therapy, 12* (2), 181-184.

Pathak, M. A. (1985). Activation of the melanocyte system by ultraviolet radiation and cell transformation. 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.

Phillips, B. 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. I. (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.