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HEALTH AND BEHAVIOR OF CHILDREN IN CLASSROOMS WITH AND WITHOUT WINDOWS

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Abstract

The aims of the study were to assess the effects of light on the production of stress hormones, classroom performance, body growth, and sick leave, of school children. About 90 children were investigated in their school environment for a duration of one school year. The children were situated in four classrooms differing in respect to the access to natural daylight and artificial fluorescent light. The results indicated the existence of a systematic seasonal variation with more stress hormones in summer than in winter. The children situated in the one classroom lacking both natural daylight and fluorescent daylight tubes demonstrated a marked deviation from this pattern. High levels of morning cortisol were associated with sociability, while moderate or low levels seemed to promote individual concentration. Annual body growth was smallest for the children with the highest levels of morning cortisol. Possibly, the production of cortisol had some influence on sick leave. It may be concluded, that windowless classrooms should be avoided for permanent use.

Introduction

The aims of the present study were to assess the effects of natural daylight vs two types of fluorescent light on the production of stress hormones, classroom performance, body growth, and sick leave, of school children. In the literature there are two main groups of studies concerned with these issues. One compares environments with and without windows, the other studies the impact of different kinds of fluorescent tubes. In her review of research on windowless environments, Collins (1975) concluded that the absence of windows did not appear to have much impact on school children. Still, she advised against windowless design, since the effects of long-term use had not been thoroughly studied. In a more recent review of classroom environments, Weinstein (1979) stated that the existing 'evidence supports neither the claim that windowless classrooms will allow increased concentration, leading to higher achievement, nor the fear that the absence of windows will have harmful psychological and physical effects' (p. 592).

The results of clinical research make it necessary to reconsider this conclusion. Wilson (1972) compared the incidence of post-operative delirium in surgical patients treated for at least 72 h in an intensive care unit without windows with patients in an intensive care unit possessing windows. Over twice as many episodes of organic delirium were seen in the intensive care unit without windows. Wilson concluded that the presence of windows was highly desirable for the prevention of sensory deprivation.

This conclusion gained further support in a similar study by Keep *et al.* (1980). Retrospective surveys were carried out on two groups of patients who had survived a stay of at least 48 h in an intensive therapy unit. One group had been kept in a unit without windows, and the other in a similar unit with translucent but not transparent windows. Survivors from the windowless unit had a less accurate memory of the length of their stay, and were less well orientated in time during their stay. The incidence of hallucinations and delusions was more than twice as high in the windowless unit.

The influence that natural daylight, and even the view through a window, may have on the recovery from surgery, was illustrated in a study by Ulrich (1984). Records on recovery after cholecystectomy of patients in a suburban hospital were examined to determine whether assignment to a room with a window view of a natural setting might have restorative influences. Surgical patients assigned to rooms with windows looking out on a natural scene had shorter post-operative hospital stays, received fewer negative evaluative comments in nurses' notes, and took fewer potent analgesics than matched patients in similar rooms with windows facing a brick building wall.

Although these studies were not on children, but on adult hospital patients, the results may be of the utmost relevance to the study of the long-term impact of the school environment. Recent chronobiological research has shown that light has a profound psychological and physiological impact on humans (Küller, 1981). When light passes into the eye, impulses are propagated not only to various visual areas but also to areas of the brain related to emotions and hormonal regulation. The most conspicuous relationship between daylight and man is the diurnal rhythm, relating the light and dark cycle of day and night to complex physiological and biochemical variations of wakefulness and sleep. The timing of diurnal and nocturnal rhythms, and the functional variations related to them, depend on internal processes usually referred to as the biological clock. Such a clock would not be very useful if it did not keep time with sunrise and sunset, and in order to do this, there must be some kind of synchronizer. In mammals, this is mediated by the retino-hypothalamic pathway which originates in the retina and terminates in the suprachiasmatic nuclei (Brainard *et al.*, 1988).

The synthesis of melatonin in the pineal gland holds a central position in mediating the effects of ocular light (Wurtman, 1975). The rate of melatonin synthesis is controlled by environmental illumination (Lewy *et al.*, 1980; Boyce & Kennaway, 1987). Results from numerous studies have implicated melatonin in the functional activities of organs including the brain, pituitary, thyroid, adrenal and smooth muscles. The secretion of melatonin by the pineal seems to be a mediator also where annual variations are concerned (Hollwich, 1979). Melatonin induces sleep, inhibits ovulation, and modifies the secretion of other hormones like cortisol, which was used as an indicator in the present study. There is also some evidence relating melatonin to psychiatric disorders (Wetterberg *et al.*, 1990). The relationship between light and psychiatric disorder is presently receiving much interest in studies of seasonal affective disorder (SAD) (Rosenthal *et al.*, 1984).

The other main line of studies has dealt with the impact of different types of fluorescent light, mostly daylight tubes and conventional cool-white or warm-white tubes. The results from some of these studies seem to indicate that daylight tubes cause less stress, both visually and in a more generalized sense, than conventional fluorescent tubes (Thorington *et al.*, 1971; Maas *et al.*, 1974). Mayron *et al.* (1974) found that hyperactive behavior decreased in school children exposed, in their classroom, to daylight tubes as compared to cool white tubes. In a study by Hollwich *et al.* (1977), subjects were first exposed to strong cool white fluorescent light tubes for two weeks, and then to fluorescent daylight tubes for another two weeks. The secretion of cortisol considerably increased under the cool white light, but returned to a normal level during the exposition to artificial daylight. Munson & Ferguson[1] found hyperactive behavior decreased under daylight tubes as compared to cool white tubes.

Other studies are either inconclusive or point in the opposite direction. O'Leary[2] compared the influence of cool white and daylight tubes on school children but found no significant differences in behavior. Küller and Wetterberg[3] investigated the differential effects of two types of fluorescent tubes, daylight and warm-white, each at two different levels of illuminance, approximately 450 and 1700 lux. For each of the four combinations the exposition lasted one day. Methods included subjective ratings of visual discomfort, ECG, EEG, and analysis of stress and sleep hormones. These authors concluded that fluorescent light of high illuminance may increase activation but also cause stress and discomfort, and that this may become accentuated if the tubes are of the daylight type.

One study by Erikson and Küller (1983) compared the effect of both daylight and of fluorescent light on well-being and the production of stress and sleep hormones in an office. Personnel working close to a window had higher levels of morning cortisol during summer than during winter, while the opposite was true for those positioned far from a window. By means of fluorescent daylight tubes it was possible to suppress the production of melatonin during winter and temporarily make the personnel feel more alert and active.

Problem

In some of the studies cited above, the effects of light were difficult to interpret, mostly due to the fact that the exposition lasted for a brief period of time. In others, natural daylight may have been an intervening or concomitant factor, having a confounding impact on the results. One purpose of the present study was to try to separate the effects of natural daylight from those of fluorescent light. It was further assumed that daylight tubes might, to some extent, compensate for the lack of natural daylight.

Another purpose was to test the assumption, embedded in chronobiological thinking, of annual variations in the secretion of hormones. As mentioned above, cortisol was used as a chronobiological indicator in the present study. The production of cortisol, which takes place in the adrenal cortex, is regulated by neurosecretion from the hypothalamus via the pituitary gland.

Basically, the secretion of cortisol follows a diurnal pattern with high values during daytime and low values during the night (Hollwich, 1979). The highest value is generally early in the morning with a minor peak also late in the afternoon. Attempts at establishing a seasonal pattern in cortisol production of children have however failed so far (Bellastella *et al.*, 1983; Hallek *et al.*, 1985). We will test the assumption of annual variations in cortisol secretion, with high values in summer and low values in winter.

The last three decades have seen growing evidence of the interdependence of biochemistry and human behavior. Urinary free cortisol levels have been reported to correlate with impulsive behavior in school children (Tennes & Kreye, 1985; Tennes *et al.*, 1986; Kruesi *et al.*, 1989). Since different levels of stress are known to promote different behaviors, it was hypothesized that variations in cortisol would be accompanied by changes in behavior.

There is some reason to believe that body growth may be affected by light. In a study of blind children, Kaloud (1970) found a slight under-development. Those children who regained their sight after an operation increased more in body growth, while children, who became blind after puberty, did not differ from children with normal sight. Hollwich (1973) and Dieckhues (1974) have also demonstrated that light perception may have an influence on the metabolism of growth hormones. We hoped to gain further support for the purpated relationship between light and body growth.

Certain support for the assumption that light perception may have an influence on general health is to be found in earlier research (e.g. Wurtman, 1975; Hollwich, 1979). The present interest in studies of seasonal affective disorders lend further support to such an assumption (Rosenthal *et al.*, 1984). We also wanted to test this assumption in terms of seasonal variations in sick leave.

Design of the Study. Methods, Procedures and Statistics

The four classrooms

About 90 children at two comprehensive schools were investigated in their school environment for the duration of one school year. The schools were

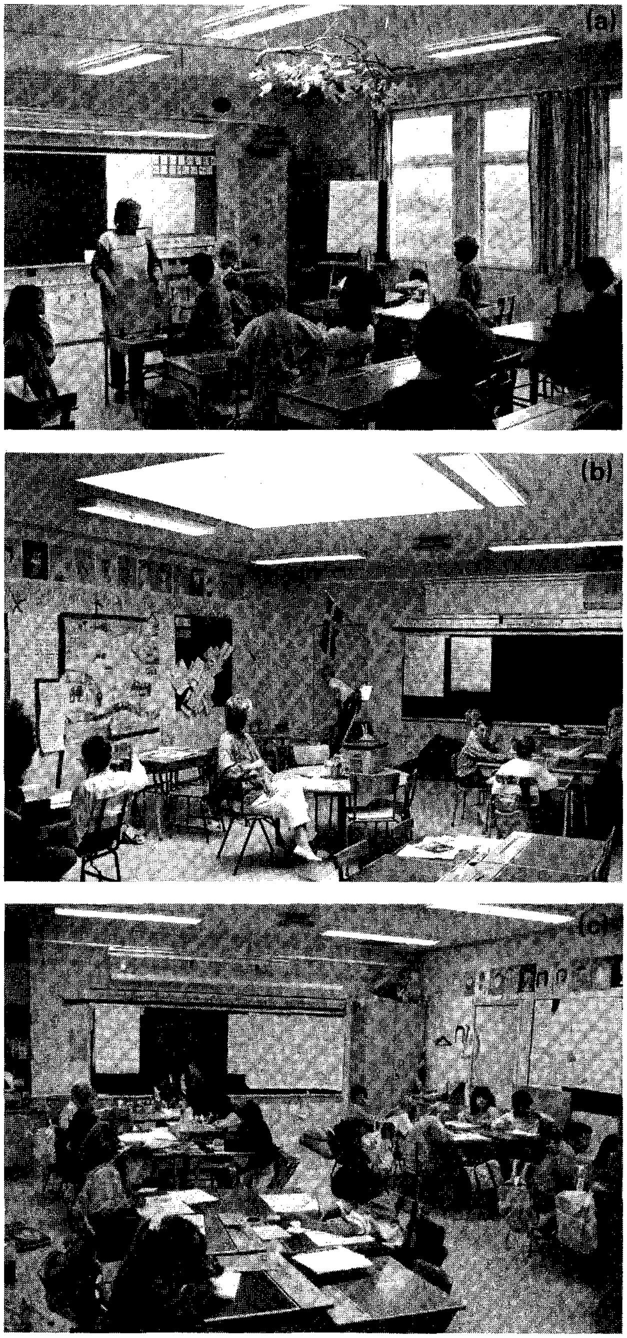

FIGURE 1. Three of the classrooms with and without daylight investigated in the study. (The children in the pictures did not take part in the study.)

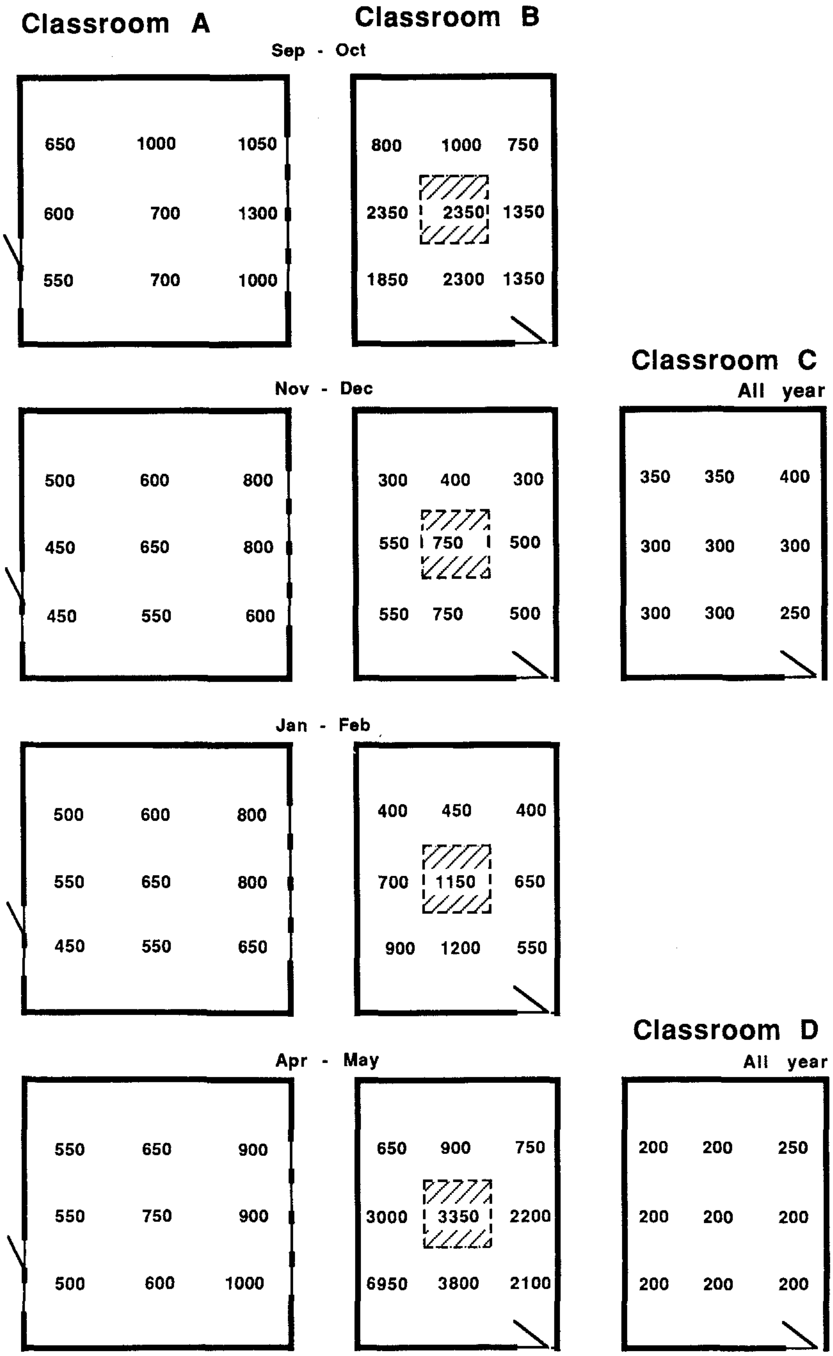

FIGURE 2. The distribution of illuminances (lux) in the four classrooms at four times of the year. (Average measurements at noon with artificial illumination on.)

situated a few hundred meters apart in a quiet suburb of Malmö in the southern part of Sweden (latitude 55° N, longitude 13° E). The climate in this region is quite cloudy and rainy with longer periods of clear sky mostly in spring and summer. In winter there is very little snow. The difference in amount of daylight between summer and winter on this latitude amounts to more than ten hours.

The children were situated in four classrooms differing in respect to the access to natural daylight and type of fluorescent light. One classroom (A) had ordinary windows on the northern wall (Figure 1a). It was 7·7 × 8·0 m with a ceiling height of 2·7 m and provided with fluorescent tubes of the warm-white type [Philips TLD83, 36W, 3000 K, color rendering index (CRI) = 85]. The second class-

TABLE 1
The overall lighting situation in the four classrooms

	Warm-white tubes	Daylight tubes
Windows	Classroom A	Classroom B
No windows	Classroom C	Classroom D

room (B) had a large transparent skylight in the middle of the ceiling (Figure 1b). It was 6·0 × 8·0 m with a ceiling height of 2·9 m and provided with fluorescent daylight tubes (Duro Test True-Lite, 40W, 5500 K, CRI = 91). The other two classrooms completely lacked windows and natural daylight (Figure 1c). Both were 6·0 × 8·0 m with a ceiling height of 2·9 m. Of these two windowless classrooms, one (C) was provided with the warm-white tubes and the other (D) with the fluorescent daylight tubes described above. Thus, there were in all two classrooms with natural daylight and two without, one of each provided with fluorescent tubes of either the warm-white type or the daylight type (Table 1).

The various lighting arrangements were made during the summer holidays as part of the normal maintenance routine. The details of the light sources, which were all available in the market, or the underlying hypotheses of the study, were not known to anybody at the involved schools.

The fluorescent lighting tubes were evenly distributed over the ceiling in order to obtain a homogeneous illuminance on the desks. (For a description of the spectral characteristics of the two different fluorescent tubes refer to Küller & Wetterberg.[3]) They were connected to the central power supply system (220 V, 50 Hz) by means of conventional ballasts. Measurements of horizontal (80 cm) illuminance and room temperature were carried out in each classroom. As expected, both illuminance level and ambient room temperature varied over the year, especially in classroom B, that is the room with the skylight (Figures 2 and 3). At times, the temperature in this room amounted to 32°C. Temperatures as high as this are known to reduce

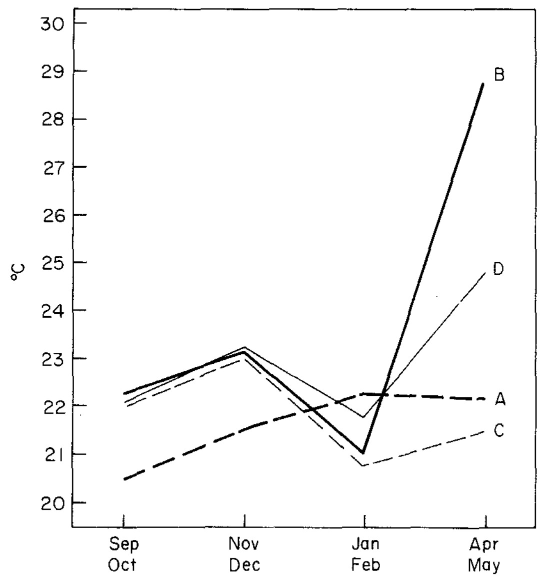

FIGURE 3. Annual variations in ambient room temperature in the four classrooms. (A, ordinary windows and warm-white tubes; B, skylight and daylight tubes; C, windowless and warm-white tubes; D, windowless and daylight tubes.)

both arousal and mental performance (Wyon *et al.*, 1979).

Dependent measures

The methods employed included behavior observation, and the analysis of morning urine for the stress hormone cortisol. These measurements were carried out at regular intervals during the school year. Also body growth and sick leave were recorded after the study was completed. Measurements were taken during the middle or second half of the school week (Wednesdays or Thursdays), and always when the children had spent at least a few weeks in school (e.g. after a major holiday). Thus, we tried to avoid the confounding impact of holidays and weekends (Figure 4).

Sampling and analysis of stress hormones

The assessment of cortisol was based on samples of urine obtained in the morning four times during the

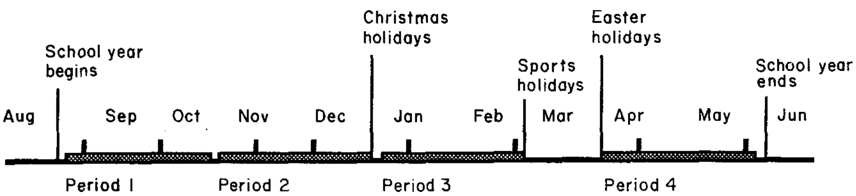

FIGURE 4. For experimental purposes, the school year was divided into four periods.

year (beginning of September and December; end of February and May). Urine samples were collected by the subjects in their homes as part of their daily routine. The first morning urine was sampled around 0700 hours, which means the values obtained in the analyses will reflect the pronounced diurnal rise in cortisol taking place in the early morning hours. All urine samples were deep frozen and later analyzed through a blind procedure at the Central Laboratory of Clinical Chemistry at the University Hospital in Lund. The analysis was by means of radio immuno assay according to Farmos, with a coefficient of variability less than 7·2%.

Behavioral observations

Based on previous experience with observational techniques, a scale consisting of 18 items of common classroom behavior was developed and pre-tested on a separate sample of children (Küller & Lindsten, 1991). The actual observations were carried out by a trained observer during the last 30 min of a standardized 40-min lecture. The lecture was part of the ordinary curriculum in mathematics. It was delivered by the classroom teacher and the children worked individually, but were allowed to communicate in an orderly way both with each other and with the teacher. Each child was observed 20 times during the 30-min period. In a previous study, total unity between three independent observers was obtained for 83% of the scores, when this technique was employed on elderly subjects (Ahlman *et al.*[4]). Observations took place in the actual classrooms after the lunch break on eight occasions spaced evenly over the school year.

Discarding ten of the 18 items, which had received very few scores, the remaining eight behavior items were subjected to factor analysis (BMDP 4M). Based on the average scores for each child, this analysis revealed two salient behavior components, accounting for 48% of the variance (Table 2). These components were clearly recognizable in terms of ability to concentrate, and sociability. Two indices were created for further behavior analyses. The first index, ability to concentrate, consisted of the items 'works independently' as opposed to 'sits at desk without working', 'motoric unrest', and 'turns over leaves absentmindedly'. The second index, sociability, consisted of the items 'talks with schooolmate' and 'inquires, gives/gets help' as opposed to 'works independently'. The scores of the individual items were transformed into standard scores and then averaged to form the two indices.

Recordings of annual body growth

Information about the body growth of each child participating in the study was obtained from the school medical care. The annual measurements were generally taken at the beginning of the autumn terms and in this study covered a period of about 400 days including the summer holidays. A statistical correction was introduced converting all values to annual growth.

Report of sick leave

The occurrence of sick leave for each child was obtained from the notes of the teachers responsible for each of the four classes. Separate records were obtained for the autumn and spring terms.

Statistics and design

Treatment of data was carried out mainly by means of analysis of variance (ANOVA), BMDP 2V, with a

TABLE 2

Factor analysis of the behavior of the school children during the standardized lecture (BMDP 4M, orthogonal rotation, loadings smaller than 0·30 are not reported, n = 88)

Item	Behavior	Factor 1	Factor 2	Factor 3
13	Sits at desk without working	0·80		
7	Motoric unrest	0·67		
6	Turns over leaves absentmindedly	0·55		
1	Works independently	−0·63	−0·77	
14	Talks with schoolmate		0·71	
2	Inquires, gives/gets help		0·70	
17	Other relevant activity			0·84
4	Yawns, sucks thumb, reclines on desk	0·36		0·56
	Part of total variance (%)	33	15	14

design with repeated measures (Dixon, 1983). This is a p × q × r factorial design involving three independent factors; daylight vs no daylight (two levels); warm-white tubes vs daylight tubes (two levels); and the periods of the school year (four levels). The first two factors as well as their interaction were tested between subjects, while the third factor and the remaining interactions were tested within subjects. A detailed discussion of this rather complicated analysis is given by Winer (1962). Other types of parametric statistical treatment included Factor Analysis, BMDP 4M, for data reduction purposes (Harman, 1967; Dixon, 1983), Product Moment Correlation and Partial Correlation. Whenever the assumptions underlying parametric analysis were not fulfilled non-parametric tests were used. These included Spearman's Coefficient of Rank Correlation and Chi-squared testing. In most analyses, data were grouped in four blocks corresponding to four periods of the school year (Figure 4).

Subjects

A total of 88 children aged eight or nine years took part in the study. All the children were in the second form of the comprehensive school. They had been allocated to their classrooms the previous year by the school authorities. Over the year, there was a drop out of about 5% depending on long-term absence and migration. Thus, most of the statistical analyses were based on at least 83 subjects (Table 3). Before the study began informed consent to participate was obtained from both parents, children, teachers, and school authorities.

The school day started at 0800 hours in the morning and ended between 1300 and 1400 hours in the afternoon, with a one-hour lunch break, at 1100–1200 hours. There were also two 20-min breaks, one in the morning and the other in the afternoon. Weather conditions being fine, these breaks were spent outdoors, otherwise the children remained indoors.

TABLE 3
The distribution of the children, who took part in the complete study. The children were in the second form of the comprehensive school and were eight or nine years of age

Classroom	A	B	C	D	Total
Girls	9	12	10	9	40
Boys	7	11	12	13	43
Total	16	23	22	22	83

Results

The impact of light on cortisol

The concentration of cortisol in individual samples varied between 10 and 1200 nmol/l. Since extremely high values of cortisol may occur sporadically in some individuals, a statistical attenuation procedure was introduced, which resulted in the following estimates: morning urine sample, M = 132, s = 98, nmol/l (n = 84). The corresponding values for the boys were M = 145, s = 99, nmol/l (n = 43) and for the girls, M = 118, s = 98, nmol/l (n = 41). There was no significant difference between genders. For statistical purposes the corrected raw values were transformed into Stanine scores (i.e. a normalized nine-step scale, Ferguson, 1959, p. 223).

For each child the level of cortisol in the morning urine was measured four times during the school year, in September, December, February and May. The average result for all four classrooms is given in Figure 5. As can be seen from this figure the secretion of cortisol declined from September till December, when it started to rise again. In May the average value was back at the same level as in September. [ANOVA BMDP 2V for period 1–4, $F_{3,240} = 3{\cdot}16$, $p = 0{\cdot}025$.] The shape of the curve strongly supports the hypothesis of an annual variation, implying that children living in the northern hemisphere produce more stress hormones in summer than in winter.

Looking at the four different classrooms one by one, the same annual pattern appears (Figure 6).

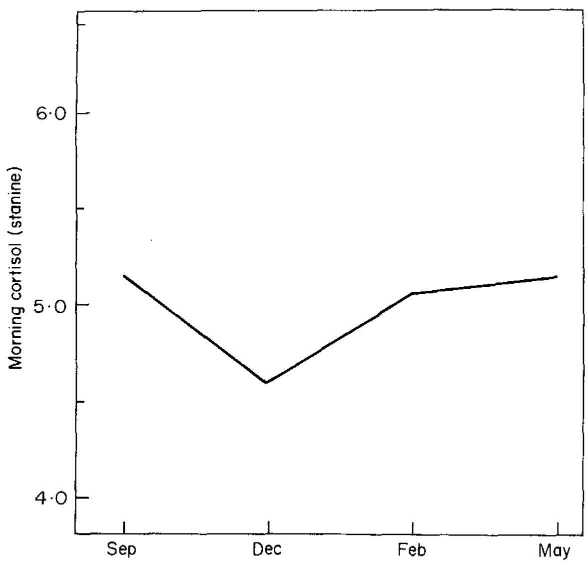

FIGURE 5. The average level of morning cortisol in the children at four times of the year (n = 84).

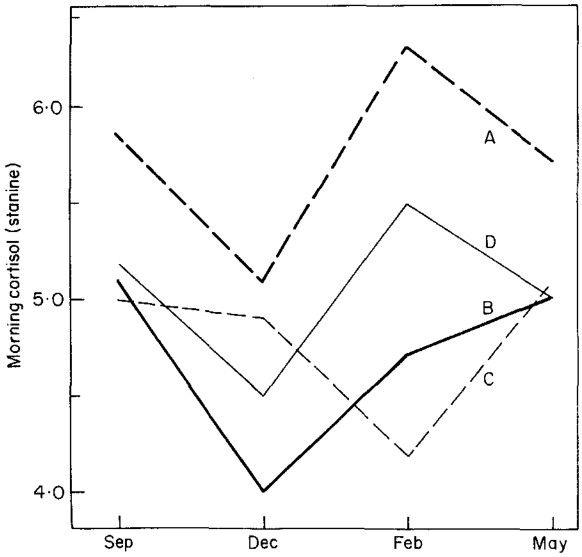

FIGURE 6. Annual variations in morning cortisol in the four classrooms. (A, ordinary windows and warm-white tubes: B, skylight and daylight tubes; C, windowless and warm-white tubes; D, windowless and daylight tubes.)

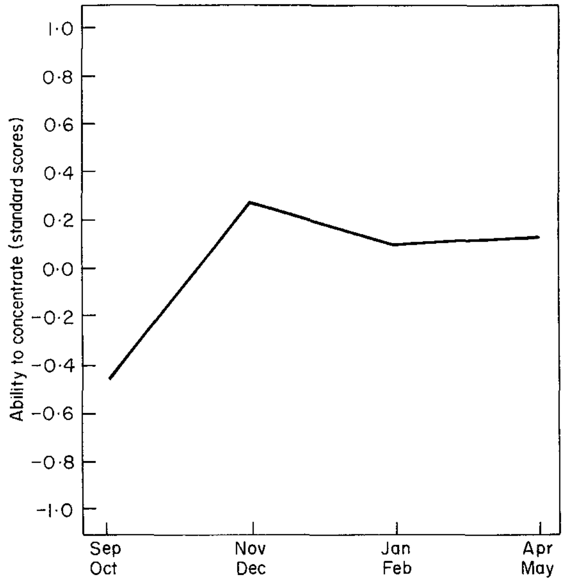

FIGURE 7. The children's ability to concentrate averaged at four times of the year. (n = 84. The scale is based on standard scores for behavior items nos 1–6–7–13/4.)

From high values in September, the production of cortisol declined and reached a minimum in December (with the exception of classroom C, which will be discussed later). Then, in spring the production of cortisol again increased. For two of the classrooms (A and D) the increase had been completed already in February.

However, the children in classroom (C) showed a marked delay in their annual pattern. [Interaction, $F_{3,240} = 2{\cdot}93$, $p = 0{\cdot}035$.] For these children, the level of cortisol kept falling even after December, and did not reach its minimum value until February. Then, there was a strong rise until the fairly high level in May. In February, the difference between the classrooms became highly significant [$F_{1,80} = 13{\cdot}62$, $p = 0{\cdot}0004$]. Since classroom (C) had neither windows nor daylight tubes, the children in this classroom were the ones which obtained the least amount of daylight. This result indicates that the absence of daylight may delay the annual variation in the production of cortisol by as much as two months.

Finally, it may be noted that the classroom (A) with normal windows had the highest all over level of cortisol [ANOVA for raw values, $F_{1,80} = 5{\cdot}52$, $p = 0{\cdot}02$.] For fairness it should be said that the pupils belonging to this form appeared to be somewhat more restless than the other children. This may well be a result of the high level of cortisol. However, there may be other confounding factors at work, like social unrest. Instead of comparing absolute levels of cortisol, it may therefore be wise to study the annual variations within each classroom.

Impact on behavior

As will be seen in Figure 7, the children's ability to concentrate, as defined above, varied over the school year. For the first one or two months after the summer holidays, the ability to concentrate was low, with noticeable elements of motoric unrest. Then, the ability to concentrate increased and reached its highest value in November or December. After the Christmas holidays, there was a slight decrease, but all in all, the concentration remained high during the spring term. [Annual variation, $F_{3,240} = 42{\cdot}94$, $p = 0{\cdot}0000$.]

Comparing Figures 5 and 7, an inverse relationship between the annual variations in cortisol and the ability to concentrate seems plausible. To investigate this further, the average cortisol levels were plotted against the average ability to concentrate (Figure 8). There is some support for the existence of a negative relationship (rho $= -0{\cdot}64$, $n = 16$, $P < 0{\cdot}01$). It should however be noted, that this correlation was not based on individual variation, but on classroom averages at four times during the year. The result must therefore be interpreted with the utmost care.

The next step in the analysis was to look at the annual variation in ability to concentrate in each of

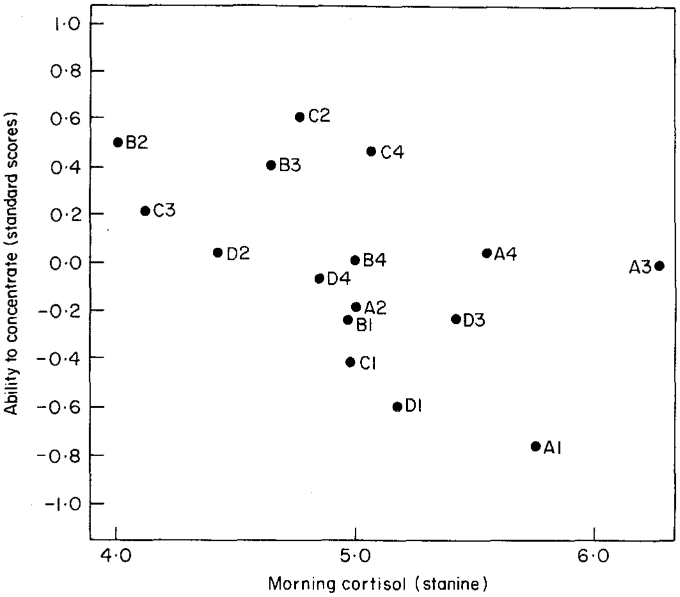

FIGURE 8. The relationship between morning cortisol and ability to concentrate averaged for four classrooms (A–D) at four times during the year (1–4) (rho = −0·64, n = 16, p < 0·01).

the four classrooms. As will be seen in Figure 9, the overall concentration was higher in classrooms B and C, than in the other two classrooms [$F_{1,80}$ = 18·85, p = 0·0000]. There was a considerable increase in all the classrooms during the autumn term. In the two classrooms with windows (A and B), the concentration remained high until February, while the ability to concentrate dropped considerably in the windowless classrooms (C and D). In these two classrooms there was a recovery in May, while there was a marked decline in the classroom (B) with the skylight, most likely as a result of the great increase in room temperature that took place in that classroom in late spring. (Compare Figure 3.)

It was evident that the ability to concentrate developed more smoothly in the classroom with conventional windows than in the other classrooms [$F_{3,240}$ = 2·90, p = 0·035]. One may conclude, that the ability to concentrate increases during the first part of the school year, but also may be sensitive to various kinds of disturbances, like lighting, and ambient room temperature. However, the annual variations may also, to some extent, depend on chronobiological changes within the individual.

As will be seen in Figure 10, the children's social behavior, as defined above, also displayed pronounced annual variations. From high values at the beginning of the autumn term, the sociability went down towards the end of the term, but again increased during the spring term [$F_{3,240}$ = 14·44, p = 0·0000]. Actually, the shape of the curve strongly resembles that of cortisol (Figure 5). As seen in Figure 11, the correlation between sociability and cortisol, again based on classroom averages, was strong and positive (rho = 0·71, n = 16, p < 0·01). The shape of the sociability curve is also partly inverted compared to the curve for concentration.

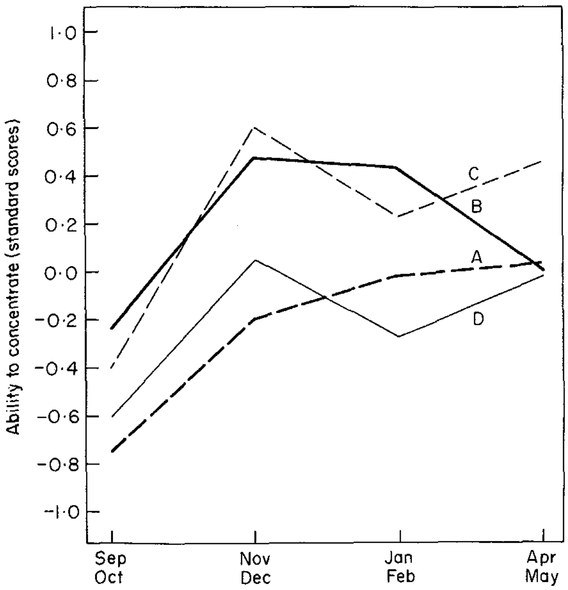

FIGURE 9. Annual variations in the ability to concentrate in the four classrooms. (A, ordinary windows and warm-white tubes; B, skylight and daylight tubes; C, windowless and warm-white tubes; D, windowless and daylight tubes.)

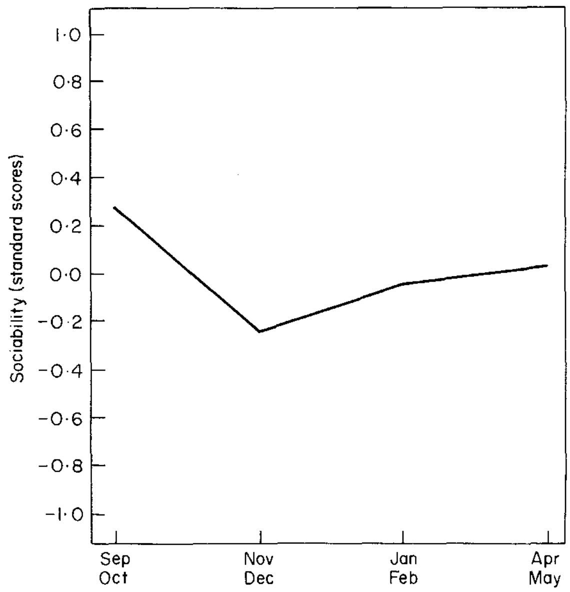

FIGURE 10. The children's sociability averaged at four times during the year (n = 84). The scale is based on standard scores for behavior items nos 2 + 14 − 1/3).

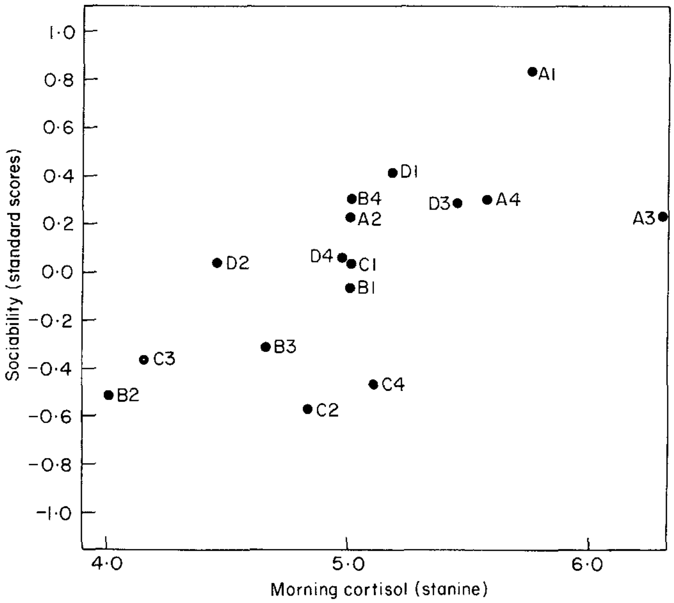

FIGURE 11. The relationship between morning cortisol and sociability averaged for four classrooms (A–D) at four times of the year (1–4) (rho = 0·71, $n = 16, p < 0.01$).

On the average, sociability was higher in classrooms A and D than in the other two classrooms [$F_{1,80} = 30{\cdot}24, p = 0{\cdot}0000$]. In all four, sociability was high at the beginning of the autumn term (Figure 12). Then, during the rest of the year, the school children worked more independently, with one exception. In the classroom with the skylight

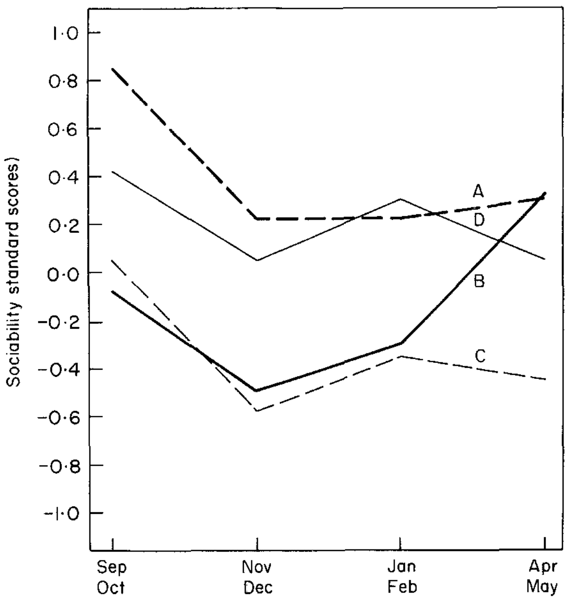

FIGURE 12. Annual variations in sociability in the four classrooms. (A, ordinary windows and warm-white tubes; B, skylight and daylight tubes; C, windowless and warm-white tubes; D, windowless and daylight tubes).

(B), sociability increased drastically at the end of the spring term [$F_{3,240} = 3{\cdot}37, p = 0{\cdot}02$]. Again, this may have been a result of the prevailing, extremely high, temperature that would make it more difficult for the children to concentrate on their mathematics (compare Figure 3).

Body growth

It would have been desirable to obtain measures of body growth at several occasions during the school year. Unfortunately, this was not possible, and we are left with an estimate for the whole year, with both light and dark periods. An estimation of annual body growth for 75 of the children gave M = 5·7 cm, s = 1·2. The girls grew, on the average, 0·5 cm more than the boys (Chi-squared = 7·68, df = 2, $p = 0{\cdot}025$). There were no significant differences between the four classrooms.

However, there was an overall correlation between morning cortisol and annual body growth ($r = -0{\cdot}30$, $n = 74$, $p = 0{\cdot}009$). This means that the children with high levels of morning cortisol did not grow as much as the other children (even when corrections for body length were made in cortisol concentration). The negative relationship between annual growth and cortisol became strongest during winter (Table 4). The reader will remember, it was during this time the production of cortisol displayed major swings. (Compare Figures 5 and 6.)

Recorded sick leave

For the children taking part in the study, sick leave varied between zero and 40 days (school year median = 5, autumn term median = 2, spring term median = 3). The difference between the two terms was significant (Chi-squared = 7·59, df = 1, $p < 0{\cdot}01$), but the spring term is somewhat longer

TABLE 4
The relationship between morning cortisol at different times of the year and the annual body growth of the children (n = 74)

Season	Correlation	Significance
All year	$r = -0{\cdot}30$	$p = 0{\cdot}009$
Autumn term	$r = -0{\cdot}28$	$p = 0{\cdot}02$
Spring term	$r = -0{\cdot}26$	$p = 0{\cdot}03$
September	$r = -0{\cdot}19$	$p = 0{\cdot}10$
December	$r = -0{\cdot}26$	$p = 0{\cdot}03$
February	$r = -0{\cdot}29$	$p = 0{\cdot}01$
May	$r = -0{\cdot}15$	$p = 0{\cdot}22$

TABLE 5
The relationship between morning cortisol and sick leave at different times of the year

Season	Correlation	Significance
All year	$r = -0.01$	$p = 0.92$
Autumn term	$r = -0.19$	$p = 0.09$
September	$r = -0.07$	$p = 0.55$
December	$r = -0.23$	$p = 0.03$
Spring term	$r = 0.05$	$p = 0.67$
February	$r = 0.05$	$p = 0.63$
May	$r = 0.03$	$p = 0.81$

than the autumn term. However, there were no significant differences in sick leave between the four classrooms. Transforming the raw values into Stanine, it became possible to correlate sick leave with morning cortisol levels (Table 5). Even if the correlations were low, some interesting tendencies appeared. Those children, who had the lowest cortisol levels in December, also were more sick during the autumn term.

Conclusions

The aims of the study were to assess the effects of natural daylight vs two types of fluorescent light on the production of stress hormones, classroom performance, body growth, and sick leave, of school children. The overall relationship between light and cortisol indicated the existence of a systematic seasonal variation with more stress hormones in summer than in winter. This is in line with chronobiological theory, where cortisol has been described as one of the circannual markers (e.g. Hollwich, 1979). However, as far as the authors know, it is the first time a circannual rhythm of urinary free cortisol has been demonstrated in children. The decline became most pronounced during a period lasting from November to December, followed by a noticeable rise, which in the south of Sweden seemed to occur around February.

The children, situated in the one classroom lacking both natural and artifical daylight, demonstrated a marked delay in this rise. This result is important, since it may indicate that work in windowless environments, or environments which lack adequate illumination, may cause a severe disturbance in the chronobiological system regulating the production of hormones. This interpretation is supported by a previous field study, were it was found that personnel positioned close to a window had higher levels of morning cortisol during summer than during winter, while those working far away from a window deviated from this pattern (Erikson & Küller, 1983). Taken together, the results from these two studies indicate that both natural daylight and artificial light will affect the chronobiological system, and that fluorescent tubes of the daylight type may be more potent than conventional fluorescent tubes. In northern countries, the critical period seems to be late autumn, winter, and early spring.

As concerns behavior, seasonal patterns were found both in the ability to concentrate and to co-operate. To some degree, these patterns were related to the major holidays during summer and Christmas. However, climatic factors, such as natural daylight and indoor temperature, also seemed to play important roles. This may partly be related to chronobiological changes within the individual and partly, especially where variations in temperature were involved, to changes in tonic arousal (Evans & Cohen, 1987; Küller, 1991). There is good reason to look further into these hypothetical relationships. High values of morning cortisol were associated with an inclination towards sociability, while moderate or low values of cortisol seemed to promote individual concentration as defined by the two indices used in our study. This is partly in line with the findings by Virkkunen (1985), that childhood histories of undersocialized conduct were associated with low levels of urinary free cortisol. This knowledge may be useful in planning the work of the school day as well as the school year.

Seasonal factors also seem to influence body growth. Those children with high values of morning cortisol had a somewhat smaller increase in annual body growth. This is in line with the observation made in some population studies that psychological stress, by affecting the secretion of growth hormone, may cause relative failure in child growth (Eveleth & Tanner, 1990, p. 204). This inverse correlation became most pronounced during the winter period from November to February. Body growth is regulated, amongst others, by the hormones somato-tropin from the pituitary gland, a process partly regulated from hypothalamic areas. Pineal melatonin may be one possible regulator of this process, which therefore would become sensitive to light stimulation.

Finally, the production of cortisol, especially during December, seemed to have some influence on sick leave. High values of cortisol during this period correlated with low rates of sick leave. A tendency only, this result, because of its intrinsic importance, should be followed up in further research. Since cortisol acts as a mobilizer of the body's defense, it seems reasonable that sick leave became highest for those children with the lowest cortisol levels. Put differently, if one managed to raise these levels by means of improved illumination, the most susceptible children might become more resistant to colds, and other infections. There was some support for this idea in a study by Lykken (1982), who found that children at day-care centers, who spent more hours out-doors during winter, became more resistant to disease.

Taken together the results indicate, work in classrooms without daylight may upset the basic hormone pattern, and this in turn may influence the children's ability to concentrate or co-operate, and also eventually have an impact on annual body growth and sick leave. This may be a partial answer to the doubts about windowless design expressed by Collins (1975) and Weinstein (1979). A better understanding is needed about what properties of light cause the various effects. The plausible components are, the intensity of light, the spectral composition, spatial distribution, and temporal fluctuations (macro and micro). Furthermore, the total exposition time to light, and the phase displacement between chronobiological rhythms and external lighting conditions, may turn out to be crucial. There might also be alternative factors at work, and we must not hasten to explain all recurrent events solely in terms of daylight variations.

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