Time-Dependent Effects of Indoor Lighting on Well-Being and Academic Performance

Kenan Eren Sansal

University College London

Research Degree: The Bartlett School of Graduate Studies

I, Kenan Eren Şansal confirm that the work presented in this thesis is my own. Where information has been derived from other sources, I confirm that this has been indicated in the thesis.

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Abstract

Our knowledge of how changes in environmental lighting conditions affect non-visual processes in humans is less than adequate and based mainly on cross-sectional laboratory studies. Thus, the present research was designed to address the questions raised by the literature and clarify the non-visual effects of indoor lighting by carrying out two field studies at two different latitudes.

During the period between the 8th of October 2008 and 10th of June 2009, the first field study was conducted in four similar classrooms of a junior school in Kent, U.K. The classrooms differed in the provision of artificial illumination and daylight. The study population consisted of fifty-six, fourth-grade students, aged between eight and nine years.

Throughout the study, five main and five supplementary data collections were executed at approximately four-week intervals to assess participants' sleep quality, mood and sleepiness by administering self-reports and also their diurnal melatonin and cortisol concentrations by collecting saliva samples. Additionally, data regarding participants' performance on school examinations were collected to evaluate academic achievement.

The results of the study revealed that natural light itself might be a potent factor in promoting the non-visual effects. Therefore, the second field study was conducted during the period between the 5th of January 2011 and 20th of January 2011 to verify the findings. The study was conducted in two similar classrooms of a junior school in Ankara, Turkey. The classrooms differed only in the provision of daylight. The study population consisted of seventy-nine, third-grade students, aged between eight and nine years.

Throughout the study, two data collections were executed to assess participants' sleep quality, mood and sleepiness by administering self-reports. Additionally, data regarding participants' performance on school examinations were collected to assess academic progress.

The second field study confirmed the findings form the previous field work. The participants who were exposed to more natural light at eye level reported significantly less daytime sleepiness and better sleep quality and overall mood. Moreover, their scholastic performance was comparatively better. Complementary information on the physiological, psychological and cognitive effects of indoor lighting that can be linked to our biophilic tendencies and Environment of Evolutionary Adaptedness is provided by the results of the two field studies.

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This dissertation is gratefully dedicated to my teacher, Assoc. Prof. Cengiz Yener (1934-2009), and my grandfather, Mr. Hasan Fehmi Alper (1917-1996).

Chapter 1

Literature review

… the future of lighting research in interiors lies in a move beyond visibility and visual discomfort to areas where lighting operates on mood and behaviour through the message it sends and on health and task performance through the circadian system.

Peter R. Boyce, 2004

Chapter 1 - Literature review

Buildings have been providing shelter from the exigencies and hazards of the natural world (*e.g.*, extreme weather conditions) for approximately three hundred thousand years (Goudie, 1990). Unlike primitive dwellings, modern-day buildings are often equipped for providing the appropriate or desired levels of heat and humidity. Further, these man-made structures contain internal lighting systems in order to compensate for the absence or limited availability of daylight penetration and allow the occupants to function during the day and, also, at night. For many years, a myriad of the empirical investigations into indoor lighting have been, therefore, confined to visibility and visual discomfort for exclusively meeting our visual needs (Boyce, 2004). However, apart from vision, it has been demonstrated that the lighting of interiors may have other implications for the physical, emotional and cognitive well-being of man. In the late 1990s, the non-visual aspects of light, primarily artificial light, began to become an area of considerable interest and be more clearly delineated (Veitch, 2002; Veitch *et al.*, 2004). Given the relative novelty of the research on light and non-visual human needs, it is apparent that a number of important and promising questions still remain to be answered by the community of lighting.

1.1 The direct effects of indoor electric lighting on mood and cognition:

A large body of work in both laboratory and field settings indicates that the way individuals feel have a potent influence on the way they think and behave (see Isen, 1984; Isen, 1987; Isen, 1999 for this discussion). More specifically, the research suggests that even mild shifts in mood[*], especially the shifts in the direction of increased positive and pleasant feelings[†], are sufficient enough to alter cognitive processing (*e.g.*, memory, learning and flexibility in thinking) and social behaviour (*e.g.*, helping, sociability and bargaining). As convincing evidence has accumulated regarding the impacts of feeling states, a growing number of researchers have sought to determine whether indoor lighting can enhance mood and, as a direct consequence, facilitate thinking. Although some of the early studies reported that differences in the illuminance generated and colour properties of illuminants did not have

[*] According to Isen (1987, p. 205), "feelings" or "feeling states," which may also be called "moods," refers to "generalised affective experiences that do not demand or seem to focus immediate attention on themselves. They are usually, but not necessarily, relatively low level. Examples would include the kinds of things one feels as one goes about the activities of the day – listens to music, finds money on the street, gets wet in a cold rain, …"

[†] The research literature on the influence of mood indicates that positive and negative feelings are not usually symmetrical or equivalent concerning their effects (see Isen, 1984; Isen, 1987; Isen, 1990; Isen, 1999 for this discussion).

any significant impact (*e.g.*, Boray *et al*., 1989; Kuller and Wetterberg, 1993; Smith and Rea, 1979; Veitch, 1997; Veitch *et al*., 1991), most of the subsequent research have provided suggestive evidence that environmental lighting conditions can alter mood and thought processes. The problems with the latter studies are that the direction of the change is not always consistent with lighting conditions and gender-specific differences have been reported by a number of investigators. Concerning their contradictory or confusing results, some of the ensuing studies are worth mentioning in this section.

One of the early and prominent contributions to the literature on non-visual light responses in humans was made by Baron *et al*. (1992). In a series of rigorous experiments conducted in a mock-up of an office room, Baron and colleagues examined whether different illuminance levels and artificial light sources could influence mood and cognition. In their first experiment, ninety-one participants were exposed to four different light sources (*i.e.*, warm white fluorescent lamps with a correlated colour temperature, or a CCT, of 3,000 K, natural white fluorescent lamps with a CCT of 3,600 K, cool white fluorescent lamps with a CCT of 4,200 K or daylight fluorescent lamps with a CCT of 5,000 K) and two different illuminances (*i.e.*, either 150 lux or 1,500 lux). While the researchers were not able to demonstrate any significant association between indoor lighting and mood, they reported that the illuminance levels had differential effects on participants' cognitive capability. The participants in the low illuminance conditions performed substantially better on a cognitive task than those in the high illuminance conditions. In their second experiment, a lower number of participants were exposed to only two of the light sources (*i.e.*, either warm white fluorescent lamps or cool white fluorescent lamps) and the same illuminance levels. Surprisingly, the results were in stark contrast to those obtained in the first experiment. There was neither a beneficial nor a detrimental effect of the different lighting conditions on participants' cognitive functioning. However, it was evident that the warm white fluorescent lamps providing 150 lux significantly improved participants' mood in comparison with the same lamps providing 1,500 lux. In their last experiment, a higher number of participants were exposed to the same lighting conditions and evaluated with respect to their mood status. There was a reasonable concordance between the results of the last two experiments. Baron and colleagues found that, under warm white lighting, the participants exposed to 150 lux were calmer and more alert.

Another early study was carried out by Daurat *et al*. (1993) to assess the psychostimulating effects of bright artificial light, both subjectively and objectively, in an adult population. Throughout the study, eight healthy male students attended two experimental sessions that took place in an environmentally controlled laboratory setting. In the sessions, following a two-hour exposure to 300 lux, all participants were exposed to either bright (*i.e.*, 2,000 lux) or dim (*i.e.*, 150 lux) light from 09:00 a.m. until the next morning for 24 hours while they were sitting around a table without sleeping. Although Daurat and colleagues failed to demonstrate any significant effect of the lighting conditions on alertness, it was apparent from the results inconsistent with those of the above-mentioned experiments that, in the high illuminance condition, their participants were in a notably better mood during the day (*i.e.*, between 09:30 a.m. and 06:30 p.m.).

An equally important contribution to the literature was made by Knez (1995). In an attempt to partially replicate and expand upon the work of Baron *et al*. (1992), Knez performed two meticulous laboratory experiments in which he investigated whether fluorescent lighting might serve as a "mood inducer" and, as a direct consequence, alter cognition in humans. In his first experiment, ninety-six participants were exposed to two different light sources (*i.e.*, either warm white fluorescent lamps with a CCT of 3,000 K or cool white fluorescent lamps with a CCT of 4,000 K) with a high colour rendering index, or CRI, of 95 and two different illuminances (*i.e.*, either 300 lux or 1,500 lux) for roughly 2 hours. Unlike Baron and colleagues, Knez were able to demonstrate that different fluorescent light sources could concurrently influence mood and cognitive performance. However, the results were gender-related. While warm white lighting was more favourable for the females, cool white lighting was more beneficial to the males. In his second experiment, the participants were exposed the same illuminances generated either by warm white (*i.e.*, 2,950 K) or cool white (*i.e.*, 4,200 K) fluorescent lamps with a low CRI of 51 for the same time period. Unexpectedly, the results were not similar to those of the first experiment. It was revealed that, in the low intensity cool and high intensity warm white lighting conditions, both the male and the female participants were in a more positive mood state and more successful in a number of cognitive tasks.

A broadly similar study by Knez and Enmarker (1998), which can be regarded as a replication of Knez's (1995) first experiment, is also of particular concern. In the study, eighty adults were exposed to two different light sources (*i.e.*, either warm white fluorescent lamps with a CCT of 3,000 K or cool white fluorescent lamps with a CCT of 4,000 K), with a high CRI of 95, arranged to provide approximately 1,500 lux on the work plane. Unfortunately, even though the light sources under investigation were the same, the results were entirely inconsistent with those of the first experiment. Unlike Knez, Knez and Enmarker could not find any relationship between the different fluorescent lighting conditions and participants' cognitive performance. Moreover, it was clear from the results that the male participants were in a considerably better mood under warm white lighting and the cool white lighting condition had the same effect on the females.

Another early empirical research by McCloughan and colleagues (1999), which is particularly relevant to the possible connection between indoor lighting and mood, is also well worth citing. In the study, sixty-four adults were exposed to two different light sources (*i.e.*, either warm white fluorescent lamps with a CCT of 3,000 K or cool white fluorescent lamps with a CCT of 4,000 K) and two different illuminances (*i.e.*, either 300 lux or 700 lux) for 45 minutes. Regrettably, there was not a high degree of concordance between the findings of McCloughan *et al*. and those of the others. Contrary to the observations of Baron *et al*. (1992), the researchers found that, under warm white lighting, the participants exposed to 700 lux became less anxious and hostile over time. By contrast, participants' mood deteriorated significantly in the high intensity cool white lighting condition. Moreover, there were unexpected gender-specific differences. While the forty-five-minute exposure to 700 lux was favourable for the females, it increased dysphoria amongst the male participants.

A methodologically similar study by Knez and Kers (2000) should also be mentioned in the present context. In an effort to expand upon and clarify the preliminary reports of Knez and colleagues, the investigators examined whether and how the observed non-visual effects of indoor lighting might vary as a function of gender and age. In the study, eighty adults were exposed to two different light sources (*i.e.*, either warm white fluorescent lamps with a CCT of 3,000 K or cool white fluorescent lamps with a CCT of 4,000 K), with a high CRI of 95, positioned to produce 500 lux on the work plane. Although Knez and Kers failed to demonstrate any significant effect of the lighting conditions on various cognitive parameters, they found that lighting-induced mood changes could slightly differ between age groups. While warm white lighting was more favourable for the young adults, cool white lighting was more beneficial to the elderly participants. Surprisingly, in sharp contrast to the previous reports, there were no gender-related differences.

A similar and an equally valuable contribution to the field was made by Knez (2001). In a new attempt to reconcile the divergent results obtained by him and other researchers, Knez conducted another experiment in an environmentally controlled laboratory setting. In his experiment, one hundred and eight university students were exposed to three different light sources (*i.e.*, warm white fluorescent lamps with a CCT of 3,000 K, natural white fluorescent lamps with a CCT of 4,000 K, cool white fluorescent lamps with a CCT of 4,200 K or daylight fluorescent lamps with a CCT of 5,500 K), with a high CRI of 95, arranged to provide 500 lux on the work plane. Unfortunately, the results were far from being conclusive and coherent. Despite the lack of significant mood changes, marked differences were observed in respect of cognition. While the warm white fluorescent lamps substantially enhanced both the short-term memory and problem-solving ability of the whole sample and the long-term memory of the females by comparison with the other lamp types, the daylight fluorescent lamps had the same effect on the long-term memory of the male participants.

Concerning our current state of knowledge as to the non-visual outcomes of artificial light exposure, a relatively recent experiment regarding the effects of different environmental conditions on mood and cognitive functioning (Knez and Hygge, 2002) should also be cited. In their study carried out in an experimental chamber, ninety-six young adults were exposed to two different noise levels (*i.e.*, either 38 dBA or 66 dBA) and two different light sources (*i.e.*, either warm white fluorescent lamps with a CCT of 3,000 K or cool white fluorescent lamps with a CCT of 4,000 K), with a high CRI of 95, generating an illuminance level of approximately 500 lux. For the present purpose, the most important finding of Knez and Hygge was that the lighting conditions improved participants' cognitive processing without altering their mood states. Furthermore, the results were not in accord with those presented by Knez (2001) and Knez and Kers (2000). Within 85 minutes, the cool white fluorescent lamps significantly impaired participants' long-term memory compared to the warm white fluorescent lamps.

A recent study by Kuller *et al*. (2006) is also of importance since it is one of the few field investigations into the effects of indoor lighting conditions on non-visual processes. With the aim of determining whether lighting indoors and colour might influence mood, Kuller and colleagues performed their study in four countries (*i.e.*, Argentina, Saudi Arabia, Sweden and United Kingdom) over two consecutive years. Throughout this longitudinal study, nearly one thousand office and factory workers were surveyed in their own working environment illuminated mainly by fluorescent lamps and exposed to average illuminance levels between 265 and 869 lux on the work plane. Unexpectedly, there was not a close correspondence between the results and those of the previous research. It was found that the influence of illuminance on mood was negligible. However, participants' mood was at its highest when indoor lighting was perceived as "neither too bright nor too dark."

It may also be necessary for the present argument to point out a more recent contribution by Iskra-Golec and Smith (2008). In order to delineate and compare the psychological and cognitive effects of "intermittent bright light" and "ordinary room light" exposures in an adult population, twenty university students were studied in eight thirteen-hour experimental sessions and exposed to constant dim (*i.e.*, 300 lux) fluorescent lighting and 15 minutes long bright (*i.e.*, 4,000 lux) light pulses* in environmentally controlled rooms. The results were similar, but not identical, to those obtained in the initial experiment of Knez (1995). The intermittent bright light pulses resulted in slightly better performance on various cognitive tasks and higher vigour ratings. Therefore, Iskra-Golec and Smith, somewhat questionably, concluded from the results that bright fluorescent lighting might have important implications for lighting research and design.

Before extending the scope of this literature review and providing a different body of empirical evidence for a possible link between lighting and our emotional experience, a recent field study by Viola *et al*. (2008) is also well worth attention. In an effort to find out whether a "novel light source" with an extremely high CCT of 17,000 K might influence a wide variety of non-visual outcomes in a population of white-collar workers, Viola and colleagues conducted their research in a large office building over eight consecutive weeks. Following the baseline examination in the existent lighting condition, ninety-four employees were exposed to two different light sources (*i.e.*, both cool white fluorescent lamps with a CCT of 4,000 K and Activiva Active fluorescent lamps) during their working hours. By far, the most prominent finding of the investigators was that the atypical fluorescent lamps notably elevated participants' mood and improved their subjective performance. Despite the fact that the "blue-enriched" lamps were producing 310 lux on the work plane, they were vastly superior to the other type of lamps emitting 421 lux.

* Except for during the brief periods of bright light exposure, 300 lux was provided in the sessions.

Chapter 1 - Literature review

1.1.1 Light therapy for general population:

The pathological mechanisms causing winter depression are largely unknown. A number of explanations based on disturbances in the endogenous rhythm of melatonin secretion and various abnormalities affecting the regulation of serotonin biosynthesis have been proposed so far. However, none of the explanations are completely satisfactory (Magnusson and Boivin, 2003). In spite of the fact that the pathogenesis of winter depression is still unclear, light therapy has been proven to be an effective non-pharmacological treatment for seasonal mood disorders (see Magnusson and Boivin, 2003; Terman and Terman, 2005 for this discussion). The finding that light therapy is effective in ameliorating depressive symptoms amongst patients with winter depression has led to the question as to whether or not bright artificial light exposure can be used to improve mood in general population. Although the early studies reported that bright light treatment did not benefit healthy individuals without season-dependent symptoms (*e.g.*, Bauer *et al*., 1994; Genhart *et al*., 1993; Kasper *et al*., 1989, 1990; Rosenthal *et al*., 1987), most of the subsequent research have indicated that it can alleviate psychological distress in general population. Concerning their complementary and convergent results, some of the later studies need to be mentioned in the present section.

One of the seminal contributions to our knowledge about the benefits of bright light treatment amongst adults was made by Partonen and Lonnqvist (2000). In a field study, the investigators measured the severity of the depressive symptoms suffered by one hundred and sixty Finnish office workers throughout the winter. Additionally, they evaluated the efficacy of bright artificial light exposure in improving participants' health-related quality of life and reducing their emotional distress. Over eight weeks, the workers were instructed to use light boxes, providing approximately 2,500 lux at eye level, for at least 1 hour a day and on five to seven days a week. Unsurprisingly, it was apparent from the results that the repeated exposures to bright light significantly increased vitality and reduced depressive symptoms. An interesting finding was that the favourable effects were not observed only in the participants with depressive symptomatology but also in those without any mood disturbance.

It should be noted here that the advantages of light therapy appear to be enhanced by combining bright light exposure with physical exercise. In southern Finland, Partonen *et al*. (1998) undertook a research into the effects of fitness training and high illuminance levels on health-related quality of life and emotional well-being in an adult population. Between November and January, one hundred and twenty employees working indoors were assigned to one of the following treatment conditions: (a) fitness training* under bright (*i.e.*, 2,500-4,000 lux) artificial lighting; (b) fitness training under ordinary (*i.e.*, 400-600 lux) room lighting or (c) relaxation training† in a "dimly lit" room. Partonen and colleagues found that the combination of taking vigorous exercise and being exposed to bright light was considerably more effective than the other conditions. More specifically, it resulted in greater relief from atypical depressive symptoms (*e.g.*, carbohydrate craving) and more vitality. Moreover, the observed effects bore no relation to the history of participants' season-dependent symptoms.

A broadly similar study by Leppamaki *et al.* (2002) is also of interest. In an effort to verify and expand upon the work of Partonen *et al.* (1998), the researchers assessed whether intense physical exercise and bright light exposure might strongly influence psychological well-being in adults. Between November and January, one hundred and twenty-four office workers were randomly assigned to one of the following three conditions: (a) aerobics training‡ under bright (*i.e.*, 2,500-4,000 lux) artificial lighting; (b) aerobics training under ordinary (*i.e.*, 400-600 lux) room lighting or (c) relaxation training supplemented with bright light exposure. The results were in accord with those reported by the other two groups. Leppamaki and colleagues found that, irrespective of the occurrence of winter depression in the sample, being exposed to high illuminance levels significantly ameliorated participants' psychological well-being.

The results of the studies reviewed above are preliminary and certainly not definitive. Further research into the effects of various light intensities and exposure durations is required to reach a firm conclusion that light therapy is beneficial to general population. In addition, the treatment efficacies of different light spectra were evaluated by none of the researchers. This can be attributed to the fact that investigating the therapeutic properties of light sources has received relatively little attention (Terman and Terman, 2005). It should be noted here that the human circadian system has been recently reported to be most sensitive to light stimuli at wavelengths between 446 and 477 nm (see Brainard *et al.*, 2001a, 2001b; Lockley *et al.*, 2003; Thapan *et al.*, 2001 for detailed information). In other words, it has been demonstrated that our circadian system has a luminous efficiency quiet distinct from either the photopic (*i.e.*, V_λ) or the scotopic (*i.e.*, V'_λ) luminous efficiency functions (see Figure 1.1).

* The sessions for fitness training were 1 hour in duration, and they were performed twice or three times a week.
† The sessions for relaxation training were 1 hour in length, and they took place only once a week.
‡ All training sessions lasted for 45 minutes and took place twice a week.

Therefore, the administration of the blue portion of visible light spectrum for treating winter depression has lately begun to draw scientific attention.

Figure 1.1 The graphical representation of the photopic (solid line), scotopic (dotted line) and circadian (dashed line) luminous efficiency functions (Rea *et al*., 2002)

A recent empirical research by Glickman and colleagues (2006), which is particularly relevant to the selection of appropriate light sources for light therapy, is well worth citing. In the study carried out between October and March, twenty-four outpatients with winter depression were requested to use one of the two portable light boxes consisting of either blue or red light emitting diodes[*] for approximately 45 minutes in the morning over three-week periods. Fortunately, there was not an unexpected disagreement between the results and assumptions of Glickman *et al*. Being exposed to short wavelength visible light was more efficacious in the relief of depressive symptoms, and it could be a substitute for the standard bright (*i.e.*, 2,000-10,000 lux) light treatment.

An equally important contribution to the elucidation of employing light emitting diodes was made by Desan and colleagues (2007). With the aim of testing the utility of a light therapy device, the study was performed in three countries (*i.e.*, Canada, Netherlands and United States) between October and January. Over four-week treatment periods, twenty-three adults with season-dependent depressive symptoms were exposed to either bright (*i.e.*, 1,350 lux) short wavelength light or a "faint high-pitched whine" produced by an inactivated negative ion generator for 30 minutes on each day. Unsurprisingly, there was a close correspondence between the findings of Desan *et al*. and those of Glickman *et al*. (2006). The light therapy device notably improved participants' mood in comparison with the inactivated

[*] While the light sources emitting blue light were arranged to provide 398 lux at eye level, 23 lux was produced by the other sources.

negative ion generator. Furthermore, it was evident that the rate of remission in the participants using the device was much greater.

A broadly similar study by Schlangen and Geerdinck (2007) should also be mentioned here since it is one of the few attempts at understanding the effects of different light spectra on seasonal mood variations in humans. In order to assess the therapeutic efficacy of a “new fluorescent light source,” fifty-two outpatients with winter depression were studied. Over two weeks, the patients were two different light sources (*i.e.*, either daylight fluorescent lamps with a CCT of 5,000 K or Activiva Active fluorescent lamps with a CCT of 17,000 K) generating an illuminance level of approximately 10,000 lux. The results were in direct contradiction to researchers’ assumptions. In spite of the fact that both of the fluorescent lamp types decreased the severity of participants’ complaints, Activiva Active fluorescent lamps were not superior to the other type of lamps. Accordingly, Schlangen and Geerdinck stated that there might be a threshold illuminance level below which short wavelength lighting could be more advantageous. Even though this hypothesis is partially supported by the findings of Glickman *et al*. (2006), there is a need to seek further scientific evidence for treating winter depression by means of light therapy.

Chapter 1 - Literature review

1.2 The indirect effects of indoor electric lighting on mood and cognition:

1.2.1 Probable association between diurnal light exposure and sleep:

Many aspects of sleep remain a mystery, including why we spend one third of our lives asleep (Griffith and Rosbash, 2008). Even though the fundamental purpose of sleep has not been well understood, it can be speculated that the quantity and quality of sleep contribute to restoring bodily and mental functions and, as a direct consequence, our physical and psychological well-being (McCrae *et al*., 2008; Hamilton *et al*., 2007; Stanley, 2005; Totterdell *et al*., 1994). Our sleep and wakefulness are governed by two largely independent mechanisms: (a) the homeostatic sleep drive and (b) the circadian system (Lack and Wright, 2007; Stanley, 2005). In brief, the homeostatic sleep drive, which is determined by the amount of sleep and wakefulness, involves an increase in sleep propensity that builds up in the course of wakefulness and dissipates during sleep. The circadian system, on the other hand, involves physiological activities recurring at an interval of 24 hours (see Figure 1.2) and appears to determine the propensity to fall asleep. The most rapid increase of sleep propensity occurs approximately 2 hours after the onset of nocturnal melatonin secretion and approximately 7 hours prior to the core temperature nadir. The propensity is then high for a period of 8 hours, during which the highest level of sleepiness coincides with the melatonin peak and core temperature nadir. The morning inhibition of melatonin secretion and rise of core temperature decrease sleep propensity and stimulate awakening.

Figure 1.2 The graphical representation of the circadian rhythms of melatonin secretion (dotted line) and core temperature (solid line), including the major sleep episode indicated by the black bar, in healthy adults with normal sleep patterns (Lack and Wright, 2007)

Although solar radiation with its characteristic spectrum and variations throughout the day can be considered to be the most powerful environmental time cue for circadian entrainment in many organisms including humans, indoor electric lighting has partially taken over this function in industrialised societies (Kuller, 2002; Stevens and Rea, 2001). It is striking that our daily exposure to natural light is quite low, approximately 1.5 hours, even in sunny locations such as San Diego (*i.e.*, 32° 43' N; 117° 09' W) during summer months (Espiritu *et al.*, 1994; Savides *et al.*, 1986). Therefore, it seems reasonable to expect that, in our increasingly urbanised world, daylight itself may not be sufficient for entraining the circadian system (Morita *et al.*, 2002) and ensuring a good night's sleep (Mishima *et al.*, 2001). A number of studies, however, have provided suggestive evidence that diurnal exposure to bright indoor electric lighting and artificial light sources rich in short wavelength light appear to compensate the lack of exposure to natural light. It is worthwhile to mention some of the available results pertaining to the probable association between diurnal light exposure and sleep.

One of the initial studies concerning the interrelationship of indoor electric lighting, nocturnal melatonin biosynthesis and sleep was performed by Hashimoto and colleagues (1997). Over two three-day periods, eight healthy young males were exposed to 5,000 lux from 11:00 a.m. until 05:00 p.m. and kept in relative darkness (*i.e.*, <200 lux[*]) in an environmentally controlled enclosure. The results were consistent with the assumptions of Hashimoto *et al.* and findings of other researchers (*e.g.*, Deacon and Arent, 1995; Wurtman and Zhdanova, 1995) documented the positive contribution of melatonin towards maintaining the quality of sleep. Being exposed to 5,000 lux significantly advanced the onset and peak of nocturnal melatonin release and, as a direct consequence, elevated melatonin production. In addition, it improved participants' sleep quality.

A broadly similar study by Park and Tokura (1999) is also of interest. With the aim of finding out whether daytime bright artificial light exposure could influence the circadian rhythms of urinary melatonin and salivary immunoglobulin A, seven diurnally active female adults were studied in two four-day experimental sessions carried out in a climatic chamber. The participants were exposed to two very different illuminances (*i.e.*, 200[†] and 5,000 lux) from 06:30 a.m. to 07:30 p.m. on the second and third days of the sessions and, also, from 06:30 a.m. to 10:30 a.m. on the fourth days. Unsurprisingly, there was a close correspondence

[*] Except for during sleep and the periods of bright light exposure, an illuminance level less than 200 lux was provided.
[†] Approximately 200 lux was maintained during the periods excluding sleep and the exposure to 5,000 lux.

between the results and those obtained by Hashimoto and colleagues (1997). Under bright electric lighting, the peak of nocturnal melatonin secretion was substantially advanced. Furthermore, it was clear that the morning inhibition of melatonin production was much greater.

Another valuable contribution to our knowledge about the entrainment of circadian rhythms by photic stimulation was made by Wakamura and Tokura (2000). They undertook an investigation into the extent to which high intensity electric lighting could influence sleep quality, core temperature and the morning melatonin decline. In two experimental sessions, seven healthy young females were required to live in an environmentally controlled laboratory setting for four days and exposed to two distinct illuminances (*i.e.*, 200 and 6,000 lux) over a ten-hour period following their waking times. The findings of Wakamura and Tokura were in accord with those of the other two groups. Being exposed to 6,000 lux drastically suppressed melatonin release in the morning. Besides, it resulted in an obvious decrease in the core temperature nadir and notably expedited the rectal temperature fluctuations of the participants. Moreover, the results regarding the quality of sleep were consistent with the literature on the causal relationship between having a low rectal temperature at night and sleeping well (*e.g.*, Monroe, 1967; Park and Tokura, 1997; Teramoto *et al*., 1998).

A similar and an equally substantial contribution to the field was made by Kanikowska *et al*. (2001). In an attempt to partially replicate and build on the work of Wakamura and Tokura (2000), Kanikowska and colleagues performed a four-day experiment in an environmentally controlled enclosure. After adapting themselves to the experimental setting, seven female young adults were kept in a low illuminance (*i.e.*, 50-100 lux*) condition for a sixteen-hour period on the second day of the study. Then, they were exposed to 3,000 lux from 07:00 a.m. until 03:00 p.m. on the third day. Unsurprisingly, there was a good concordance between the findings of the two research groups. Following the exposure to 3,000 lux in the daytime, participants' rectal temperature values were significantly lower between 10:00 p.m. and 02:30 a.m. Furthermore, being exposed to bright light for 8 hours slightly increased urinary melatonin excretion at night.

It is also important for the present purpose to mention a more recent study by Noguchi and colleagues (2004). In order to gather evidence for the existence of a link between artificial illumination and the circadian rhythms of melatonin secretion and core temperature, four male

* Except for during sleep and the period of bright light exposure, an illuminance level less than 100 lux was provided.

office workers were studied in their own working environment over two three-week exposure periods. During the first period, the illuminance provided on the work plane was adjusted to 750 lux and increased to 2,500 lux in the morning, between 09:00 a.m. and 11:00 a.m., and afternoon, between 12:45 p.m. and 01:45 p.m. Throughout the second three-week period, the participants were exposed only to 750 lux on each working day. Conceivably, there was not a contradiction between the findings of Noguchi *et al*. and those of the others. Being exposed to 2,500 lux marginally augmented melatonin release and the nocturnal fall of core temperature.

Before proceeding to review the results of empirical research into a plausible connection between artificial illumination and daytime somnolence, a recent study by Sato *et al*. (2005) is also worthwhile citing. In three two-day experimental sessions conducted in a laboratory, Sato and colleagues examined whether different illuminance levels and artificial light sources could influence the biorhythms of core temperature and melatonin production. On the second days, each participant[*] was awakened 2 hours after their own core temperature nadirs and briefly (*i.e.*, for 2 hours) exposed to three different lighting conditions: (a) <50 lux; (b) 2,500 lux generated by daylight fluorescent lamps with a CCT of 6,480 K and (c) 2,500 lux provided by warm white fluorescent lamps with a CCT of 3,150 K. Interestingly, it was demonstrated that only the last lighting condition significantly expedited the morning melatonin decline and rise of core temperature. Unexpectedly, the first and second conditions had similar effects.

[*] Nine young adults participated in the study.

1.2.2 Possible connection between diurnal light exposure and somnolence:

In addition to the aforementioned indirect effects of environmental lighting conditions, it has been demonstrated that the diurnal secretory rhythm of cortisol (see Figure 1.3) and degree of sleepiness experienced during the day appear to be altered by electric lighting. Due to the fact that low endogenous cortisol levels have been associated with somnolence or diminished arousal (*e.g.*, Born *et al*., 1986; Follenius *et al*., 1992; Phihal *et al*., 1996) being detrimental to emotional well-being and cognitive functioning (*e.g.*, Chasens and Olshansky, 2008; Franzen *et al*., 2008; Lingenfelser *et al*., 1994; Roth and Roehrs, 1996), reviewing some of the investigations into the beneficial influences of diurnal light exposure is of vital importance.

Figure 1.3 The graphical representation of the diurnal secretory rhythm of salivary cortisol in individuals following normal daily schedules (Kirschbaum and Hellhammer, 2000)

One of the early attempts at finding convincing evidence of a direct link between morning light exposure and our daily cortisol rhythm was made by Scheer and Buijs (1999). On two consecutive days, fourteen male adults were exposed to total darkness (*i.e.*, 0 lux) and 800 lux at eye level for a one-hour period following waking in their own homes. The results were in line with the expectations of the investigators. In comparison with being exposed to 0 lux, the light exposure in the early morning significantly increased participants' salivary cortisol concentrations in the samples collected 20 and 40 minutes after the end of sleep.

Another early empirical research by Leproult *et al*. (2001) is also well worth mentioning in this section. In order to determine whether being exposed to high artificial illumination levels during the day might have stimulating effects attributable to observable modifications of various circadian rhythms in humans, eight young males subjected to sleep deprivation were studied in three thirty-six-hour experimental sessions conducted in a laboratory. In one of the sessions, the participants were continuously exposed to less than 150 lux. In the other sessions, the continuous dim light exposure was interrupted by being exposed to a relatively very high illuminance (*i.e.*, 2,000-4,500 lux) over two separate time periods (*i.e.*, from 05:00 a.m. until 08:00 a.m. and from 01:00 p.m. until 04:00 p.m.). The findings of Leproult and colleagues were in accord with those of Scheer and Buijs (1999). As expected, the exposure to copious amounts of light in the morning resulted in a robust inhibition of melatonin release and elevation of cortisol concentrations. In addition, the increased cortisol production did not appear to be related to an acute stress response, and it limited the deterioration of vigilance. Unexpectedly, the afternoon exposure scheduled to coincide the secondary peak of cortisol synthesis (see Figure 1.3) did not have any notable effect.

A methodologically similar study by Phipps-Nelson and colleagues (2003) needs to be cited in the present section. In an effort to verify the existent research findings regarding the relationship between daytime bright light exposure and sleepiness, sixteen young adults subjected to sleep deprivation were requested to live in a laboratory for two consecutive days. The participants were either kept continuously in darkness (*i.e.*, <5 lux) over the whole study period or exposed to approximately 1,000 lux from 12:00 p.m. to 05:00 p.m. on the second day. Unexpectedly, there was a partial disagreement between the observations of Phipps-Nelson *et al*. and those of Leproult *et al*. (2001). Being exposed to roughly 1,000 lux in the afternoon significantly attenuated the detrimental effects of inadequate sleep experienced by the participants during the day. Specifically, it markedly improved participants' performance in a vigilance task and alleviated their sleepiness measured both subjectively and objectively.

A more recent contribution to the field was made by Ruger *et al*. (2006). In a demanding experiment conducted in a "time isolation facility" over two two-day experimental sessions, Ruger and colleagues examined whether the identified impacts of bright light exposure on human psychophysiology were heavily dependent upon the time of day. In each session, twelve young male adults were assigned to one of the two lighting conditions: (a) continuous exposure to less than 10 lux or (b) exposure to 5,000 lux* between 12:00 p.m. and 04:00 p.m. on the last day. There was a reasonable concordance between the findings of Ruger *et al*. and Phipps-Nelson *et al*. (2001). Being exposed to 5,000 lux in the afternoon

* An illuminance level less than 10 lux was provided during the periods excluding sleep and the exposure to 5,000 lux.

notably relieved participants’ fatigue and sleepiness. However, it was ineffective in modifying participants’ diurnal rhythms of core temperature and cortisol biosynthesis.

Before further extending the scope of the review and providing a compelling body of empirical evidence relevant to the non-visual effects of natural light on us, a recent work of Viola *et al*. (2006) is also worthwhile to point out. With the aim of assessing the psychostimulating effects of four different monochromatic light stimuli, Viola and colleagues carried out four-day experimental sessions in a dimly (*i.e.*, <8 lux) lit laboratory setting. On the third days of the sessions, twelve male adults were exposed to light stimuli at wavelengths of 420, 440, 470 and 600 nm from 07:15 a.m. until 11:15 a.m. Unlike Sato *et al*. (2005), the investigators were able to demonstrate that short wavelength visible light was potentially more effective in eliciting psychophysiological responses. In comparison with the exposure to monochromatic light at 600 nm, being exposed to light at shorter wavelengths induced alertness in the study population.

1.3 The non-visual responses of human beings to natural light:

1.3.1 The general attitude towards daylight:

Based on the previous sections, it is reasonable to infer that scientific attention has been particularly directed towards the assessment of the non-visual responses elicited by electric lighting since the late 1990s. However, one should not mistakenly assume that there is no need or incentive to investigate the utilisation of natural light within buildings. The potential importance of the sun to human existence has been widely recognised since antiquity[*] (Ackroyd *et al*., 2001; Baker and Steemers, 2002), and this conventional wisdom has been extensively supported by numerous empirical studies. For example, a concerted effort has been made to determine whether daylight is preferable to artificial illumination. In this regard, there is convincing evidence that the vast majority of us favour the sun as a light source. Furthermore, this general trend of inclination is consistent with the finding that building occupants would rather be in close proximity to windows. These results are of great interest in the light of the reported link between the expected benefits of interacting with nature (*i.e.*, emotional and cognitive restoration) and our strong preference for natural environments (*e.g.*, Hartig and Staats, 2006; Staats and Hartig, 2004; Staats *et al*., 2003; van den Berg *et al*., 2003). Therefore, some of the investigations into our propensity to prefer daylight and sit beside windows are well worth citing.

One of the early studies on our particular preference for natural light and windows was carried out by Wells (1965) almost fifty years ago. Wells' study took place in an office building on two separate days in August, and it was performed in order to attest the presupposition that having a window, or having access to daylight, would be closely associated with satisfactory working conditions. Accordingly, the study sample, which was composed mainly of clerical personnel, was required to respond a number of questions concerning the building. For the present section, two of them are of paramount importance. One of the questions was posed to assess the extent to which being able to see outside was important for the employees. Wells found that roughly ninety per cent of the employees appraised the availability of an outside view as being either very or moderately important. In

[*] Theophratus, the successor to Aristotle, stated that "the sun provides the life-sustaining heat in animals and plants…" (cited in Baker and Steemers, 2002, p. 7).

addition, there was a question as to the desirability of daylight and electric lighting. Wells reported that almost seventy per cent of the respondents expressed a strong preference for daylight. A mere three per cent of the respondents strongly advocated the superiority of artificial lighting.

Another early study was conducted by Heerwagen and Heerwagen (1986) in a similar office building. On a working day in November and August, a questionnaire was administered to the occupants in order to elicit their opinions on the lighting conditions, perceptions of the visual and thermal comfort conditions, attitudes towards daylight and electric lighting and views on various other features of the building. In the present context, the most relevant finding of Heerwagen and Heerwagen was concerning the relative merits of natural light and artificial lighting. Not unexpectedly, most of the respondents expressed the belief that daylight was superior to electric lighting in meeting various needs (see Table 1.1). Furthermore, it was observed that the distance between the windows and occupants impacted on the perceived advantages of natural light. The greater the distance, the more pronounced the subjective benefits of daylight were.

Table 1.1 Participants' preferences expressed in percentages

Needs	Daylight better	Electric lighting better	No difference	No opinion
Psychological comfort	88	3	3	6
Office appearance and pleasantness	79	0	18	3
General health	73	3	15	8
Visual health	73	9	9	9
Colour appearance of people and furnishings	70	9	9	12
Work performance	49	21	27	3
Jobs requiring fine observation	46	30	18	6

A more recent and extensive study, which was conducted by Roche *et al*. (2000) in the United Kingdom, confirmed the observations from the previous two studies. In contrast to the above-mentioned studies, Roche and colleagues' study took place in sixteen office buildings on a working day in winter and summer. As in the other two studies, a questionnaire, which was comprised of questions concerning the physical features of the different working environments, was administered to the occupants. For the present purpose, two findings are of particular interest. Unsurprisingly, Roche and colleagues found that the majority of the respondents desired to work under natural lighting. On the contrary, approximately four per cent of the respondents, only a small minority, preferred electric lighting. In addition, the researchers observed that having a window in a working environment was highly valued. The seventy-three per cent of the occupants considered that having a window was extremely important.

Another early study was reported by Markus (1967) who attempted to determine the significance of sunshine and windows for building occupants. The study was performed in the same type of building as in the aforementioned studies. The occupants were surveyed by means of a questionnaire of which two items directly relevant to respondents' attitudes towards sunshine and windows. One of the items had been worded in order to evaluate whether the office employees were pleased with having sunshine in the facility and reveal whether there was a seasonal preference for sunlight. In accord with the other researchers, Markus observed that the eighty-six per cent of the respondents (*i.e.*, approximately three hundred and forty participants) prized sunshine all the year round. The other item was regarding the desirability of working beside the windows. Markus found that roughly sixty per cent of the respondents preferred to work by the windows and stated that the distance between the windows and employees had a dramatic effect on the desirability. The greater the distance, the more the occupants coveted to be close the windows.

A relatively more recent and compelling study on the sentimental value of windows was undertaken by Kim and Wineman (2005). The study was designed in order to investigate the relationship between seat selection patterns and windows, and it took place in a university cafeteria and library on several days either in summer or in autumn. In both settings, occupant behaviour and various environmental parameters, including the amount of indoor illumination, were closely monitored. It was observed that occupancy rates were substantially higher amongst the seats located alongside the windows, especially when the cafeteria and library were not very crowded. Therefore, based on the perusal of the records of the seat occupancy rates, Kim and Wineman stated that the patrons were more likely to select the seats in the proximity of the windows and concluded that a considerable amount of sentimental value was placed on the windows in both settings. Moreover, the researchers speculated that the provision of daylight through the windows and, as a direct consequence, the increased availability of light might account for their findings.

Before extending the scope of the present section and providing a different body of evidence concerning our non-visual responses to natural light, a study by Wang and Boubekri (2009), which is broadly similar to that of Kim and Wineman (2005), should also be cited. For the purpose of demonstrating the influence of daylight on space occupancy patterns, the study was carried out in a student lounge on three consecutive afternoons in April. As the other researchers, Wang and Boubekri relied solely upon their observations of occupants' seating preferences. Not unexpectedly, there was a reasonable concordance between the findings of the two research groups. It was perceived that the most desirable seats were in the immediate vicinity of the windows and occupied almost ten times more frequently than some of the distant seats. Furthermore, in line with the findings of Markus (1967) regarding our devotion to sunshine, it was observed that, in general, the occupants preferred to face the incoming sunlight despite the fact that they did not gaze through the windows.

1.3.2 The effects of natural light on our well-being:

There is no doubt at all that, for many of us, it is a blessing or pure joy to feel the warmth of sun and be able to perceive the meaningful variations of daylight. Even if these were only aesthetic preferences, they would be of great value. But perhaps these are more than just simple appraisals. In addition to the restorative potential of solar radiation, it is not implausible to link our predilection to the fact that humans are largely diurnal animals, heavily reliant on sight and colour vision for ensuring survival (Mollon, 1989). Therefore, from an evolutionary perspective, it seems reasonable to surmise that we are both physically and mentally attuned to natural light. Unsurprisingly, various research groups have provided supportive evidence that the adequacy of daylight exposure is critically important for our general health. Before mentioning some of the main contributions to our current knowledge, it is illuminating to note here that the comorbidity of physiological and psychological disorders has been well documented (*e.g.*, Keefe *et al.*, 1986; Meakin, 1992; Turner and Romano, 1984). Accordingly, the successful incorporation of natural light into building design appears to be crucial not only for maintaining our physical health but also for preserving emotional well-being.

A valuable contribution to our understanding of the importance of daylight was made by Keep *et al*. (1980). By means of a questionnaire, Keep and colleagues compared the memories of seventy-eight former patients who had been treated in a windowless intensive care unit for at least two days with those of seventy-two patients who had been given medical care in another unit with translucent windows. It was found that the provision of daylight for habitable spaces could be an essential design issue. Not unexpectedly, most of the respondents who had been accommodated in the windowless unit had a vague recollection of their stay. Only fifteen per cent of the respondents could accurately estimate the length of their stay. Moreover, the incidence of disorientations, disturbances, hallucinations and delusions in these respondents was higher than the other group of respondents (see Table 1.2).

A similar and an equally valuable contribution was made by Beauchemin and Hays (1996). By retrieving and analysing hospital records for over a two-year period, the researchers compared the average duration of hospitalisation in a cohort of psychiatric inpatients who had been suffering from severe depression and assigned to “bright and sunny” rooms in a Canadian ward with that of a corresponding group of patients who had been treated in "dull" rooms. Beauchemin and Hays observed that a plentiful supply of daylight could significantly expedite recovery. The discharge of the patients who had been accommodated in the sunny rooms was almost three days earlier. This finding is firmly supported by an analogous study of Benedetti and colleagues (2001) in an Italian facility. In accord with the other researchers, they stated that the length of stay was approximately four days shorter in a group of psychiatric inpatients who had been hospitalised for bipolar depression in comparatively brighter and sunnier rooms.

Table 1.2 The number of the patients expressed in percentages

Retrospective reports	Intensive care unit	
	Without windows	With windows
Being aware of day	5	24
Being aware of time	9	40
Sleep disturbance	25	16
Visual disturbance	23	16
Hallucinations and delusions	48	23

Another study by Beauchemin and Hays (1998), which can be regarded as a partial replication of their previous work, is also of interest. By scrutinising hospital records for over a span of four years, the researchers compared the average length of hospitalisation and incidence of mortality in two hundred and ninety-three critically ill cardiac inpatients who had been given medical care in "bright southerly" rooms with those of a similar group who had been assigned to "dark northerly" rooms. Surprisingly, it was found that the hospitalisation period among the patients who had stayed in the southerly rooms was shorter. However, the significant difference was confined to women patients. Another interesting finding of Beauchemin and Hays was that the risk of mortality was inversely associated with "brightness" or, in other words, the presence of sunlight. It was observed that the sixty-five per cent of all deaths had occurred in the northerly rooms.

The observations of another research group that are pertaining to the beneficial effects of daylight on patient outcomes are also of importance. In order to evaluate whether there was a significant relationship between the availability of daylight and intake of analgesic medications, Walch *et al.* (2005) carried out a study on two comparable groups of post-operative patients who had undergone spinal surgery. One of these two groups was allocated to "bright" rooms, and it was exposed to an average of forty-six per cent more daylight per day than the other group that was assigned to "dim" rooms. The findings of Walch and colleagues were in line with their expectations. The patients who were staying in the "bright" rooms required twenty-two per cent less morphine during their hospitalisation. Therefore, a significant reduction in medication cost was achieved. It should be also mentioned that the "dim" rooms were receiving less daylight because of a fundamental design flaw. An adjacent structure, which was located approximately 25 meters away, was shading the patient rooms.

In addition to the above-mentioned health-related advantages of daylight for various patient populations, it has been contemplated that being exposed to a physiologically sufficient dose of solar radiation and, as a consequence, maintaining an adequate production of vitamin D[*] are closely associated with a low risk of common deadly cancers[†]. It has been documented that the likelihood of dying from colon, prostate, breast, ovarian and other deadly cancer types is strongly related to living at high latitudes and being at risk from vitamin D deficiency (Holick, 2005). One of the early studies on this possible linkage was undertaken by Garland *et al.* (1990). The researchers investigated the geographic variation of breast cancer mortality rates in the U.S. It was observed that the mortality rates were almost two-fold higher in northern and north-eastern states than in sunny southern and south-western states. While the mortality rate was approximately eighteen deaths per one hundred thousand inhabitants in the southerly states, the rate in the northerly states could reach up to thirty-three deaths per one hundred thousand inhabitants.

The beneficial effects of daylight on our well-being have not been identified not only in a number of patient populations but also in healthy individuals. There is suggestive evidence that daylight is a powerful synchroniser of our circadian rhythms. For example, the findings of Morita *et al.* (2002) can be regarded as circumstantial evidence that daylight has a profound effect on the circadian rhythm of salivary melatonin secretion. In a naturalistic study, Morita and colleagues examined the relationship between the circadian variation of salivary melatonin and amount of daily light exposure in forty-one healthy young women. While the participants were performing their habitual activities, their temporal patterns of light exposure and salivary melatonin concentrations were measured. Strikingly, it was observed that the women who were exposed to low light levels during the day and at night had relatively unusual, or abnormal, melatonin rhythms. Their melatonin concentrations reached a peak almost in the afternoon and were comparatively very low. In marked contrast to the other participants, those who were exposed to high light intensities during the day and

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[*] Vitamin D is naturally present in minor quantities in certain foods and beverages, and it is derived mostly from cutaneous synthesis in response to sensible exposure to solar ultraviolet B radiation (Holick, 2005).

[†] At this point, it is appropriate to briefly review that the effects of vitamin D and, consequently, daylight are not limited to cancer and cancer patients. There is substantial evidence that vitamin D deficiency, an unrecognised endemic in both adults and children throughout the world, is closely linked to an increased prevalence of rickets, osteoporosis, rheumatoid arthritis, multiple sclerosis, hypertension and many other health risks (Holick, 2005).

low light intensities at night were able to maintain the natural rhythm of salivary melatonin secretion.

The findings of Morita *et al.* (2002) are solidly supported by a study of another Japanese research group (Mishima *et al.*, 2001). The study was conducted amongst ten healthy young males and twenty institutionalised elderly adults with and without insomnia in order to understand whether insufficient environmental illumination and age-related reductions in melatonin synthesis might be causal or exacerbating factors for sleep disturbances in the elderly. As in the previous study, participants' daily light exposures and melatonin concentrations were measured in their daily routine. In addition, their sleep and wake patterns were also evaluated by means of actigraphy. Mishima and colleagues demonstrated that the elderly adults, especially the elderly insomniacs, were exposed to daylight for a very short period of less than 48 minutes per day and, therefore, much more prone to impaired melatonin production and sleep problems in comparison with the young adults. It should be noted that even the young participants had the benefit of daylight for a brief period of time, approximately 2 hours per day, and mainly relied upon electric lighting in their living environment.

Apart from the aforementioned positive effects, it has been reported that even a brief exposure to daylight may alleviate daytime sleepiness and augment mood in adults having neither physical nor mental health problems. A recent experimental study by Kaida *et al.* (2006) can be exemplified concerning the efficacy of natural light in the enhancement of vigilance. On two different days, sixteen healthy females were housed in a dimly lit laboratory from 11:00 a.m. to 04:10 p.m. in order to quantify their subjective sleepiness and physiological arousal. Except during the period of daylight exposure, all experimental procedures were performed at an illuminance level of less than 100 lux. In one of the experimental sessions, the participants were exposed to a daylight illuminance of more than 2,000 lux at eye level for 30 minutes in the afternoon. It was observed that being exposed to natural bright light significantly and immediately alleviated self-reported sleepiness and notably improved physiological arousal during the post-exposure period. It should be mentioned here that the thirty-minute exposure to daylight made a profound impact not only on participants' sleepiness but also on their mood. In a later article, Kaida and colleagues (2007) reported that they had also measured participants' mood status by means of two self-report instruments, and they stated that the participants were in a more "pleasant" mood during the natural light exposure.

1.3.3 The effects of natural light on cognition:

Because of the demonstrated association between how we feel and how we think, it is not unreasonable to expect that the sun and its light restoring or augmenting our psychological well-being should also enhance or amplify our cognitive capacity. Unfortunately, there is not enough direct evidence for confirming this deduction. While most of the empirical studies have been focused upon the extent to which electric lighting alters cognition, comparatively less research effort has been devoted to the assessment of daylight. Although the scientific work in this area is scarce, two different research groups have demonstrated that the provision of natural light is essential in learning environments. Their findings are well worth mentioning here.

One of the studies on the link between the provision of daylight in school buildings and cognitive performance was carried out by Nicklas and Bailey (1996) in Johnston County, U.S. By retrieving and analysing student records for several academic years, the researchers compared the test scores of a population of children in three new “daylit schools” with those of the others in neighbouring schools. It was found that there might be an impact of the availability of natural light on the test scores. Particularly, the findings in regard to the progression of the students in one of the three schools are of interest. After being allocated mobile classrooms because of a major fire, the students of Four Oaks Elementary School had a decrease over six per cent in their reading and mathematics scores and, as a consequence, were outperformed by their peers. Following their move from the mobile classrooms to a new school building with maximal daylight utilisation, their scores increased by approximately thirteen percentage points and were higher than those of the students in Johnston County.

Since Nicklas and Bailey (1996) made their comparisons between new and relatively old school buildings, it is possible to argue that improving daylight illumination can only be a contributing factor, but not a prerequisite, for the optimisation of cognitive functioning. Contrary to this argument, the favourable effects of daylight on cognitive performance are firmly supported by a report of Heschong *et al.* (2002) that has generated a lot of interest. In this report, an extensive epidemiological study on the relationship between natural light in classrooms and the standardised test scores of students in three different U.S. school districts was presented. In accord with my proposition, Heschong and colleagues were able to establish a statistically compelling connection between daylight and preadolescent children’s scholastic achievements. It was observed that, in one of the districts, student achievement in reading and mathematics was over twenty per cent greater in the classrooms with the best daylight conditions than in those with the worst conditions. Similarly, in the other two districts, the students who could expose themselves to more natural light were considerably more successful.

1.3.4 Artificial light versus natural light:

Owing to rapid increases in energy prices and environmental concerns about power plant emissions contributing to the degradation of nature, encouraging the utilisation of the sun as the main source of light within buildings can be an effective strategy for considerably reducing our energy consumption (Leslie, 2003). This statement leads the question as to whether we should prefer daylight to artificial light. Physically, natural light is just another kind of electromagnetic radiation in the wavelength range that is absorbed by the photoreceptors in our eyes (Boyce and Raynham, 2009). In this respect, it does not differ from electric lighting. However, one should not leap to the conclusion that no other reasons can be given for favouring daylight. If the above-mentioned supposition that we are both physically and mentally attuned to natural light is true, it is plausible to suggest that daylight is likely to be superior to artificial light with respect to our well-being and cognitive functioning. Therefore, we should prefer natural light. There are a number of studies validating this hypothesis. It is worthwhile to cite some of them in this section.

A study by Wirz-Justice *et al*. (1996), which is acknowledged to be the first scientific evidence for the efficacy of daylight exposure as a non-pharmacological treatment for winter depression, is of particular importance. In the study, twenty patients suffering from winter depression were treated either with daily one-hour walks or with thirty-minute bright electric lighting for one week. In addition to patients' diagnostic status and depressive symptoms, their various sleep parameters and salivary melatonin and cortisol rhythms were also assessed by the researchers. Consistent with their expectations, Wirz-Justice and colleagues demonstrated that walking outdoors in the morning, or more specifically, being exposed to natural light in the morning for one hour, could be a viable alternative to the conventional method of utilising artificial light therapy. While it was observed that walking significantly alleviated depression in the patients, being exposed to electric lighting was found to be comparatively less effective. Furthermore, it was reported that, as opposed to the conventional method, walking significantly improved sleep maintenance and modified the rhythms of melatonin and cortisol production.

In this context, it is appropriate to mention a recent empirical analysis by Kahn *et al*. (2008) with regard to whether the pervasive and highly sophisticated technologies of our time can be employed for simulating or replicating nature. The analysis was conducted in a full-size mock office where occupants' heart rates and gazing behaviours were closely monitored in the presence of a real window with a view, plasma window displaying the digitized image of the same view or no windows of any kind. Kahn and colleagues observed that having a real window, providing not only a visual access to the outside environment but also natural light, was significantly more effective in maintaining an optimal heart rate than the other two conditions. Interestingly, the influence of having a plasma window was not different from having a blank wall. Furthermore, the researchers reported that the occupants preferred to spend comparatively more time in looking at the real window and found that this behaviour could be linked to the cardiac activity of the occupants.

Another recent study by an Austrian research group (Hoffmann *et al.*, 2010) concerning whether the characteristic spectrum and natural variations of daylight can be imitated by innovative electric lighting systems is also of interest. In an attempt to demonstrate the probable superiority of dynamic electrical lighting over static electrical lighting, the researchers carried out an experiment on eleven healthy males. In two three-day experimental sessions, the participants were housed in a laboratory from 08:45 a.m. to 05:00 p.m. in order to assess their cognitive performance, melatonin concentrations in blood and various other physiological parameters (*e.g.*, blood pressure). While a conventional lighting system providing an illuminance level of 500 lux and a CCT of 4000 K was utilised in one of the sessions, a dynamic lighting system providing variable illuminance levels between 500 and 1800 lux and a CCT of 6500 K was adopted in the other. The findings of Hoffmann and colleagues were in sharp contrast to their expectations. There was no measurable superiority of their dynamic lighting system in comparison with the static lighting system.

1.4 A synopsis of our current knowledge:

Based on the in-depth literature review presented in the previous sections, it is not implausible to state that our knowledge of humans' non-visual responses to photic stimuli is still in its infancy and, therefore, incomplete. As mentioned at the beginning of this chapter, there are numerous issues that remain to be addressed by the community of lighting. Firstly, despite the fact that numerous studies have been carried out for exploring the direct effects of electric lighting on our mood and cognition, it is difficult to reach a definitive conclusion with respect to the optimal utilisation of artificial illumination in indoor environments and validity of the assumption that light influences cognitive performance via emotional processes. Apart from their contradictory and confusing results, almost all of the investigations have a number of common limitations that should be acknowledged.

One of the prominent limitations is the artificiality of the research settings. More specifically, the vast majority of the studies have taken place in university laboratories bearing little resemblance to participants' habitual living conditions. This raises an important question as to whether the research findings can be generalised or extrapolated to real-world settings. It seems that they cannot. According to Proshansky (1976, p. 306), "no matter how well a research setting duplicates the real physical world of the individual, his knowledge that it is not the actual setting immediately invalidates the integrity of any person-environment phenomenon being studied in relation to that real-world setting…"

Most of the investigations into our emotional and cognitive functioning can also be criticised for lacking repeated measures or, in more sophisticated terms, being cross-sectional studies. Therefore, it is not possible to infer that being exposed to electric lighting at multiple points in time may elicit exactly the same or completely different non-visual responses. For example, Knez (2001) administered a cognitive task at only 03:40 p.m. (*i.e.*, not over the course of time) for comparing the effects of three different artificial light sources on participants' problem-solving skills. Because of the cross-sectional nature of his study design, Knez's findings are not necessarily applicable to other time points (*e.g.*, early morning hours during which the inhibition of melatonin secretion and peak of cortisol release occur).

Another serious limitation that needs to be mentioned is the possible selection of inaccurate or unreliable measurement tools for assessing participants' emotional and cognitive states that can be considered to be a contributory factor in obtaining inconsistent results. For example, the Positive and Negative Affect Schedule (PANAS; Watson *et al*., 1988) is one of the most commonly employed measures of mood in lighting research. However, it has been severely criticised for not being sensitive enough to detect the mild shifts in feeling states caused by different lighting conditions (*e.g.*, Baron *et al.*, 1992) and not including certain emotions that are central to our affective experience (*e.g.*, Larsen and Diener, 1992).

Secondly, the findings reported on the influences of electric lighting upon our diurnal biological rhythms, sleep and somnolence are, at best, tentative. Even though there is empirical evidence that both very high illuminance levels (*i.e.*, generally >2,500 lux) and artificial light sources emitting most of the energy in the short wavelength portion of the visible spectrum (*i.e.*, approximately between 380 and 480 nm) benefit the participants of various laboratory experiments, we still do not have the knowledge of what the ideal light exposure is for maintaining or improving our bodily functions, mood and cognitive performance. Furthermore, it should be emphasised here that the vast majority of the investigations into the bodily processes affecting sleep and sleepiness suffer from some limitations having implications for the findings.

In addition to the above-mentioned disadvantage of being “artificial” or laboratory studies, relying almost entirely on gender-specific results and interpreting the results as being applicable to both sexes impose further limitations. For example, there is convincing evidence that the circadian rhythms of melatonin secretion and core temperature are entrained to notably earlier times in women (*e.g.*, Cain *et al*., 2010; Duffy *et al*., 2012). Therefore, a serious question arises as to whether the investigations carried out on a cohort of either male and female participants provide adequate and accurate information about the effects of different lighting conditions on general population for which one normally wishes to make inferences.

Thirdly, and lastly, one of the key questions that have not been answered clearly is whether our particular preference for daylight is based on the superiority of solar radiation to electric lighting in eliciting various biologically, emotionally and intellectually advantageous responses in humans. A number of research groups have demonstrated that natural light exposure is beneficial to our well-being and cognitive functioning. However, it is difficult to empirically justify the uniqueness of daylight since most of the data have been gathered from patient medical records, but not from healthy individuals. Moreover, scant attention has been paid to concurrently assess the non-visual effects of natural light and artificial illumination on us. Therefore, there is insufficient evidence to strongly advocate or refute the possible association between the superiority of daylight and our predilection for it.

Chapter 2

Research objectives

Chapter 2- Research objectives

Firstly, before explaining the research objectives derived from Chapter 1, it is imperative to have a clear understanding of why there is an incentive for lighting practitioners to undertake research in the role of light in eliciting non-visual responses in man. The most general reason is that different lighting conditions have been demonstrated to have dissimilar effects on the fundamentals of human life and survival, namely physical health, emotional well-being and cognitive functioning. Therefore, there is no doubt at all that generating scientific knowledge about the non-visual influences of light by means of empirical studies is well worth the attention of specialists in lighting (Boyce, 2004; van Bommel, 2005; Veitch, 2002; Veitch *et al*., 2004).

Secondly, and lastly, it is important to consider whether there is a current necessity of improving our ability to predict the physiological, psychological and cognitive outcomes of exposure to the visible electromagnetic spectrum. It seems that there is. The vast majority of the research into indoor lighting have been confined to visibility and visual discomfort for a long time and, as a result, provided sound evidence for the lighting conditions required to achieve a high level of visual performance and avoid visual discomfort (Boyce, 2004). Conversely, the non-visual aspects of light, primarily artificial light, have become an increasingly important topic since the late 1990s (Veitch, 2002; Veitch *et al*., 2004). Because of the relative novelty of the field, several key questions still remain to be answered by the community of lighting:

- In the light of the thorough literature review provided in the previous chapter, it is possible to deduce that it is quite hard to make an unambiguous statement about the expected effects of indoor lighting conditions on our body and mind. The optimal quantity, spectrum, timing and duration of light exposure for eliciting favourable non-visual responses have not been clearly defined yet. Therefore, one of the main research objectives is to seek an answer to the following questions: "*Is there an ideal indoor lighting condition for sustaining or augmenting our general well-being and cognitive abilities?"; "If so, what is it?"*
- As a substantial portion of the research into light and its non-visual impacts on humans has been carried out in laboratory settings, there is lack of knowledge about whether the conclusions solely drawn from the laboratory experiments are valid for real-world environments. Hence, another research objective is to provide a clear

answer to the question: "*Do we underestimate or overestimate the actual effects of light on us?*"

- Since the introduction of incandescent lamp technology at the end of the eighteenth century, electric lighting has become a ubiquitous part of everyday life. It is noteworthy that our daily exposure to daylight is considerably shorter (*i.e.*, not more than 1.5 hours) than our artificial light exposure on an average day (Espiritu *et al*., 1994; Savides *et al*., 1986). Not surprisingly, the non-visual effects of electric lighting have been investigated more frequently than those of natural light. Although the available empirical evidence is scarce, it has been demonstrated that daylight can be a more potent photic stimulus influencing our health, mood and cognition. Accordingly, the third research objective is to give a more definitive answer to the following question: "*Is the illumination produced naturally, by the sun, superior to its artificial substitute?*"

In an attempt to answer the questions posed above, it was decided to carry out a longitudinal study involving repeated measures as opposed to a cross-sectional one. It is believed that collecting data at multiple points in time can provide us with a better understanding of the time-dependent effects of indoor lighting being ambiguous. Moreover, it was chosen to undertake the research in a junior school rather than conducting it in a laboratory setting. Apart from the fact that we are in need of naturalistic studies on the non-visual influences of light, there are three other reasons for this choice. One of them is that school-age children are considered the healthiest segment of the population in industrialised societies (Shonkoff, 1984). Therefore, any health-related factor that could interfere was eliminated beforehand. Another reason is that junior schools provide an ideal setting for assessing cognitive performance since all students are exposed to a highly standardised curriculum and tested for their progress by means of standardised examinations. The last reason is that most of the schools collect extensive demographic information about their students that can be useful for detecting possible differences.

Chapter 3

Methodology

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3.1 Setting:

The main field study was carried out in the fourth-grade classrooms of a junior school in Kent, U.K. Kent (*i.e.*, 51° 11' N; 0° 43' E) is a county in the south-eastern part of England. The climate in this region is moderately cold and rainy, and it is characterised by the short monthly durations of sunshine varying between 49 and 72 hours in winter months (Met Office, 2011). The classrooms, in which the study was conducted, were on two different floors of the school building (see Figure 3.1) and almost identical to each other (see Figure 3.2). In particular, they were quite similar in size and interior décor. Each classroom had a ceiling height of approximately 3 meters and floor area of 53 m^2. Classrooms' floors were covered with fitted carpets having neutral colours. Their walls and ceilings had been painted off-white. However, in general, the windowless walls of the classrooms were used for displaying teaching materials and students' work. In other words, they were covered with colourful paper at all times. In spite of the similarity between the four classrooms, they were considerably different from each other with respect to the provision of daylight and electric lighting.

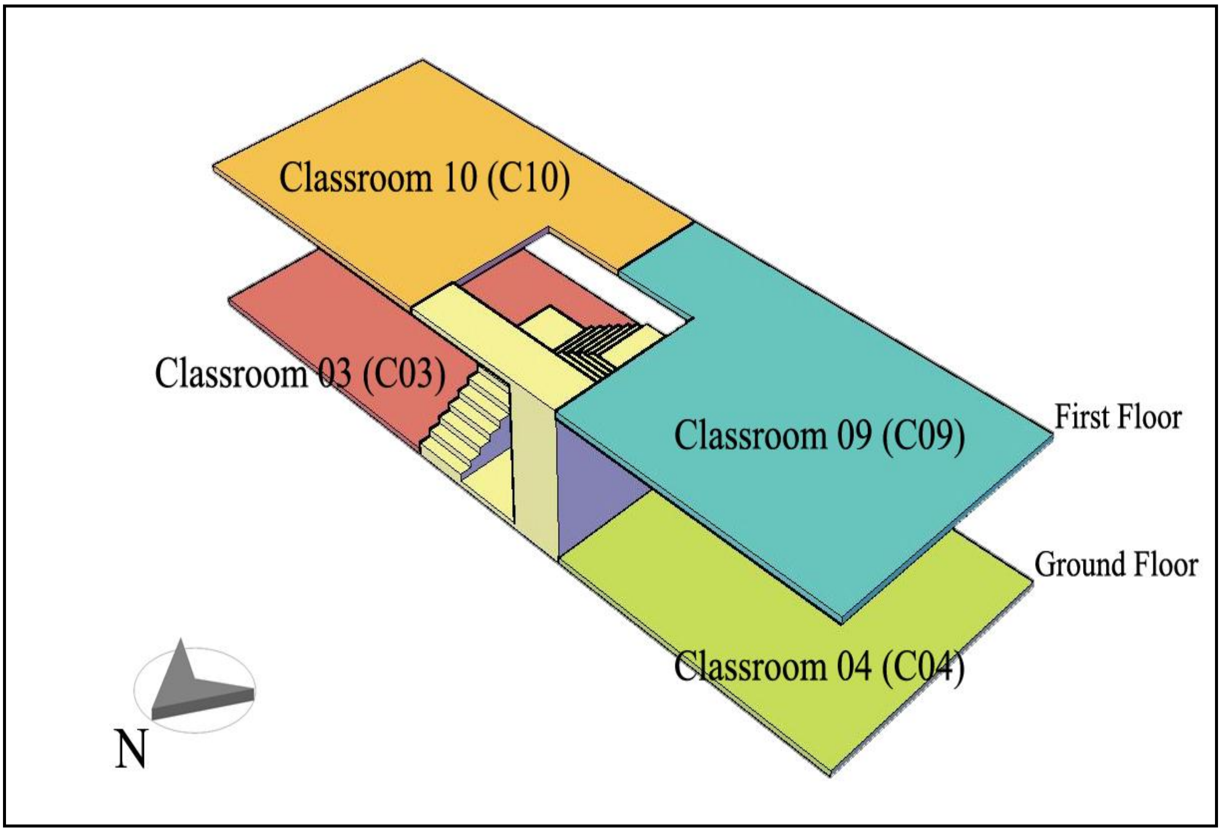

Figure 3.1 The locations and names of the classrooms

Figure 3.2 The images of the classrooms

Figure 3.3 The southern and northern windows of the classrooms

While the ground-floor classrooms had only three windows, covering an area of almost 14 m^2, on the south façade, the first-floor classrooms had not only the southern windows but also two additional windows, covering an area of approximately 8 m^2, on the north façade (see Figure 3.3). All windows with PVC frames were double-glazed in order to provide both sound and thermal insulation. It is relevant to mention here that, in contrast to the southern windows, the northern openings were not equipped with blinds. Therefore, the windows in C09 and C10 could allow comparatively more daylight to enter the classrooms. Table 3.1, giving information on the measured average daylight factors in each classroom, indicates their potential for supplying noticeably more natural light to the first-floor classrooms.

Table 3.1 The measured average daylight factors expressed in percentages

The positions of the blinds	Classrooms			
	C03	C04	C09	C10
Completely open	2.43	1.57	4.67	5.53
Completely closed	0.06	0.04	1.71	1.73

Table 3.2 The measured illuminance levels expressed in lux

Average levels	Classrooms			
	C03	C04	C09	C10
Horizontal illuminance level at desktop height	302	498	494/587	296
Vertical illuminance level at sitting eye height	138	240	236/278	142

In C03 and C10, an average horizontal illuminance level of approximately 300 lux at desktop height, or at 67 cm, was generated by the improved version of the existent electrical lighting system consisting of cool white fluorescent lamps (*i.e.*, Philips Master TL-D Super 80) with a CCT of 4,000 K and ceiling-mounted luminaires (*i.e.*, Fagerhult Allround) with high frequency ballasts and prismatic diffusers (see Table 3.2 for further information on illumination). The lighting system in C04 and C09 was replaced with new ones. Both of the new systems were quipped with occupancy and daylight sensors for minimising electric lighting usage and meeting the requirements of the junior school with respect to electrical energy consumption. In an attempt to increase the vertical illumination at sitting eye height*, or at 96 cm, new louvered luminaires (*i.e.*, Fagerhult Como and DTI) having dimmable high frequency ballasts and housing 4,000 K fluorescent lamps (*i.e.*, Philips Master TL5 HO) were utilised. The illuminance level provided on students' desks was adjusted to roughly 500 lux†

* Based on the aforementioned studies in which mainly vertical illumination was measured at participants' eye height, it is reasonable to infer that the amount of light reaching the eye is particularly important for eliciting non-visual responses in man. Since students' main direction of gaze was towards the whiteboard in each classroom, the vertical illuminance measurements were carried out in the direction perpendicular to the board.

† Since electrical energy consumption was a matter of concern to the administrators of the school, 500 lux was provided in accordance with BS EN 12464: Part 1.

in C04 and C09, and it was gradually increased by twenty per cent in the morning, between 08:50 a.m. and 09:50 a.m., and in the afternoon, between 01:10 p.m. and 02:10 p.m.* in C09.

In addition to the measurements performed for electrical lighting, the total illumination obtained from both the windows and electrical lighting systems were also determined horizontally and vertically over the course of the study. The total levels were measured on ten different days at three different time points (see Table 3.3). It is evident from the table that the participants in the first-floor classrooms could expose themselves to copious amounts of light, or more specifically, daylight, in comparison with those in the ground-floor classrooms. All measurements regarding the illuminance levels were carried out with a cubic illuminance meter (model CIM; Megatron Ltd., London, U.K.) mounted on a tripod. For measuring the daylight factors, a portable illuminance meter (model T-10; Konica Minolta Inc., Osaka, Japan) and an architectural illuminance meter (model AML; Megatron Ltd., London, U.K.) were also used.

Table 3.3 The total illuminance levels expressed in lux

Classrooms	Dates	Times	Average horizontal levels	Average vertical levels
C03	08 Oct.	08:50 a.m.	715	447
		01:10 p.m.	546	349
		03:20 p.m.	638	398
		Average	633	398
	05 Nov.	08:50 a.m.	511	312
		01:10 p.m.	432	256
		03:20 p.m.	376	177
		Average	440	248
	09 Dec.	08:50 a.m.	514	329
		01:10 p.m.	499	309
		03:20 p.m.	461	295
		Average	491	311
	14 Jan.	08:50 a.m.	547	283
		01:10 p.m.	532	268
		03:20 p.m.	461	243

* The increments were scheduled to coincide with the decline of cortisol and melatonin secretion in the morning and secondary peak of cortisol synthesis in the afternoon (see Figure 1.3; Section 3.3.4 for further information). It is essential to note here that, by taking both the preference of the classroom teacher and concern for energy conservation into consideration, the increments regulated by the dynamic lighting system in C09 were limited to approximately 600 lux. The levels higher than 600 lux were perceived as “unfavourable” and “too artificial.”

		Average	513	265
	10 Feb.	08:50 a.m.	499	319
		01:10 p.m.	510	336
		03:20 p.m.	471	302
		Average	493	319
	04 Mar.	08:50 a.m.	710	415
		01:10 p.m.	475	305
		03:20 p.m.	564	361
		Average	583	360
	25 Mar.	08:50 a.m.	490	313
		01:10 p.m.	578	392
		03:20 p.m.	380	243
		Average	483	316
	29 Apr.	08:50 a.m.	647	378
		01:10 p.m.	730	449
		03:20 p.m.	434	269
		Average	604	365
	20 May	08:50 a.m.	665	421
		01:10 p.m.	477	305
		03:20 p.m.	558	357
		Average	567	361
	10 Jun.	08:50 a.m.	552	353
		01:10 p.m.	536	343
		03:20 p.m.	495	317
		Average	528	338
	Average	08:50 a.m.	585	357
		01:10 p.m.	532	331
		03:20 p.m.	484	296
	Average		533	328
C04	08 Oct.	08:50 a.m.	631	405
		01:10 p.m.	580	316
		03:20 p.m.	565	274
		Average	592	332

	05 Nov.	08:50 a.m.	527	256
		01:10 p.m.	518	248
		03:20 p.m.	501	236
		Average	515	247
	09 Dec.	08:50 a.m.	592	268
		01:10 p.m.	530	288
		03:20 p.m.	502	244
		Average	541	267
	14 Jan.	08:50 a.m.	598	319
		01:10 p.m.	532	274
		03:20 p.m.	503	236
		Average	544	276
	10 Feb.	08:50 a.m.	561	253
		01:10 p.m.	647	292
		03:20 p.m.	518	237
		Average	575	261
	04 Mar.	08:50 a.m.	602	317
		01:10 p.m.	514	232
		03:20 p.m.	592	292
		Average	569	280
	25 Mar.	08:50 a.m.	509	284
		01:10 p.m.	653	363
		03:20 p.m.	522	295
		Average	561	314
	29 Apr.	08:50 a.m.	604	337
		01:10 p.m.	613	341
		03:20 p.m.	507	286
		Average	575	321
	20 May	08:50 a.m.	562	361
		01:10 p.m.	517	282
		03:20 p.m.	517	303
		Average	532	315
	10 Jun.	08:50 a.m.	723	356
		01:10 p.m.	648	292

		03:20 p.m.	610	321
		Average	660	323
	Average	08:50 a.m.	591	316
		01:10 p.m.	575	293
		03:20 p.m.	534	272
	Average		567	294
C09	08 Oct.	08:50 a.m.	972	540
		01:10 p.m.	850	474
		03:20 p.m.	868	484
		Average	897	499
	05 Nov.	08:50 a.m.	752	336
		01:10 p.m.	695	311
		03:20 p.m.	506	250
		Average	651	299
	09 Dec.	08:50 a.m.	913	408
		01:10 p.m.	879	397
		03:20 p.m.	688	305
		Average	827	370
	14 Jan.	08:50 a.m.	770	347
		01:10 p.m.	693	312
		03:20 p.m.	558	291
		Average	674	317
	10 Feb.	08:50 a.m.	922	412
		01:10 p.m.	1072	479
		03:20 p.m.	688	306
		Average	894	399
	04 Mar.	08:50 a.m.	1006	449
		01:10 p.m.	1391	621
		03:20 p.m.	681	308
		Average	1026	459
	25 Mar.	08:50 a.m.	809	407
		01:10 p.m.	1286	721
		03:20 p.m.	570	314
		Average	888	481

	29 Apr.	08:50 a.m.	912	459
		01:10 p.m.	915	513
		03:20 p.m.	772	431
		Average	866	468
	20 May	08:50 a.m.	1011	562
		01:10 p.m.	884	493
		03:20 p.m.	903	503
		Average	933	519
	10 Jun.	08:50 a.m.	1133	506
		01:10 p.m.	1091	487
		03:20 p.m.	890	398
		Average	1038	464
	Average	08:50 a.m.	920	443
		01:10 p.m.	976	481
		03:20 p.m.	712	359
	Average		869	428
C10	08 Oct.	08:50 a.m.	1058	529
		01:10 p.m.	1003	507
		03:20 p.m.	932	467
		Average	998	501
	05 Nov.	08:50 a.m.	675	339
		01:10 p.m.	689	347
		03:20 p.m.	486	224
		Average	617	303
	09 Dec.	08:50 a.m.	1007	496
		01:10 p.m.	970	479
		03:20 p.m.	792	391
		Average	923	455
	14 Jan.	08:50 a.m.	703	385
		01:10 p.m.	630	332
		03:20 p.m.	520	283
		Average	618	333
	10 Feb.	08:50 a.m.	798	477

		01:10 p.m.	949	568
		03:20 p.m.	571	286
		Average	773	444
	04 Mar.	08:50 a.m.	1413	709
		01:10 p.m.	1646	813
		03:20 p.m.	626	314
		Average	1228	612
	25 Mar.	08:50 a.m.	858	428
		01:10 p.m.	1045	567
		03:20 p.m.	511	289
		Average	805	428
	29 Apr.	08:50 a.m.	1160	578
		01:10 p.m.	1399	761
		03:20 p.m.	688	389
		Average	1082	576
	20 May	08:50 a.m.	1121	561
		01:10 p.m.	1063	537
		03:20 p.m.	1087	548
		Average	1090	549
	10 Jun.	08:50 a.m.	1058	532
		01:10 p.m.	1019	510
		03:20 p.m.	832	417
		Average	970	486
	Average	08:50 a.m.	985	503
		01:10 p.m.	1041	542
		03:20 p.m.	705	361
	Average		813	469

3.2 Participants:

In total, fifty-six fourth-grade students or the forty-nine per cent of all fourth graders, aged between eight and nine years, voluntarily participated in the main field study (see Table 3.4 for further information). It should be mentioned here that, in addition to the written consent of the parents, the informed consent of each participant was obtained. By utilising an appropriate and a simplistic language in order to ensure comprehension, each classroom teacher orally explained the study protocol[*] to their students and sought their consent. Even though all participants were free to withdraw from the research at any time, none of them expressed unwillingness to cooperate throughout the study period. For maintaining continuity, on each assessment day, the participants received a small carton of fruit juice as an honorarium in appreciation of their time. Furthermore, it is important to note that participants' names were transformed into code numbers blindly by an independent research assistant who was not involved in any other part of the study. By assigning code numbers to the participants, their confidentiality and anonymity were protected both during and after the conduct of the research.

Table 3.4 Quantitative information on the fourth-grade students of the junior school in the U.K.

Student numbers and participation percentages	Classrooms				Totals
	C03	C04	C09	C10	
The number of participating students (NPS)	14	11	16	15	56
The number of participating male students (NPMS)	7	7	9	7	30
The number of participating female students (NPFS)	7	4	7	8	26
The total number of students (TNS)	30	29	29	29	117
The total number of male students (TNMS)	15	14	14	15	58
The total number of female students (TNFS)	15	15	15	14	59
Total participation percentage (NPS×100/TNS)	47	38	55	52	49
Male participation percentage (NPMS×100/TNMS)	47	50	64	47	52
Female participation percentage (NFMS×100/TNFS)	47	27	47	57	44

[*] Although the students were thoroughly informed about their rights and responsibilities, no information on the possible outcomes of the study was given to them in order to minimise the confounding effects of prior knowledge or expectations on their responses (see Veitch, 1997; Veitch *et al.*, 1991 for further information). For the discussion of any issues arising out of or related to the research, a debriefing session was held with the classroom teachers approximately two weeks after the completion of the study protocol. The teachers provided any necessary information for the participants following the debriefing session.

Prior to the execution of the field study, the administrators of the junior school were interviewed in order to gather information on the participants. They provided the following details about their students:

- All students were in good physical and psychological health. They did not suffer from serious acute or chronic diseases that could influence the study outcomes, and none of them were on any kind of medication.
- The students had normal or corrected-to-normal vision, and they had no colour vision deficiencies.
- There was no obvious mechanism or practice of allocating “better” classrooms or assigning “more experienced or skilful” teachers to “more successful or capable” students. In addition, the administrators assured that the scholastic achievements of the children in the classrooms under investigation had been even in the 2007-2008 school year. Moreover, they affirmed that all fourth-grade students were following the same educational programme.
- The parents or guardians of the students were similar in terms of their socioeconomic status. According to the administrators, there were not large or considerable differences in the education and income levels of the families that might affect the results.

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3.3 Data acquisition:

3.3.1 Sleep quality:

Although sleep quality is a widely used construct, it represents a complex phenomenon that is hard to define and evaluate (Buysse *et al.*, 1989; Chartier-Kastler and Davidson, 2007). While sleep quality includes quantitative aspects of sleep, such as sleep duration and the number of arousals during sleep, it also includes more subjective aspects, such as the depth and restfulness of sleep (Buysse *et al.*, 1989; Chartier-Kastler and Davidson, 2007). There are two objective methods of assessing sleep quality, namely polysomnography and actigraphy (Chartier-Kastler and Davidson, 2007; Yi *et al.*, 2006).

Polysomnography is considered to be the gold standard for monitoring sleep (Lashley, 2004) and provide accurate information on the physiologic indices of sleep quality (Chartier-Kastler and Davidson, 2007). Various measurement techniques, such as electroencephalography, electrooculography and electromyography, are employed for simultaneously and continuously recording neurophysiological, cardiorespiratory and other physiological and physical parameters over the duration of several hours (at least 6.5 hours) or during an entire night (Bloch, 1997). In order to eliminate the potential interference of environmental stimuli, polysomnography is usually carried out in a formal sleep laboratory under the supervision of a technician.

Even though polysomnography is generally acknowledged as a superior technique for monitoring sleep, it has certain limitations that need to be addressed. One of the limitations of this technique relates to the measurement conditions that might not reflect the circumstances of a regular night sleep. It has been demonstrated that measurement equipment and unusual occurrences during the monitoring period can induce a false representation of the usual sleep pattern (Bloch, 1997; Bourne *et al.*, 2007). Furthermore, the technical complexity of polysomnography requires expensive equipment, specially trained personnel and a substantial amount of time for recording and interpretation (Bloch, 1997; Bourne *et al.*, 2007; Chartier-Kastler and Davidson, 2007). For example, manual and computer-assisted analysis of a whole night polysomnography by a skilled technician has been reported to take from 83 to 186 and from 53 to 86 minutes, respectively (Bloch, 1997). It should be also noted that the manual review and scoring of polysomnographic recordings, which is prone to observer bias, is the preferred method (Bloch, 1997; Bourne *et al.*, 2007). This is because many of the commercially available computerised systems have not been well validated (Bloch, 1997).

Actigraphy is another method for objective sleep monitoring, and it is based on the principle that there is reduced bodily movements during sleep and increased motility during wakefulness (Ancoli-Israel *et al.*, 2003; Lashley, 2004; Littner *et al.*, 2003). Actigraphy involves the use of a portable device that records the movement of a limb, most commonly of the non-dominant wrist (Sadeh and Acebo, 2002). The particular advantage of actigraphy over polysomnography is that actigraphy can collect data continuously over extended periods of time, such as for 24 hours a day for several weeks (Ancoli-Israel *et al.*, 2003). Employing actigraphy has also been reported to be relatively easy, cheap and unobtrusive compared to polysomnography (Ancoli-Israel *et al.*, 2003; Lashley, 2004). Moreover, actigraphy makes home monitoring, which allows the evaluation of sleep in a natural setting and minimises the possible environmental impacts on the typical sleep pattern, more accessible (Ancoli-Israel *et al.*, 2003).

In addition to the aforementioned advantages of actigraphy over the gold standard for monitoring sleep, one should also consider the limitations of actigraphy. Compared to polysomnography, actigraphy has been found to be moderately valid and reliable for detecting sleep (Ancoli-Israel *et al.*, 2003; Littner *et al.*, 2003; Morgenthaler *et al.*, 2007). However, the accuracy of this method for detecting sleep and wakefulness in individuals who have long motionless periods of wakefulness (*e.g.*, insomnia patients) or who have disorders involving altered motility patterns (e.g., sleep apnoea) has been reported to be low (Ancoli-Israel *et al.*, 2003; Sadeh and Acebo, 2002). Another limitation is that there are a variety of actigraphic devices and computer programmes using different algorithms to process actigraphic data, many of which have not been well validated (Sadeh and Acebo, 2002). In addition, it is unclear what the minimum duration of actigraphic studies should be. In a review on the use of actigraphy, Littner and colleagues (2003) stated that actigraphic studies should be conducted for 24 hours a day for at least three days. However, Sadeh and Acebo (2002) suggested that as many as five nights are required in order to obtain reliable measurements.

Another approach to assess sleep quality has been the employment of self-report methods, such as questionnaires (Chartier-Kastler and Davidson, 2007; Yi *et al.*, 2006). A self-report-based evaluation of sleep is easy, cheap, unobtrusive and invaluable in the assessment of perceived sleep experience (Chartier-Kastler and Davidson, 2007; Lashley, 2004; Yi *et al.*, 2006), but it has some drawbacks intrinsic to self-reporting. For example, it has been reported to be prone to respondent and recall bias (Lashley, 2004). In addition to these drawbacks, one should also note that the subjective measures of sleep quality do not correlate well with the objective techniques (Baker *et al.*, 1999; Harvey *et al.*, 2008; Lashley, 2004). There are a number of standardised instruments available for a comprehensive assessment of sleep quality in adults.

One of those instruments is the Pittsburgh Sleep Quality Index (PSQI; Buysse *et al.*, 1989). It is a self-rated questionnaire that has been widely used in order to assess sleep quality and disturbances during the preceding month. The PSQI consists of nineteen items[*] rated on a scale of zero, indicating no difficulty, to three, indicating severe difficulty. Responses to these items are grouped into seven component scores, namely subjective sleep quality, sleep latency, sleep duration, habitual sleep efficiency, sleep disturbances, daytime dysfunction and the use of sleeping medication. A global PSQI score is obtained by adding the scores for each component scores, and it can vary from zero to twenty-one. A score greater than five was reported to provide a sensitive and specific measure of poor sleep quality (Buysse *et al.*, 1989). However, PSQI responses were not found to correlate well with polysomnographic findings and sensitive to daily variability (Buysse *et al.*, 1989).

Although children from eight years of age are considered to be able to report their well-being (Laerhoven *et al.*, 2004), the studies that have attempted to survey sleep and sleep disturbances in school-aged children have largely relied almost exclusively on parental assessments, which might lead to inaccurate or, at least, incomplete interpretations of the sleep behaviour in this age group (Owens *et al.*, 2000a; Owens *et al.*, 2000b; Paavonen *et al.*, 2000). In part, this might be ascribed to the lack of appropriate self-report measures whose psychometric properties are well established. There are a few instruments that have been developed for school-aged children.

One of these instruments is the Sleep Self-Report (SSR; Owens *et al.*, 2000b), which is a widely used measure of the perceived sleep in children. The SSR is a twenty-six-item, one-week retrospective questionnaire that can be administered to or self-administered by children from seven to twelve years of age. Most of the items in the questionnaire are rated on three-point scale, with the response options being “usually (five-seven times per week),” “sometimes (two-four times per week)” and “rarely (one time per week or never).” Only twenty-three items are used in order to obtain a global SSR score representing the severity of sleep problems. A higher score is indicative of more disturbed sleep.

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[*] In order to obtain further information, the PSQI might also include five additional items rated by the bed partner or roommate. However, these items are not used in the scoring of the PSQI.

Since there was a need for a method that would be easy, convenient and inexpensive, it was decided to administer a self-report instrument to the participants. Because of the absence of a suitable instrument for assessing sleep quality in children from eight to nine years of age, an abbreviated version of the SSR was utilised. Most of the empirical research on the subjective meaning of sleep quality among individuals with and without sleep complaints has indicated that a good night's sleep is associated with the ease of sleep initiation, frequency and duration of wakefulness during the night, ease of awakening and feelings of being rested, restored and refreshed on awakening (Baker *et al*., 1999; Kecklund and Akerstedt, 1997; Harvey *et al*., 2008). Therefore, only the relevant items of the SSR were employed for assessing the perceived sleep quality in the participants. The items were as follows: "Is it hard for you to go to bed?"; "Do you fall asleep in 20 minutes?"; "Do you wake up at night when your parents think you're asleep?"; "Do you have trouble falling back to sleep if you wake up during the night?"; "Do you have trouble waking up in the morning?"; "Do you feel rested after a night's sleep?"

Since confirming the validity[*] and reliability[†] of assessment tools is a prerequisite for assuring the integrity of research findings (DeVon *et al*., 2007), the psychometric properties of the abbreviated version of the SSR (SSR-A) were investigated. Initially, the face validity[‡] of the SSR-A was evaluated by a number of students from eight to nine years of age (N[§]=11) and their classroom teachers (N=4). The purpose of the instrument was explained to the classroom teachers. Then, they were asked to administer the self-report measure to some of their students and report on whether it was easily comprehensible to their students. Because the SSR-A was considered to be an appropriate measure, no alterations were made to this abbreviated version.

In addition to the face validity, the construct validity[**] of the SSR-A was determined by conducting a confirmatory factor analysis (CFA)[††] on the data from the first administration

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[*] Validity is the capability of an instrument to evaluate the attributes of the construct under study.

[†] Reliability refers to the consistency of assessment outcomes. According to DeVon and colleagues (2007), it is an essential, but not a sufficient, component of the validity of an assessment tool.

[‡] Face validity is the subjective assessment of the suitability or relevance of an instrument for its intended use. Therefore, it provides an insight into how potential respondents might interpret and utilise the instrument (DeVon *et al*., 2007).

[§] N denotes the number of respondents.

[**] Construct validity is the extent to which an instrument is able to assess the construct that it purports to measure. For example, an instrument intended to evaluate perceived sleep quality is construct valid if all items in the instrument have the capability to exclusively measure the attributes of perceived sleep quality.

[††] Factor analysis is a generic term referring to the statistical methods for exploring the interrelationship among a number of observed variables and constructing hypothetical variables underlying that interrelationship (*i.e.*, latent variables or factors). CFA is a type of factor analysis. It is employed in order to determine the extent to

of the instrument. Specifically, a single-factor model was postulated and assessed the extent to which this factor model fitted the observed variables. It was revealed that no items had to be removed from the instrument due to satisfactory factor loadings*. The goodness of fit between the sample data from the six items and conceptual model was evaluated by computing three fit indices†, namely the Tucker-Lewis Index (TLI; Tucker and Lewis, 1973), Comparative Fit Index (CFI; Bentler, 1990) and Root Mean Square Error of Approximation (RMSEA; Steiger, 1990). The fit indices were in accordance with the commonly accepted ranges. The TLI, CFI and RMSEA values for the single-factor model were 0.91, 0.93 and 0.07, respectively.

In order to verify the reliability of the SSR-A, the internal consistency of the items comprising the instrument was evaluated by computing Cronbach's alpha coefficient‡ (Cronbach, 1951). The internal consistency was found to be 0.86, indicating a high§ level. In other words, each of the items appears to measure a particular aspect of the same construct (i.e., perceived sleep quality). All items were rated on the same three-point scale as the SSR. A total score** was obtained by adding up the scores for each item. The teachers of the participants were given written instructions on how to administer the sleep quality measure and help the participants (see Appendix 1.1 for the SSR-A).

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which a predefined factor model fits the observed variables. Therefore, CFA is considered to be an effective method of investigating the construct validity of an instrument (DeVon *et al*., 2007; Rahim and Magner, 1995).

* One of the outcomes of a factor analysis is factor loading. It can be defined as the measure of the degree of closeness between an observed variable and a factor. Variables having a factor loading equal to or greater than 0.40 are conventionally considered to be satisfactory (Rose *et al*., 2008).

† Following the specification of the factor model, various fit indices are obtained in order to determine the adequacy of the fit between the sample data on observed variables and conceptual model. Although there are numerous fit indices available, the most common indices are the TLI, CFI and RMSEA (Schreiber, 2008). Generally, TLI and CFI values greater than 0.90 and a RMSEA value less than 0.08 are considered to be representative of an acceptable fit (Pai *et al*., 2007).

‡ Cronbach's alpha is a widely accepted statistical tool that determines the internal consistency or average correlation of items in a survey instrument in order to gauge its reliability. Cronbach's alpha can take values between zero and one. The higher the value, the more reliable the generated instrument is.

§ Although an alpha value equal to or greater than 0.70 is conventionally considered to be acceptable, the number of items and response categories of an assessment tool should be considered in interpreting Cronbach's alpha (Cronbach, 1951; Voss *et al*., 2000).

** The total score can vary from six to eighteen. The higher the score, the better the evolutions of perceived sleep experience.

3.3.2 Mood:

Mood[*] is a complex and poorly defined phenomenon that is difficult to assess empirically. According to Larsen and Fredrickson (1999, p. 40), mood states "are only probabilistically linked to [mood] measures." In other words, none of the existing methods may serve as the gold standard for defining and evaluating mood in adults and children (Larsen and Fredrickson, 1999; Larsen and Prizmic-Larsen, 2006; Mauss and Robinson, 2009; Zeman *et al*., 2007). Although numerous techniques, having their own strengths and limitations, are available, facial analysis systems and self-report instruments are more frequently employed for measuring children's mood status (Brenner, 2000).

Facial expressions are the changes in facial musculature in response to various external and internal stimuli including mood (Ekman and Friesen, 1976). Therefore, facial expression analysis has been an ongoing and a long-standing research topic for behavioural scientists since the pioneering work of Charles Darwin published in 1872 (Mauss and Robinson, 2009). The Facial Action Coding System (FACS; Ekman and Friesen, 1976; 1978) is one of the most comprehensive and commonly utilised analysis systems for "coding" mood-related expressions on adults' and children's faces (Brenner, 2000; Larsen and Fredrickson, 1999; Mauss and Robinson, 2009). Specifically, the FACS is an anatomically-based system for exhaustively describing any observable facial movement. In total, it distinguishes forty-four different movements called "action units" or "AUs." For example, AU 12 (*i.e.*, the retraction of lip corners), produced by the contraction of the Zygomatic major, appears to be a sign of spontaneous happiness (Ekman *et al*., 1980).

Because of its particular advantage of being conveniently performed on the adults and children having limited or no literacy skills, the FACS can be deemed superior to self-report measures. However, it has certain limitations that need to be acknowledged. One of its major limitations is that the technical complexity of the system requires recording equipment for photographic or videotaped images, specially trained personnel and a considerable amount of time for coding. For example, at least 40 hours of initial training is necessary to generate satisfactory facial evaluations (Ekman and Friesen, 1976). Moreover, it should be kept in mind that all observable facial movements may not always be reliable indices of mood-related

[*] Since the literature on emotional responding does not provide absolute or differential definitions of affect, emotion and mood (Forgas, 1995; Zeman *et al*., 2007), for the present purpose, the term mood is used as a generic label to refer both affect and emotion.

responses. In striking contrast to the common belief that smiles are indicative of happiness or other positive mood states, Schneider and Josephs (1991) found that preschool children could smile more often after failure than after success.

Self-report methodologies are the most widely used tools for gathering mood data from both adults and children (Brenner, 2000; Larsen and Prizmic-Larsen, 2006). A self-report-based assessment is easy, unobtrusive and invaluable in determining perceived mood intensity (Larsen and Fredrickson, 1999; Larsen and Prizmic-Larsen, 2006). It is important to recognise that respondents are in the unique position of being able to "monitor, assess and integrate information about their own [mood]… Therefore, self-report measures should not be thought of as second-rate proxies…" (Larsen and Prizmic-Larsen, 2006, p. 343). Despite being efficient and advantageous, these measures have some drawbacks intrinsic to self-reporting. It has been frequently criticised that they rely on the assumptions that respondents are both able and willing to monitor and give accurate information on their mood status and reported that respondents may be unaware of or repress their mood, particularly negative or inappropriate mood states (Larsen and Fredrickson, 1999; Larsen and Prizmic-Larsen, 2006; Zeman *et al.*, 2007). In spite of their limitations, a large number of self-report instruments have been developed and utilised for the measurement of mood.

Two of them, which worth mentioning here, are the PANAS and Positive and Negative Affect Scale for Children (PANAS-C; Laurent *et al.*, 1999). The PANAS is one of the most extensively employed questionnaires for assessing positive and negative mood in adults, and it has been used in various lighting studies (*e.g.*, Baron *et al.*, 1992). The schedule contains ten items for each mood dimension. On a scale of one (*i.e.*, "very slightly or not at all") to five (*i.e.*, "extremely"), respondents are asked to rate the extent to which they are experiencing, or have experienced, a certain mood (*e.g.*, feeling "nervous"). From the responses, two scores are obtained by adding the scores for the items pertaining to each separate dimension. Unlike the PANAS, the PANAS-C was specially developed for children and adolescents. However, its items were derived from the PANAS and its expanded version, called PANAS-X (Watson and Clark, 1999). It also differs from the original version in consisting of twenty-seven items rated in terms of the frequency with which a specific mood has been experienced before.

Another instrument by Derbaix and Pecheux (1999) is of interest and concern. This self-report measure, or the DPMS, is a brief, nine-item questionnaire that can be administered to or self-administered by children from eight to twelve years of age for assessing their current positive and negative mood status. The items of the DPMS are rated on a four-point scale, with the response options being “YES,” “yes,” “no” and “NO.” From the responses, two separate scores are obtained for each mood dimension. Because of its superior brevity and simplicity by comparison with those of other methods and instruments, it was decided to administer the DPMS to the participants in spite of the fact that an English version of the questionnaire was not available. Therefore, the DPMS was translated from French into English and vice versa in order to ensure comparability[*].

Since research instruments must be valid and reliable in the culture being studied (Maneesriwongul and Dixon, 2004), the psychometric properties of the English version of the DPMS (DPMS-E) were also investigated. Initially, the face validity of the DPMS-E was evaluated by a number of students from eight to nine years of age (N=11) and their classroom teachers (N=4). The purpose of the instrument was explained to the classroom teachers. Then, they were asked to administer the self-report measure to some of their students and report on whether it was easily comprehensible to their students. Because the DPMS-E was considered to be an appropriate measure, no alterations were made to this English version.

In addition to the face validity, the construct validity of the DPMS-E was determined by conducting a CFA on the data from the first administration of the instrument. Specifically, a two-factor model was postulated and assessed the extent to which this factor model fitted the observed variables. It was revealed that no items had to be removed from the instrument due to satisfactory factor loadings. The goodness of fit between the sample data from the nine items and conceptual model was evaluated by computing the aforementioned fit indices. The fit indices were in accordance with the commonly accepted ranges. The TLI, CFI and RMSEA values for the two-factor model were 0.98, 0.98 and 0.06, respectively.

In order to verify the reliability of the DPMS-E, the internal consistencies of the items in two different item sets[†] were evaluated by means of the alpha coefficient. The internal consistencies of the items in the same sets were found to be 0.80, indicating an adequate level. In other words, each set of items appears to measure a particular aspect of the same construct (*i.e.*, either positive or negative mood). All items were rated on the same four-point scale as

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[*] During the translation process, two independent translators were consulted. Firstly, one of the translators worked independently to produce a translated version. Secondly, this new version was translated back into the original language by the other translator. Finally, both versions were compared with each other for detecting and resolving any inconsistencies.

[†] One of the sets consists of the items regarding positive mood. The items are as follows: "At the moment, I am feeling cheerful."; "At the moment, I feel like laughing."; "At the moment, I am happy."; "At the moment, I am having great fun." The other set is comprised of the items regarding negative mood. The items are as follows: "At the moment, I am in bad mood."; "At the moment, I am feeling grouchy."; "At the moment, I am feeling sad."; "At the moment, I am feeling grumpy."; "At the moment, I am angry."

the DPMS. Two scores[*] were obtained for each factor by adding up the scores for appropriate items. The teachers of the participants were given written instructions on how to administer the mood scale and help the participants (see Appendix 2.1 for the DPMS-E).

[*] One of the scores is a positive mood score. It can vary from four to sixteen. The higher the score, the better the evolutions of positive mood states. The other score is a negative mood score. It can vary from five to twenty. The higher the score, the worse a respondent's mood state.

3.3.3 Daytime sleepiness:

Conceptually, sleepiness can be considered to be the composite of three factors, namely physiologic, manifest and introspective sleepiness (Eberhart *et al*., 2000; Hirshkowitz, 2007; Mysliwiec *et al*., 2002). Physiologic sleepiness can be defined as the end result of the biological drive to sleep, and it is typically evaluated by the amount of time it takes to fall asleep in the absence of alerting factors. Manifest sleepiness, dissimilar from physiologic sleepiness, is the manifestation of an individual's inability to sustain wakefulness, and this state is generally assessed by measuring how long it takes to lose the ability to remain awake under soporific conditions. Introspective, or perceived, sleepiness, considerably different from physiologic and manifest sleepiness, is the subjective perception of the need to sleep, and it is quantified by means of self-report methods. In an attempt to evaluate these distinct factors, numerous techniques and instruments have been devised for many years.

The Multiple Sleep Latency Test (MSLT) is considered to be the most reliable technique for assessing physiologic sleepiness (Eberhart *et al*., 2000). This test was developed in the early 1970s, and it has achieved a widespread acceptance and become the de facto standard for the objective measurement of daytime sleepiness since that time (Afifi and Kushida, 2005; Mitler and Miller, 1996; Sullivan and Kushida, 2008; Wise, 2006). The MSLT is intended to quantify the propensity to fall asleep under standardised conditions, and it is based on the common-sense premise that sleepy individuals are likely to fall asleep more quickly than those who are not. The test consists of a number of polysomnographically-recorded nap opportunities scheduled at two-hour intervals during the day. At the beginning of each nap opportunity, the person under study is instructed to lie and not to resist falling asleep. It is commonly accepted that falling asleep in less than 5 minutes, on average, is indicative of severe or pathological daytime sleepiness in adults (Afifi and Kushida, 2005; Mitler and Miller, 1996; Sullivan and Kushida, 2008).

Even though the MSLT is widely acknowledged as an impeccable technique for assessing sleepiness, it has certain limitations that need to be addressed. One of the limitations of the MSLT is that it is subject to certain interpretative difficulties. The instructions of the test can be counterintuitive to the persons who complain of the difficulty in remaining awake (Mitler and Miller, 1996) and some children (Wise, 2006). Another limitation is that the result of the MSLT can be detrimentally affected by the psychological state of the person under study. For example, anxiety or stress may increase the amount of time it takes to fall asleep

(Wise, 2006) and, as a direct consequence, impinge upon the findings. It should be also noted that this test is very cumbersome and expensive (Johns, 1991; Mitler and Miller, 1996) and that it is not suitable for large-scale epidemiologic studies and all field work (Maldonado *et al*., 2004).

The Maintenance of Wakefulness Test (MWT), a variant of the MSLT, is the most frequently employed technique for quantifying manifest sleepiness (Eberhart *et al*., 2000). This test, like the MSLT, is a polysomnographic procedure for the evaluation of daytime sleepiness in a non-stimulating environment (Doghramji and Mitler, 2005; Mitler and Miller, 1996; Sullivan and Kushida, 2008; Wise, 2006). In addition, the MWT resembles the de facto standard for the objective measurement of daytime sleepiness in that the person under study is given a number of nap opportunities scheduled at two-hour intervals during the day. Although it is procedurally similar to the MSLT, a crucial difference between the two techniques lies in the instructions given at the beginning of each nap opportunity. In the MWT, the person under study is asked to sit and remain awake as long as possible. Thus, it may be argued that this technique more closely reflects the challenge faced in the soporific situations of everyday life (Doghramji and Mitler, 2005). Even though the normative values of the MWT are not unanimous (Sullivan and Kushida, 2008; Wise, 2006), never falling asleep during any of the nap opportunities can be considered to be the strongest evidence of the manifestation of the ability to resist the pressure to fall asleep (Wise, 2006).

Before making the decision to utilise the MWT, one should be aware of the fact that this test is subject to many of the aforementioned limitations of the MSLT. One of the most severe limitations is that the psychological state of the person under study impacts upon the maintenance of wakefulness. For example, depression may decrease the amount of time it takes for an individual to succumb to sleep (Wise, 2006) and, as a direct consequence, impinge upon the result of the MWT. This technique also shares the disadvantages of the MSLT in being a very cumbersome and expensive test (Johns, 1991; Mitler and Miller, 1996) and being not suitable for large-scale epidemiologic studies and all field work (Maldonado *et al*., 2004). In addition to these limitations, it is not feasible to employ the MWT for assessing daytime sleepiness in non-adult age groups because of the paucity of normative data (Hoban and Chervin, 2001).

There is a wide variety of self-report instruments that have been devised to subjectively evaluate introspective sleepiness. Assessing sleepiness by utilising self-report methods has the advantage of being simple, inexpensive, unobtrusive and invaluable in the quantification of introspective sleepiness (Cluydts *et al*., 2002; Curcio *et al*., 2001;

Hirshkowitz, 2007; Silber, 2006), but it has some drawbacks intrinsic to self-reporting. It has been frequently reported to be prone to misinterpretation, unintended bias and purposeful falsification (Cluydts *et al*., 2002; Curcio *et al*., 2001; Hirshkowitz, 2007). In addition to these drawbacks, one should also note that the subjective measures of sleepiness may be discordant with the aforementioned techniques (Cluydts *et al*., 2002; Hirshkowitz, 2007; Mysliwiec *et al*., 2002). According to Cluydts and colleagues (2002), these subjective measures can be roughly divided into two categories, those evaluating sleepiness on the basis of the sleep propensity in various daily life situations and those assessing sleepiness at a particular time. The measures of the first category give an indication of an individual's enduring and stable level of sleepiness, named as trait sleepiness.

One of the most widely used instruments to evaluate trait sleepiness is the Epworth Sleepiness Scale (ESS; Johns, 1991). The ESS is a simple, self-administered questionnaire that asks respondents to rate their usual chance of dozing off or falling asleep on a scale of zero ("would never doze") to three ("high chance of dozing") in eight different soporific situations commonly encountered in daily life (*e.g.*, "in a car, while stopped for a few minutes in the traffic"). An ESS score is obtained by adding the scores for each of the situations, and it can vary from zero to twenty-four. A score greater than ten is considered to be indicative of abnormal or pathological sleepiness (Johns, 1991; Johns and Hocking, 1997).

The second category of the self-report measures can be employed in order to assess short-term changes in sleepiness or, in other words, to quantify state sleepiness. Unlike the measures of the first category, these instruments are more appropriate for research purposes than for clinical examination and diagnosis (Hirshkowitz, 2007).

The Stanford Sleepiness Scale (SSS; Hoddes *et al*., 1973) is one of the most extensively utilised instruments for quantifying state sleepiness. The SSS is a single-item, Likert-type scale that contains seven ordinal anchor points ranging from one ("feeling active and vital; alert; wide-awake") to seven ("almost in reverie; sleep onset soon; lost struggle to remain awake"). Respondents are asked to select the most appropriate anchor point that indicates the level of their immediate perception.

It can be speculated that the ESS and SSS are the most ubiquitous measures of perceived sleepiness. However, neither of these scales is suitable to be administered to schoolchildren (Hoban and Chervin, 2001). In spite of the fact that school-aged children are acknowledged to be able to provide reliable reports on their sleepiness (Blunden *et al*., 2006), there are not many instruments that have been designed for the evaluation of introspective sleepiness in this age group.

One of these scarce instruments is a pictorial scale (Maldonado *et al*., 2004) that assesses state sleepiness in both children and adults. This scale was specifically developed for the children and adults whose reading and writing skills are deficient. Therefore, it consists of only five cartoon faces that depict various sleepiness levels. Respondents select the cartoon face that better reflects their level of perceived sleepiness at a particular time. It is worth noting here that Maldonado and colleagues compared their pictorial scale with the two most common measures of state sleepiness (*i.e.*, the SSS and the Karolinska Sleepiness Scale*). They observed that the comparison among their scale and the two other measures showed remarkably good agreement. In addition, Maldonado and colleagues demonstrated that the scale could be easily and reliably administered to children from seven to fourteen years of age.

Since there was a need for a method that would be easy, convenient and inexpensive, it was decided to administer a self-report tool to the participants. In order to investigate the fluctuations in sleepiness over the course of a school day and compare their magnitude, the pictorial scale of Maldonado *et al*. (2004), which had been proven to be a valid and sensitive measure of state sleepiness in children from eight to nine years of age, was utilised (see Appendix 3.1). The teachers of the participants were given written instructions on how to administer the pictorial sleepiness scale and help the participants.

* The Karolinska Sleepiness Scale (Akerstedt and Gillberg, 1990) is very similar to the SSS. It is a single-item, Likert-type scale that contains nine ordinal anchor points ranging from one ("extremely alert") to nine ("extremely sleepy; fighting sleep"). Respondents are asked to choose the most pertinent anchor point that indicates their immediate level of sleepiness.

3.3.4 Cortisol and melatonin:

Cortisol, a corticosteroid, is the end product of the Hypothalamic-Pituitary-Adrenal (HPA) axis (Jessop and Turner-Cobb, 2008; Nicolson, 2008; Pollard and Ice, 2007). The HPA axis is an important homeostatic[*] system which maintains a circadian rhythm under normal conditions and activates in response to cognitive (*e.g.*, fear) or non-cognitive (*e.g.*, infection) disturbances (Jessop and Turner-Cobb, 2008). As its name implies, the HPA axis consists of the hypothalamus, pituitary gland and adrenal cortex (Levine *et al*., 2007; Nicolson, 2008; Pollard and Ice, 2007). Briefly, the activity of the axis is initiated by the release of corticotrophin releasing hormone from the paraventicular nucleus of the hypothalamus. Then, the pituitary gland secretes adrenocorticotrophic hormone that prompts the production and release of cortisol by the cortex of the adrenal gland.

As it is concisely presented in the first chapter, cortisol shows a marked circadian rhythm (Hanrahan *et al*., 2006; Kirschbaum and Hellhammer, 2000; Pollard and Ice, 2007), which is believed to be established in early infancy (Hanrahan *et al*., 2006; Pollard and Ice, 2007). Typically, cortisol concentrations reach a nadir until midnight. Following a dormant period of several hours, the concentrations begin to increase and reach a primary peak shortly (*i.e.*, approximately 30 minutes) after awakening[†]. Then, they decline steadily and rapidly until a secondary peak, which is associated with the food consumption at lunch time, and resume declining over the rest of the afternoon and throughout the evening.

Apart from the traditional and invasive method of sampling blood by means of venipuncture or intravenous cannulation, numerous endocrine parameters including steroid hormones can be evaluated by analysing urine and saliva specimens (Ellison, 1988; Nicolson, 2008; Pollard and Ice, 2007). Even though there is extensive evidence that both urine and saliva are viable alternatives to blood in order to determine the circulating levels of cortisol in humans (Casale *et al*., 2001; Kirschbaum and Hellhammer, 1994, 2000; Trainer *et al*., 1993), one should consider that these body fluids represent slightly different aspects.

It should be recognised that most of the cortisol present in human plasma is bound to plasma proteins, such as corticosteroid binding globulin and albumin (Kirschbaum and Hellhammer, 2000; Pollard and Ice, 2007). Only a diminutive percentage circulates freely,

[*] Homeostasis can be defined as the ability of a biological entity to counteract changes and retain a constant internal equilibrium.

[†] It has been hypothesised that the increase in the concentrations of cortisol may ameliorate sleepiness (Pollard and Ice, 2007).

and it is responsible for the biological activity of the hormone (Kirschbaum and Hellhammer, 1994, 2000; Pollard and Ice, 2007). While total cortisol concentrations[*] are conventionally obtained from blood samples, the free or biologically active fraction of cortisol can be directly derived from both urine and saliva specimens without involving complex and expensive secondary procedures (Ellison, 1988; Nicolson, 2008; Trainer *et al*., 1993). It should also be recognised that the analysis of urine provides the cumulative amount of the cortisol, or any other hormone, excreted into this medium during the period between the previous urination and the collection of the subsequent urine sample (Ellison, 1988; Pollard and Ice, 2007). In contrast to urine, blood and saliva can be collected at almost any frequency for assessing the activity of the HPA axis momentarily (Ellison, 1988; Nicolson, 2008).

Since the early 1980s, the evaluation of salivary cortisol has been employed in various scientific disciplines and, inevitably, become the most popular approach (Levine *et al*., 2007; Pollard and Ice, 2007). The popularity of this approach can probably be attributed to the relative ease and non-invasive nature of collecting samples, ability to obtain specimens from individuals in both laboratory and field settings and possibility of sampling at short intervals without raising ethical issues (Ellison, 1988; Jessop and Turner-Cobb, 2008; Kirschbaum and Hellhammer, 1994, 2000; Levine *et al*., 2007; Nicolson, 2008; Pollard and Ice, 2007). Furthermore, cortisol is markedly stable in saliva. Saliva samples can be stored at 20°C for up to four weeks without a significant reduction in cortisol concentrations (Kirschbaum and Hellhammer, 1994). However, it is recommended to store them at -20°C or lower temperatures[†] (Kirschbaum and Hellhammer, 2000).

Saliva specimens can be collected either by drooling into small containers or, more frequently, by means of the Salivette (Sarstedt AG and Co., Numbrecht, Germany) with a cotton swab (Kirschbaum and Hellhammer, 1994, 2000; Pollard and Ice, 2007). The Salivette mainly consists of a dental roll within a plastic vessel. By gently chewing on the roll between thirty seconds and one minute, the collection of an adequate sample volume is assured (Kirschbaum and Hellhammer, 1994). In spite of being a convenient and an acceptable technique, a number of influential factors need to be considered in utilising the Salivette. Dietary intake and oral bleeding have been documented that they may artificially affect the quantitative estimates of salivary cortisol (Ellison, 1988; Hanrahan *et al*., 2006; Levine *et al*., 2007; Nicolson, 2008). Therefore, it is advised to refrain from eating or drinking for 30

[*] Total cortisol concentrations represent the sum of bound and free cortisol concentrations.
[†] Saliva samples can be stored at -20°C or lower temperatures for almost two years without a significant reduction in cortisol concentrations (Nicolson, 2008).

minutes and rinse the mouth thoroughly with cold water prior to sampling (Ellison, 1988; Hanrahan *et al*., 2006).

Melatonin, a methoxyindole, is acknowledged to be the hand of the endogenous oscillator in mammals and responsible for conveying information concerning the daily cycle of light and darkness, being the main zeitgeber[*], to body physiology (Claustrat *et al*., 2005; Geoffriau *et al*., 1998). It is primarily synthesised and secreted by the pineal gland despite the fact that several other organs and cells are also involved in the biosynthesis of melatonin (Claustrat *et al*., 2005; Karasek and Winczyk, 2006). The activity of the pineal gland is regulated by a long and complex neural circuit (Brzezinski, 1997; Claustrat *et al*., 2005; Geoffriau *et al*., 1998; Karasek and Winczyk, 2006). In humans and other mammalian species, the photic information is detected by the eyes and transmitted to the suprachiasmatic nucleus, which is the oscillator of biological rhythms (see Figure 3.4), principally through the retinohypothalamic tract. Subsequently, the suprachiasmatic nucleus sends neural signals to different brain regions including the pineal gland.

Figure 3.4 The suprachiasmatic nucleus is the endogenous oscillator of biological rhythms (Geoffriau *et al*., 1998)

As it is briefly presented in the first chapter, melatonin shows a robust circadian rhythm (Brzezinski, 1997; Claustrat *et al*., 2005; Geoffriau *et al*., 1998; Karasek and Winczyk, 2006), which is believed to appear by the end of the neonatal period (*i.e.,* forty days of age) and persist thereafter (Ardura *et al*., 2003). Typically, melatonin concentrations reach a nadir between 07:00 a.m. and 09:00 a.m. Following a quiescent period during the day, the concentrations begin to increase continuously at approximately 09:00 p.m. and reach a peak

[*] Circadian rhythms are entrained by factors termed zeitgebers.

between 02:00 a.m. and 04:00 a.m. Then, they decline steadily until the morning inhibition of melatonin synthesis.

Like cortisol, melatonin can be assessed in humans by analysing blood, urine and saliva specimens (Benloucif *et al.*, 2008; Claustrat *et al.*, 2005; Geoffriau *et al.*, 1998). Although there is unambiguous evidence that all of these body fluids can be utilised effectively and interchangeably in order to determine the circulating levels of melatonin, it should be noted that the evaluation of salivary melatonin provides the same above-mentioned advantages of quantifying salivary cortisol (Bagci *et al.*, 2009; Benloucif *et al.*, 2008; Kennaway and Voultsios, 1998; Nowak *et al.*, 1987). In addition to its distinct advantages, the potential pitfalls of assessing melatonin by collecting saliva samples should also be recognised. It has been reported that dietary intake and oral bleeding may contaminate saliva specimens (Benloucif *et al.*, 2008; Nowak *et al.*, 1987). For averting contamination, it is advised not to eat or drink anything for twenty minutes and rinse the mouth before providing saliva samples (Nowak *et al.*, 1987). Furthermore, it is recommended to store the samples at -20°C or lower temperatures[*] in order to avoid degradation (Bagci *et al.*, 2009; Nowak *et al.*, 1987).

Since there was a need for a method that would be simple, convenient and cheap, it was decided to collect saliva specimens by means of the cotton version of the Salivette for determining the diurnal levels of cortisol and melatonin at certain times of the day. The participants were given full instructions on how to use the Salivette, and they were asked to refrain from eating or drinking for at least 30 minutes and rinse their mouths with cold water prior to sampling[†]. The samples were stored at -20°C until being analysed, and they were shipped to the laboratory of Linkoping University[‡] on dry dice for the prevention of thawing.

[*] Saliva samples can be stored at room temperature for at least three days and at -20°C or lower temperatures for years without a significant reduction in melatonin concentrations (Bagci *et al*., 2008).

[†] In order to allow enough time for the re-establishment of natural oral flora (Hanrahan *et al*., 2006), the specimens were provided approximately 5 minutes after rinsing.

[‡] The laboratory analysis of the samples was conducted in Linkoping University, Sweden.

3.3.5 Academic performance:

By compiling and comparing the examination results of the participants for the 2008-2009 school year, their scholastic performance or educational success, which was also indicative of their cognitive abilities and limitations (Thompson *et al.*, 1991), was assessed. In order to evaluate the extent to which they were successful in reading, writing and mathematics, the students were examined by means of standardised tests in September, January and May. According to the classroom teachers, the tests were designed for the assessment of the following knowledge and skills in the fourth graders:

- In the fourth grade, students should have the capability to use their knowledge of words, sentences and texts for understanding and responding to the meaning. Furthermore, it is expected that they are able to read challenging and lengthy texts independently.
- Fourth graders learn the main rules and conventions of written English, and they start to explore how the English language can be employed in order to express meaning in different ways.
- At this level, students are expected to calculate accurately with all four number operations. In addition, they should be able to discuss and present their reasoning by utilising diagrams, charts and other visuals.

3.4 Protocol:

The study took place between the 8th of October 2008 and 10th of June 2009 (see Figure 3.5). It is apparent from the figure that, in total, ten data collection sessions were executed at approximately four-week intervals. More specifically, except for the first and last terms, one main and one supplementary sessions were scheduled for each term. In the main sessions lasting for the entire school day (see Table 3.5), the students rated their mood and sleepiness and supplied saliva specimens on three different occasions subsequent to the retrospective evaluation of their sleep quality. At 09:50 a.m., data gathering was carried out promptly after resetting the light output of the dynamic lighting system to its normal level for determining the immediate efficacy of the system and existence of possible group-related differences in the early hours of the day. Before having lunch, the participants were assessed for a second time in order to find out whether the lighting system had any prolonged effects and evaluate whether its effects were more favourable and substantial than those of the others.

It should be mentioned here that, at 11:45 a.m. and also at 02:45 p.m., the participants provided saliva samples only for the quantification of their cortisol concentrations. The justification for this decision is that the secretion of melatonin during the daytime is undetectable (Claustrat *et al.*, 2005; Geoffriau *et al.*, 1998). At 02:45 p.m., the final assessments were performed in order to appraise and compare the differential effects of the lighting conditions in the classrooms. One may notice that the afternoon investigations were not conducted immediately after the maximal increase in the light output of the dynamic lighting system. For minimising and avoiding the disturbance of teaching, they were executed at 02:45 p.m. rather than at 02:10 p.m.

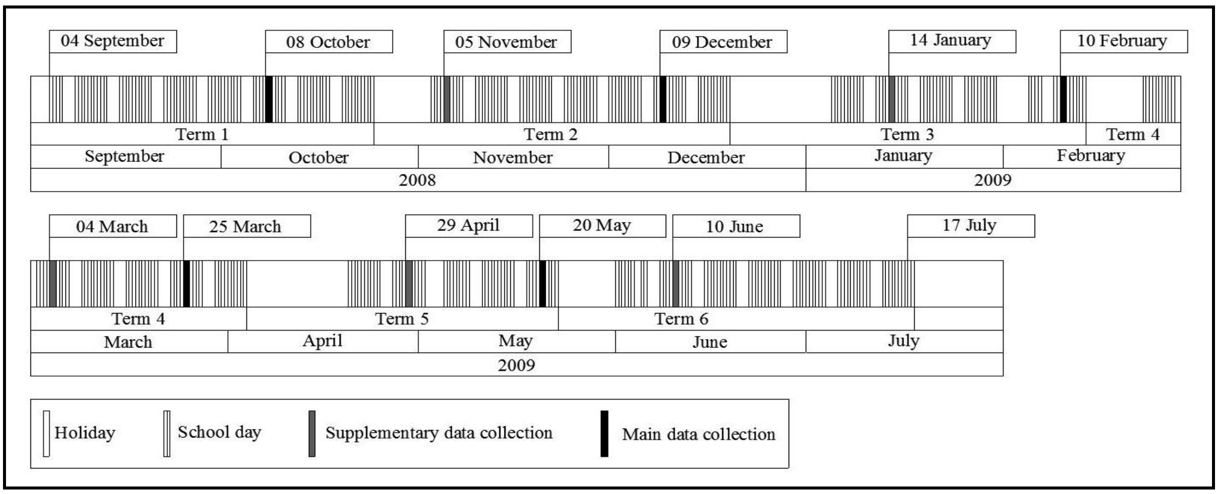

Figure 3.5 The schedule of the main field study

Table 3.5 The daily routine of main data collection sessions

Times	Operations
08:00-08:50 a.m.	Preparations
08:50 a.m.	The start of school day – Subjective sleep quality reports
09:50 a.m.	Subjective mood and sleepiness reports + Saliva samples (melatonin + cortisol)
10:15-10:30 a.m.	Morning break
11:45 a.m.	Subjective mood and sleepiness reports + Saliva samples (cortisol)
12:00-01:10 p.m.	Lunch break
02:45 p.m.	Subjective mood and sleepiness reports + Saliva samples (cortisol)
03:20 p.m.	The end of school day

Since it was impractical to measure participants' melatonin concentrations after 09:50 a.m., the supplementary data collection sessions were carried out for the provision of further information on the morning inhibition of melatonin synthesis and its likely association with students' sleep quality. Accordingly, in the supplementary sessions lasting for approximately two hours (see Table 3.6), the participants only rated their sleep quality at 08:50 a.m. and supplied saliva specimens at 09:50 a.m. It is important to note here that none of the main and supplementary sessions were performed either on Monday or on Friday. Furthermore, both sessions were not conducted in the week after Christmas and Easter holidays. Therefore, the possible confounding effects of weekends and the major holidays on the outcomes of the study were sought to be minimised. The study protocol was approved by the Ethical Committee of University College London.

Table 3.6 The daily routine of supplementary data collection sessions

Times	Operations
08:00-08:50 a.m.	Preparations
08:50 a.m.	The start of school day – Subjective sleep quality reports
09:50 a.m.	Saliva samples (melatonin)
10:15-10:30 a.m.	Morning break

Chapter 3 - Methodology

3.5 Statistics:

Classic parametric statistical significance tests, such as the analysis of variance (ANOVA) and Student's *t* test are widely used by researchers in many disciplines, including light and lighting. For valid statistical conclusions to be reached by employing these parametric tests, it is necessary that the assumptions underlying them, such as the assumptions that the data being analysed are normally distributed[*] (*i.e.*, normality) and the populations from which the samples are drawn have the same variance[†] (*i.e.*, homoscedasticity), are met (Erceg-Hurn and Mirosevich, 2008; Leech and Onwuegbuzie, 2002)[‡]. However, in practice, these assumptions are rarely met (Erceg-Hurn and Mirosevich, 2008).

The use of classic parametric tests when the assumptions are violated can have serious consequences, in particular for the Type I[§] and Type II[**] error rates (Erceg-Hurn and Mirosevich, 2008; Leech and Onwuegbuzie, 2002). It can cause the Type I error rate to distort, substantially reduce the power of the tests and, as a direct consequence, lead to significant errors in the evaluation and interpretation of the data under investigation (Erceg-Hurn and Mirosevich, 2008). For example, Wilcox (1998) demonstrated that only a slight departure from normality could reduce the power of the Student's *t* test from 0.96 to 0.28.

In addition to the above-mentioned limitations, one should also consider the type of the data collected in order to decide upon the most appropriate statistical significance test. For example, it has been argued that parametric methods, based on the calculations of means and standard deviations, are inappropriate for analysing ordinal data[††] having no meaningful numerical characteristics (Jakobsson, 2004; Kuzon *et al.*, 1996; Shah and Madden, 2004). Indeed, utilising these methods for ordinal data analysis is contended to be the first of "the

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[*] The characteristic properties of the normal distribution are that the sixty-eight per cent of all data falls within a range of ±one standard deviation from the mean and a range of ±two standard deviations contains the ninety-five per cent of the data.

[†] Variance is a measure of how spread out a distribution is, and it is the square of the standard deviation.

[‡] It should be noted that researchers should not rely on statistical assumption tests in order to check whether the assumptions are met because of the frequency with which these tests produce inaccurate results (Erceg-Hurn and Mirosevich, 2008).

[§] A Type I error involves rejecting the null hypothesis when it is, in fact, true (*i.e.*, concluding that a real effect exists when it does not).

[**] A Type II error involves failing to reject the null hypothesis when it is, in fact, false (*i.e.*, concluding that a real effect does not exist when it does). The power of a test is the probability of rejecting the null hypothesis when it is false.

[††] Ordinal data, more specifically ordered categorical data, can be simply defined as the collection of the ratings of individual items into ordered categories. The categories are usually assigned qualitative labels, such as "no pain," "mild pain," moderate pain," and "severe pain," relating to their natural order. However, no measure of distance is explicitly defined between adjacent categories. For example, one cannot assume that "severe pain" represents twice as much as pain as "mild pain."

seven deadly sins of statistical analysis" (Kuzon *et al*., 1996). Although such data should be analysed with nonparametric methods (Jakobsson, 2004; Kuzon *et al*., 1996; Shah and Madden, 2004), the nonparametric counterparts of classic parametric tests, such as the Kruskal-Wallis and Wilcoxon Mann-Whitney tests, suffer from many limitations. One major limitation is that classic nonparametric tests are not appropriate for analysing factorial designs involving interactions (Erceg-Hurn and Mirosevich, 2008; Shah and Madden, 2004).

Modern robust statistics[*] can solve many of the problems caused by violating the assumptions of classic parametric statistical significance tests. Modern robust techniques provide very effective methods for dealing with the violations, and they also perform well when the assumptions are met (Erceg-Hurn and Mirosevich, 2008; Wilcox, 1998). Furthermore, these techniques, including modern nonparametric procedures, are not susceptible to the limitations of classic nonparametric tests (Erceg-Hurn and Mirosevich, 2008; Shah and Madden, 2004).

Because of the reported superiority of modern robust statistics, the ANOVA-Type Statistic (ATS; Brunner *et al*., 2002; Brunner and Puri, 2001; Shah and Madden, 2004), a modern nonparametric technique, was adopted instead of the conventional techniques. The ATS tests whether the groups being compared have identical distributions and their relative treatment effects ($\hat{p}_i$ s) are the same (Erceg-Hurn and Mirosevich, 2008). It may be helpful to provide here an example in order to understand the computation and interpretation of relative treatment effects. The following calculations are presented in Table 3.7.

Table 3.7 Example calculations

Scores and calculations	Groups							
	Group A				Group B			
Original score	5	6	11	12	4	5	7	9
Corresponding rank score	2.5	4	7	8	1	2.5	5	6
Sum (rank scores)	21.5				14.5			
Mean (rank scores)	5.38				3.63			
Relative treatment effect	0.61				0.39			

Suppose an experiment compares two groups on a dependent variable[†] and let there be four participants in each group. Firstly, participants' scores should be converted to ranks in order to compute the relative treatment effect of each group. For example, the lowest score in

[*] According to Erceg-Hurn and Mirosevich (2008, p. 593), "the term robust statistics refers to procedures that are able to maintain the Type I error rate of a test at its nominal level and also maintain the power of the test."
[†] A dependent variable is the observed result of the independent variable being manipulated or changed.

the data set is assigned a rank of 1. It should be noted that tied scores are assigned midranks. The second and third lowest scores, which are both 5, are assigned an average rank (or a midrank) of 2.5 (*i.e.*, $\frac{2+3}{2}=2.5$). Secondly, the ranks in each group are added together and then divided by the number of observations in these groups in order to calculate each group's mean rank. For example, the mean rank of Group A is 5.38 (*i.e.*, $\frac{2.5+4+7+8}{4}=5.38$). Finally, the relative treatment effect of each group is computed by the following equation:

$$\hat{p}_i = \frac{1}{N}\left(\overline{R}_{i\bullet} - \frac{1}{2}\right), \tag{2.1}$$

where $\hat{p}_i$* denotes the *i*th group's estimated relative treatment effect, $\overline{R}_{i\bullet}$ the *i*th group's mean rank and *N* the total number of observations in all groups. Given that there are eight observations, the estimated relative treatment effects of Group A and B are 0.61 (*i.e.*, $\frac{5.38-0.5}{8}=0.61$) and 0.39 (*i.e.*, $\frac{3.63-0.5}{8}=0.39$), respectively.

The interpretations of relative treatment effects and means are very much alike. If the groups being compared have similar relative treatment effects, it can be interpreted that the groups do not differ markedly with respect to participants' typical response. In contrast, the large differences in relative treatment effects indicate that the groups differ considerably. For example, one can report that the participants in Group A ($\hat{p}_A = 0.61$) tend to have higher scores on the dependent variable than the participants in Group B ($\hat{p}_B = 0.39$).

All calculations regarding the ATS were carried out with the SAS Statistical Software Package for Windows (version 9.0; SAS Institute Inc., Cary, NC, U.S.) The calculations on the above-mentioned factor analyses were performed by using Mplus for Windows (version 4.1; Muthen and Muthen; Los Angeles, CA, U.S.) In addition to the SAS and Mplus, the SPSS Statistical Software Package for Windows (version 11.5; SPSS Inc., Chicago, IL, U.S.) was utilised for computing the descriptive statistics of all sample data and aforementioned reliability coefficients (*i.e.*, Cronbach's alphas). The level of significance was set at a *p* value equal to or less than 0.05.

* Relative treatment effects can range between zero and one.

Chapter 4

Results

Chapter 4 - Results

4.1 Sleep quality

The descriptive statistics of the study population regarding their self-report-based evaluations of their sleep experience are presented in Table 4.1. The results are based on a total number of 560 observations, of which 53 (*i.e.*, 9.5%) are missing. It can be inferred from Table 4.1 that the medians[*] of the participants' ratings do not differ considerably among the classrooms and concluded that there are modest differences in the medians of the dates. In addition, it can be deduced from the table that the participants did not frequently experience difficulties with sleep initiation, maintenance and restoration over the course of the study.

Table 4.1 The descriptive statistics regarding participants' evaluations of their sleep experience

Classrooms	Dates	N*	Medians	Minimums	Maximums
C03	08 Oct.	14	12.0	7.0	16.0
	05 Nov.	14	12.0	8.0	16.0
	09 Dec.	12	13.0	7.0	16.0
	14 Jan.	13	12.0	8.0	15.0
	10 Feb.	12	11.5	8.0	16.0
	04 Mar.	13	11.0	8.0	18.0
	25 Mar.	12	12.5	6.0	18.0
	29 Apr.	9	12.0	6.0	17.0
	20 May	13	12.0	7.0	16.0
	10 Jun.	13	12.0	6.0	17.0
	Total	125	12.0	6.0	18.0
C04	08 Oct.	11	9.0	6.0	16.0
	05 Nov.	9	10.0	6.0	16.0
	09 Dec.	9	13.0	6.0	17.0
	14 Jan.	8	11.5	6.0	18.0
	10 Feb.	10	12.0	6.0	16.0
	04 Mar.	11	13.0	6.0	15.0
	25 Mar.	9	14.0	6.0	18.0
	29 Apr.	9	13.0	6.0	17.0
	20 May	10	12.0	6.0	17.0
	10 Jun.	9	12.0	5.0	17.0
	Total	95	12.0	5.0	18.0

[*] If we order a data set from the lowest score to the highest score, the median of the data set is the numeric value separating the higher half of the scores from the lower half. When the number of the scores in a data set is even, it can be computed as the average of the two scores in the middle of the ordered data set.

C09	08 Oct.	15	12.0	6.0	16.0
	05 Nov.	12	12.5	9.0	16.0
	09 Dec.	14	12.0	8.0	16.0
	14 Jan.	16	12.5	7.0	16.0
	10 Feb.	16	12.0	7.0	16.0
	04 Mar.	15	12.0	7.0	17.0
	25 Mar.	14	12.0	6.0	17.0
	29 Apr.	15	13.0	6.0	17.0
	20 May	16	12.0	7.0	18.0
	10 Jun.	16	11.5	7.0	18.0
	Total	149	12.0	6.0	18.0
C10	08 Oct.	15	12.0	9.0	16.0
	05 Nov.	15	13.0	8.0	18.0
	09 Dec.	13	13.0	6.0	17.0
	14 Jan.	14	13.0	5.0	16.0
	10 Feb.	15	13.0	8.0	18.0
	04 Mar.	13	13.0	9.0	17.0
	25 Mar.	14	14.0	7.0	17.0
	29 Apr.	13	13.0	9.0	16.0
	20 May	14	13.5	11.0	18.0
	10 Jun.	12	13.0	10.0	17.0
	Total	138	13.0	5.0	18.0
Total	08 Oct.	55	12.0	6.0	16.0
	05 Nov.	50	12.0	6.0	18.0
	09 Dec.	48	13.0	6.0	17.0
	14 Jan.	51	12.0	5.0	18.0
	10 Feb.	53	12.0	6.0	18.0
	04 Mar.	52	12.0	6.0	18.0
	25 Mar.	49	13.0	6.0	18.0
	29 Apr.	46	13.0	6.0	17.0
	20 May	53	13.0	6.0	18.0
	10 Jun.	50	12.0	5.0	18.0
	Total	507	12.0	5.0	18.0

* N denotes the number of observations.

In order to investigate whether participants' self-report-based evaluations of their sleep experience had significantly differed among the classrooms over the course of the study, F1-

LD-F1* design was deemed the most appropriate one. In this design, the effects of the classrooms (*i.e.*, Factor A), dates (*i.e.*, Factor T) and interaction of these two factors (*i.e.*, Factor AT) were evaluated. The results regarding the effects of the three factors are presented in Table 4.2.

Table 4.2 The results regarding the effects of the classrooms, dates and interaction of these two factors

Factors	*p* values
A	0.6511
T	***0.0335***
AT	0.1968

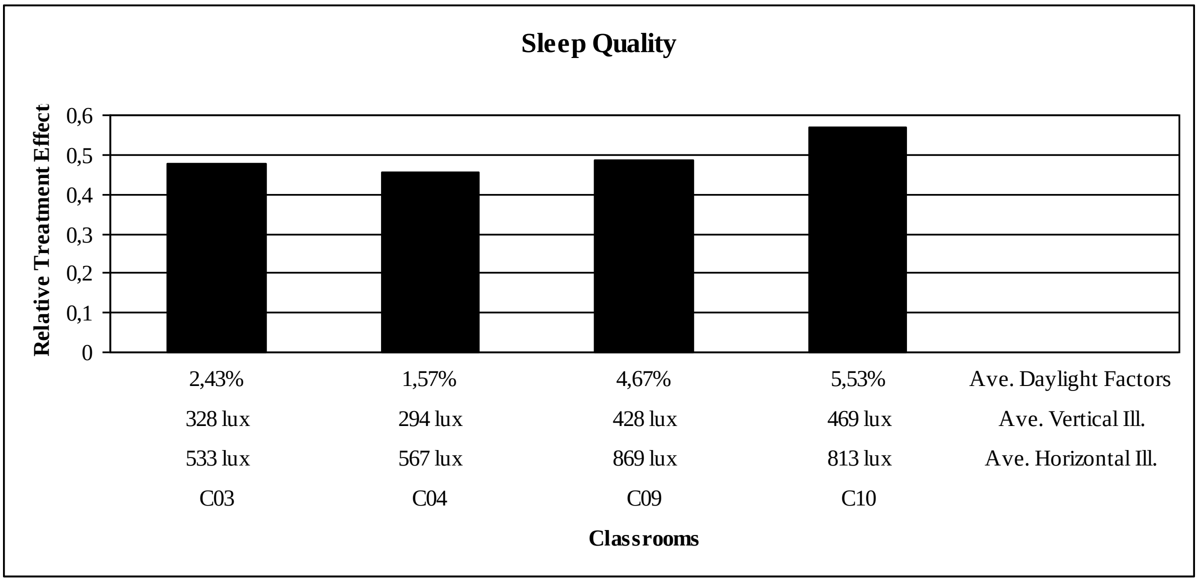

Figure 4.1 The relative treatment effects of the classrooms

It can be inferred from Table 4.2 that the participants' ratings do not differ significantly among the classrooms (p=0.6511). It is apparent from Figure 4.1 that the classrooms have similar relative treatment effects. However, it should be noted that the relative treatment effects of C09 ($\hat{p}_{C09} = 0.4877$) and C10 ($\hat{p}_{C10} = 0.5687$) are relatively higher than those of C03 ($\hat{p}_{C03} = 0.4757$) and C04 ($\hat{p}_{C04} = 0.4559$). More specifically, the occupants of C09 and C10 who were exposed to comparatively more daylight and, as a direct consequence, higher vertical illuminance levels reported marginally better sleep quality.

* Brunner *et al*. (2002) introduced a systematic notation in order to indicate the structures of the nonparametric factorial designs for longitudinal data analysis. The designs are denoted by Fx-LD-Fx. In F1-LD-F1, LD in the middle stands for the longitudinal data containing the observations of the same research units (*e.g.*, participants' evaluations of their sleep quality) over the course of the study. F1 on the left side of LD represents that there is only one group factor (*e.g.*, Factor A), and the one on the right side of LD represents that there is only one time factor (*e.g.*, Factor T).

There is not a clear association between the amount of light on the work plane and participants' nocturnal sleep. In addition, it can be deduced from the table that the dates differ significantly with respect to the participants' evaluations of their sleep quality (p=0.0335). It is evident from Figure 4.2 that the participants' ratings differ among the dates. It can also be inferred from the table that the effect of the interaction factor (*i.e.*, Factor AT) is insignificant (p=0.1968).

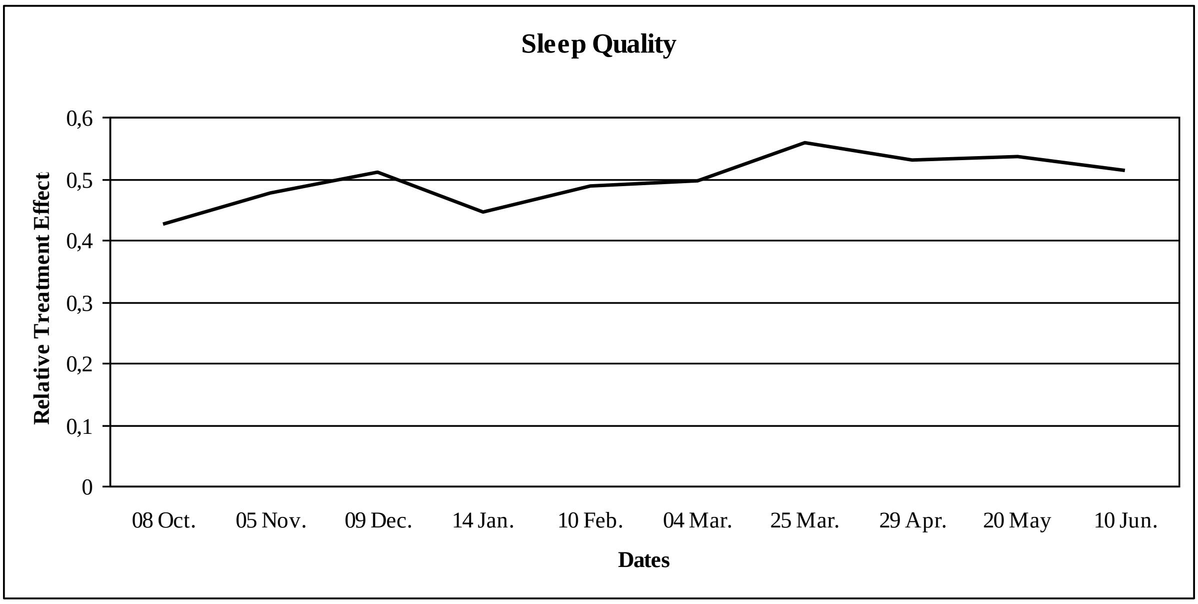

Figure 4.2 The relative treatment effects of the dates

4.2 Mood:

4.2.1 Positive mood:

The descriptive statistics of the study population regarding their self-report-based evaluations of their positive affective experience are presented in Table 4.3. The results are based on a total number of 840 observations, of which 101 (*i.e.*, 12%) are missing. It can be inferred from Table 4.3 that the medians of the participants' ratings differ considerably neither among the classrooms nor among the dates. However, it can be inferred from the table that there are modest differences in the medians among the hours. In addition, it can be deduced from the table that the vast majority of the participants were in an elated mood state over the course of the study.

Table 4.3 The descriptive statistics regarding participants' evaluations of their positive affective experience

Classrooms	Dates	Hours	N	Medians	Minimums	Maximums
C03	08 Oct.	09:50 a.m.	14	12.0	4.0	16.0
		11:45 a.m.	14	13.0	4.0	16.0
		02:45 p.m.	14	13.0	4.0	16.0
		Total	42	13.0	4.0	16.0
	09 Dec.	09:50 a.m.	14	11.0	4.0	15.0
		11:45 a.m.	14	12.0	4.0	16.0
		02:45 p.m.	14	11.0	4.0	16.0
		Total	42	110	4.0	16.0
	10 Feb.	09:50 a.m.	13	13.0	4.0	16.0
		11:45 a.m.	13	13.0	8.0	16.0
		02:45 p.m.	13	13.0	6.0	16.0
		Total	39	13.0	4.0	16.0
	25 Mar.	09:50 a.m.	13	12.0	5.0	16.0
		11:45 a.m.	14	12.0	9.0	16.0
		02:45 p.m.	14	11.5	9.0	16.0
		Total	41	12.0	5.0	16.0
	20 May	09:50 a.m.	14	13.0	6.0	16.0
		11:45 a.m.	14	14.0	7.0	16.0
		02:45 p.m.	14	13.0	10.0	16.0
		Total	42	13.0	6.0	16.0

	Total	09:50 a.m.	68	12.0	4.0	16.0
		11:45 a.m.	69	13.0	4.0	16.0
		02:45 p.m.	69	12.0	4.0	16.0
		Total	206	12.0	4.0	16.0
C04	08 Oct.	09:50 a.m.	9	12.0	4.0	16.0
		11:45 a.m.	10	13.0	4.0	16.0
		02:45 p.m.	9	13.0	6.0	16.0
		Total	28	13.0	4.0	16.0
	09 Dec.	09:50 a.m.	10	11.0	4.0	16.0
		11:45 a.m.	10	13.0	4.0	16.0
		02:45 p.m.	10	13.0	4.0	16.0
		Total	30	12.0	4.0	16.0
	10 Feb.	09:50 a.m.	10	11.5	4.0	16.0
		11:45 a.m.	10	11.0	4.0	16.0
		02:45 p.m.	10	12.0	4.0	16.0
		Total	30	11.5	4.0	16.0
	25 Mar.	09:50 a.m.	9	10.0	4.0	16.0
		11:45 a.m.	8	12.0	4.0	16.0
		02:45 p.m.	7	12.0	4.0	16.0
		Total	24	12.0	4.0	16.0
	20 May	09:50 a.m.	9	13.0	4.0	16.0
		11:45 a.m.	9	11.0	4.0	16.0
		02:45 p.m.	7	14.0	4.0	16.0
		Total	25	12.0	4.0	16.0
	Total	09:50 a.m.	47	11.0	4.0	16.0
		11:45 a.m.	47	12.0	4.0	16.0
		02:45 p.m.	43	12.0	4.0	16.0
		Total	137	12.0	4.0	16.0
C09	08 Oct.	09:50 a.m.	15	13.0	8.0	16.0
		11:45 a.m.	12	12.0	4.0	16.0
		02:45 p.m.	10	13.5	7.0	16.0
		Total	37	13.0	4.0	16.0
	09 Dec.	09:50 a.m.	12	12.5	4.0	16.0
		11:45 a.m.	12	13.5	5.0	16.0
		02:45 p.m.	13	12.0	4.0	16.0

		Total	37	12.0	4.0	16.0
	10 Feb.	09:50 a.m.	13	13.0	8.0	16.0
		11:45 a.m.	13	13.0	9.0	16.0
		02:45 p.m.	14	13.0	4.0	16.0
		Total	40	13.0	4.0	16.0
	25 Mar.	09:50 a.m.	13	14.0	9.0	16.0
		11:45 a.m.	13	13.0	9.0	16.0
		02:45 p.m.	13	13.0	6.0	16.0
		Total	39	13.0	6.0	16.0
	20 May	09:50 a.m.	13	12.0	8.0	16.0
		11:45 a.m.	13	12.0	7.0	16.0
		02:45 p.m.	12	13.0	8.0	16.0
		Total	38	12.5	7.0	16.0
	Total	09:50 a.m.	66	13.0	4.0	16.0
		11:45 a.m.	63	13.0	4.0	16.0
		02:45 p.m.	62	13.0	4.0	16.0
		Total	191	13.0	4.0	16.0
C10	08 Oct.	09:50 a.m.	12	11.0	6.0	16.0
		11:45 a.m.	12	13.5	8.0	16.0
		02:45 p.m.	13	13.0	7.0	16.0
		Total	37	13.0	6.0	16.0
	09 Dec.	09:50 a.m.	14	10.5	6.0	16.0
		11:45 a.m.	14	13.0	9.0	16.0
		02:45 p.m.	13	13.0	7.0	16.0
		Total	41	13.0	6.0	16.0
	10 Feb.	09:50 a.m.	15	11.0	8.0	16.0
		11:45 a.m.	15	14.0	9.0	16.0
		02:45 p.m.	14	13.5	9.0	16.0
		Total	44	13.5	8.0	16.0
	25 Mar.	09:50 a.m.	14	13.5	5.0	16.0
		11:45 a.m.	14	14.0	9.0	16.0
		02:45 p.m.	14	13.5	5.0	16.0
		Total	42	14.0	5.0	16.0
	20 May	09:50 a.m.	14	13.0	10.0	16.0
		11:45 a.m.	13	14.0	11.0	16.0
		02:45 p.m.	14	13.0	6.0	16.0

		Total	41	13.0	6.0	16.0
	Total	09:50 a.m.	69	13.0	5.0	16.0
		11:45 a.m.	68	14.0	8.0	16.0
		02:45 p.m.	68	13.0	5.0	16.0
		Total	205	13.0	5.0	16.0
Total	08 Oct.	09:50 a.m.	50	12.0	4.0	16.0
		11:45 a.m.	48	13.0	4.0	16.0
		02:45 p.m.	46	13.0	4.0	16.0
		Total	144	13.0	4.0	16.0
	09 Dec.	09:50 a.m.	50	11.0	4.0	16.0
		11:45 a.m.	50	13.0	4.0	16.0
		02:45 p.m.	50	12.0	4.0	16.0
		Total	150	12.0	4.0	16.0
	10 Feb.	09:50 a.m.	51	12.0	4.0	16.0
		11:45 a.m.	51	13.0	4.0	16.0
		02:45 p.m.	51	13.0	4.0	16.0
		Total	153	13.0	4.0	16.0
	25 Mar.	09:50 a.m.	49	12.0	4.0	16.0
		11:45 a.m.	49	12.0	4.0	16.0
		02:45 p.m.	48	12.0	4.0	16.0
		Total	146	12.0	4.0	16.0
	20 May	09:50 a.m.	50	13.0	4.0	16.0
		11:45 a.m.	49	13.0	4.0	16.0
		02:45 p.m.	47	13.0	4.0	16.0
		Total	146	13.0	4.0	16.0
	Total	09:50 a.m.	250	12.0	4.0	16.0
		11:45 a.m.	247	13.0	4.0	16.0
		02:45 p.m.	242	13.0	4.0	16.0
		Total	739	13.0	4.0	16.0

In order to investigate whether participants' self-report-based evaluations of their positive affective experience had significantly differed among the classrooms over the course of the study, F1-LD-F2* design was deemed the most appropriate one. In this design, the

* In F1-LD-F2, LD in the middle stands for the longitudinal data containing the observations of the same research units (*e.g.*, participants' evaluations of their positive affective experience) over the course of the study.

effects of the classrooms (*i.e.*, Factor A), dates (*i.e.*, Factor C), hours (*i.e.*, Factor T) and interactions of these three factors (*i.e.*, Factor AC, Factor AT, Factor CT and Factor ACT) were evaluated. The results regarding the effects of these seven factors are presented in Table 4.4.

Table 4.4 The results regarding the effects of the classrooms, dates, hours and interaction of these three factors

Factors	*p* values
A	0.8195
C	0.2995
T	***0.0002***
AC	0.4573
AT	0.3256
CT	0.2020
ACT	0.5623

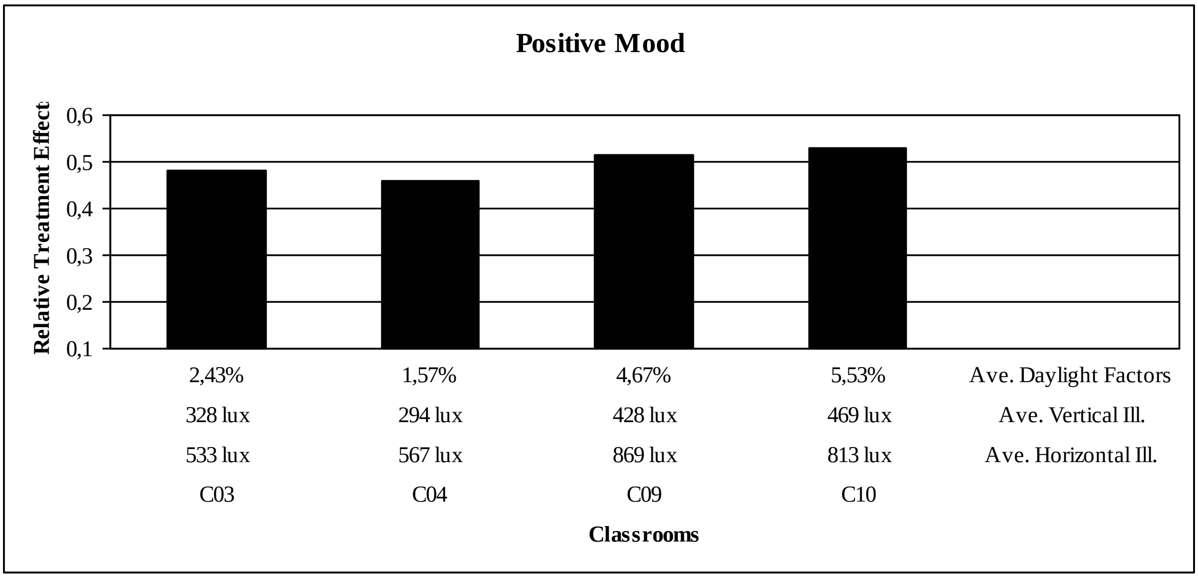

Figure 4.3 The relative treatment effects of the classrooms

It can be inferred from Table 4.4 that the participants' ratings differ significantly neither among the classrooms (*p*=0.8195) nor among the dates (*p*=0.2995). It is apparent from Figure 4.3 that the classrooms have similar relative treatment effects. However, it should be noted that the relative treatment effects of C09 ($\hat{p}_{C09} = 0.5153$) and C10 ($\hat{p}_{C10} = 0.5309$) are relatively higher than those of C03 ($\hat{p}_{C03} = 0.4831$) and C04 ($\hat{p}_{C04} = 0.4605$). In other words, participants' mood was slightly better in the classrooms providing more natural light at eye

F1 on the left side of LD represents that there is only one group factor (*e.g.*, Factor A), and F2 on the right side of LD represents that there are two time factors (*e.g.*, Factor C and Factor T being the stratification of Factor C).

level. It should also be noted that the participants' positive mood improved gradually, but not markedly, from the 8th of October to the 20th of May (see Figure 4.4). In addition, it can be deduced from the table that the hours differ significantly with respect to the participants' evaluations of their positive mood (p=0.0002). It is evident from Figure 4.5 that the participants were in a more elated mood state at 11:45 a.m. ($\hat{p}_{11:45} = 0.4993$) and 02:45 p.m. ($\hat{p}_{02:45} = 0.5001$) than at 09:50 a.m. ($\hat{p}_{09:50} = 0.4929$) throughout the study. It can also be inferred from the table that the effects of Factor AC, Factor AT, Factor CT and Factor ACT are insignificant (p=0.4573, p=0.3226, p=0.2020 and p=0.5623, respectively).

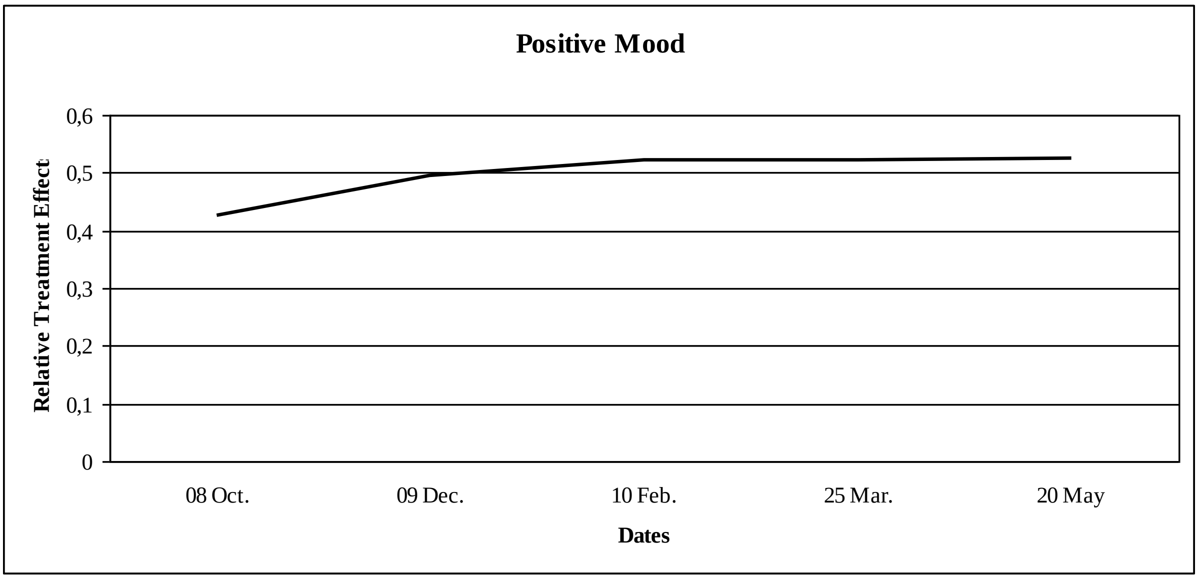

Figure 4.4 The relative treatment effects of the dates

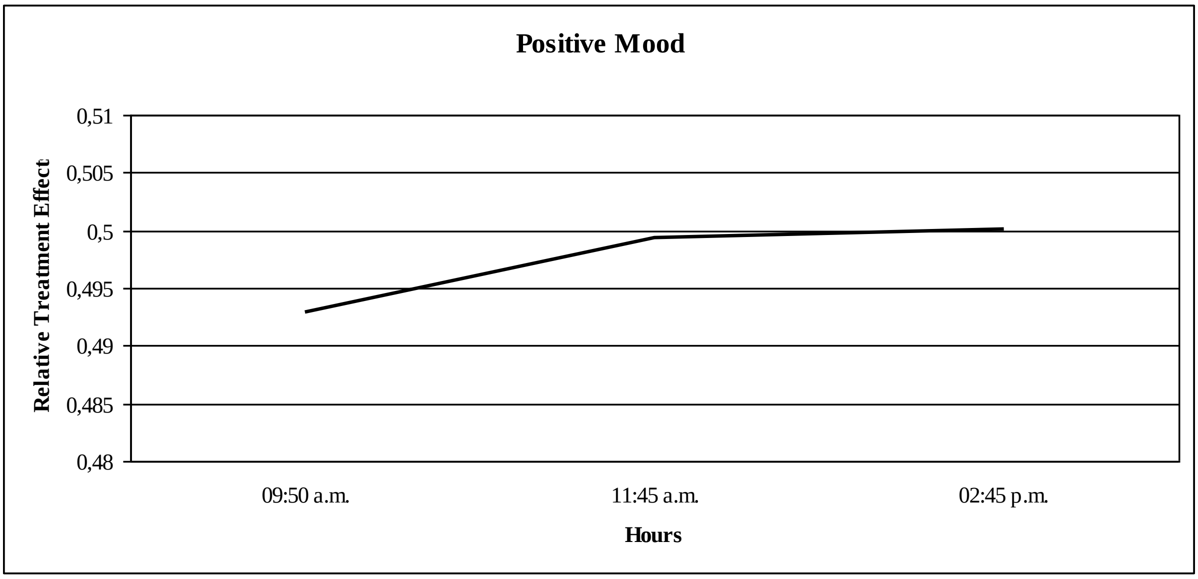

Figure 4.5 The relative treatment effects of the hours

4.2.2 Negative mood:

The descriptive statistics of the study population regarding their self-report-based evaluations of their negative affective experience are presented in Table 4.5. The results are based on a total number of 840 observations, of which 101 (*i.e.*, 12%) are missing. It can be inferred from Table 4.5 that the medians of the participants' ratings differ considerably neither among the classrooms and nor among the dates. However, it can be inferred from the table that there are modest differences in the medians among the hours. In addition, it can be deduced from the table that most of the participants were not in a distressed mood state over the course of the study.

Table 4.5 The descriptive statistics regarding participants' evaluations of their negative affective experience

Classrooms	Dates	Hours	N	Medians	Minimums	Maximums
C03	08 Oct.	09:50 a.m.	14	7.5	5.0	16.0
		11:45 a.m.	14	6.0	5.0	16.0
		02:45 p.m.	14	5.5	5.0	20.0
		Total	42	6.5	5.0	20.0
	09 Dec.	09:50 a.m.	14	6.5	5.0	20.0
		11:45 a.m.	14	6.0	5.0	19.0
		02:45 p.m.	14	7.0	5.0	15.0
		Total	42	7.0	5.0	20.0
	10 Feb.	09:50 a.m.	13	5.0	5.0	14.0
		11:45 a.m.	13	6.0	5.0	13.0
		02:45 p.m.	13	5.0	5.0	17.0
		Total	39	5.0	5.0	17.0
	25 Mar.	09:50 a.m.	13	6.0	5.0	16.0
		11:45 a.m.	14	6.0	5.0	18.0
		02:45 p.m.	14	6.0	5.0	17.0
		Total	41	6.0	5.0	18.0
	20 May	09:50 a.m.	14	5.0	5.0	14.0
		11:45 a.m.	14	5.0	5.0	15.0
		02:45 p.m.	14	5.0	5.0	15.0
		Total	42	5.0	5.0	15.0
	Total	09:50 a.m.	68	6.0	5.0	20.0
		11:45 a.m.	69	6.0	5.0	19.0

		02:45 p.m.	69	6.0	5.0	20.0
		Total	206	6.0	5.0	20.0
C04	08 Oct.	09:50 a.m.	9	6.0	1.0	16.0
		11:45 a.m.	10	5.0	5.0	17.0
		02:45 p.m.	9	5.0	5.0	12.0
		Total	28	5.0	1.0	17.0
	09 Dec.	09:50 a.m.	10	6.5	5.0	18.0
		11:45 a.m.	10	6.0	5.0	17.0
		02:45 p.m.	10	6.5	5.0	17.0
		Total	30	6.0	5.0	18.0
	10 Feb.	09:50 a.m.	10	7.0	5.0	17.0
		11:45 a.m.	10	6.0	5.0	17.0
		02:45 p.m.	10	8.0	5.0	17.0
		Total	30	7.0	5.0	17.0
	25 Mar.	09:50 a.m.	9	8.0	5.0	17.0
		11:45 a.m.	8	5.0	5.0	17.0
		02:45 p.m.	7	5.0	5.0	17.0
		Total	24	5.0	5.0	17.0
	20 May	09:50 a.m.	9	5.0	5.0	17.0
		11:45 a.m.	9	10.0	5.0	16.0
		02:45 p.m.	7	8.0	5.0	17.0
		Total	25	8.0	5.0	17.0
	Total	09:50 a.m.	47	7.0	1.0	18.0
		11:45 a.m.	47	6.0	5.0	17.0
		02:45 p.m.	43	5.0	5.0	17.0
		Total	137	6.0	1.0	18.0
C09	08 Oct.	09:50 a.m.	15	7.0	4.0	12.0
		11:45 a.m.	12	8.0	5.0	17.0
		02:45 p.m.	10	7.0	5.0	11.0
		Total	37	7.0	4.0	17.0
	09 Dec.	09:50 a.m.	12	6.0	5.0	14.0
		11:45 a.m.	12	6.0	5.0	14.0
		02:45 p.m.	13	7.0	5.0	16.0
		Total	37	6.0	5.0	16.0
	10 Feb.	09:50 a.m.	13	6.0	5.0	14.0
		11:45 a.m.	13	8.0	5.0	13.0

		02:45 p.m.	14	5.0	5.0	17.0
		Total	40	6.0	5.0	17.0
	25 Mar.	09:50 a.m.	13	6.0	5.0	12.0
		11:45 a.m.	13	6.0	5.0	11.0
		02:45 p.m.	13	5.0	5.0	15.0
		Total	39	6.0	5.0	15.0
	20 May	09:50 a.m.	13	7.0	5.0	16.0
		11:45 a.m.	13	5.0	5.0	14.0
		02:45 p.m.	12	5.0	5.0	12.0
		Total	38	5.0	5.0	16.0
	Total	09:50 a.m.	66	6.0	4.0	16.0
		11:45 a.m.	63	7.0	5.0	17.0
		02:45 p.m.	62	5.0	5.0	17.0
		Total	191	6.0	4.0	17.0
C10	08 Oct.	09:50 a.m.	12	5.0	5.0	18.0
		11:45 a.m.	12	5.0	5.0	13.0
		02:45 p.m.	13	5.0	5.0	11.0
		Total	37	5.0	5.0	18.0
	09 Dec.	09:50 a.m.	14	7.0	5.0	14.0
		11:45 a.m.	14	5.0	4.0	11.0
		02:45 p.m.	13	5.0	5.0	11.0
		Total	41	5.0	4.0	14.0
	10 Feb.	09:50 a.m.	15	6.0	5.0	10.0
		11:45 a.m.	15	5.0	5.0	10.0
		02:45 p.m.	14	5.0	5.0	10.0
		Total	44	5.0	5.0	10.0
	25 Mar.	09:50 a.m.	14	6.0	5.0	12.0
		11:45 a.m.	14	5.0	5.0	14.0
		02:45 p.m.	14	5.0	5.0	13.0
		Total	42	5.0	5.0	14.0
	20 May	09:50 a.m.	14	5.5	5.0	14.0
		11:45 a.m.	13	5.0	5.0	10.0
		02:45 p.m.	14	5.0	5.0	11.0
		Total	41	5.0	5.0	14.0
	Total	09:50 a.m.	69	6.0	5.0	18.0
		11:45 a.m.	68	5.0	4.0	14.0

		02:45 p.m.	68	5.0	5.0	13.0
		Total	205	5.0	4.0	18.0
Total	08 Oct.	09:50 a.m.	50	7.0	1.0	18.0
		11:45 a.m.	48	6.0	5.0	17.0
		02:45 p.m.	46	5.0	5.0	20.0
		Total	144	6.0	1.0	20.0
	09 Dec.	09:50 a.m.	50	6.5	5.0	20.0
		11:45 a.m.	50	5.5	4.0	19.0
		02:45 p.m.	50	6.5	5.0	17.0
		Total	150	6.0	4.0	20.0
	10 Feb.	09:50 a.m.	51	6.0	5.0	17.0
		11:45 a.m.	51	6.0	5.0	17.0
		02:45 p.m.	51	5.0	5.0	17.0
		Total	153	6.0	5.0	17.0
	25 Mar.	09:50 a.m.	49	6.0	5.0	17.0
		11:45 a.m.	49	5.0	5.0	18.0
		02:45 p.m.	48	5.0	5.0	17.0
		Total	146	5.0	5.0	18.0
	20 May	09:50 a.m.	50	5.0	5.0	17.0
		11:45 a.m.	49	5.0	5.0	16.0
		02:45 p.m.	47	5.0	5.0	17.0
		Total	146	5.0	5.0	17.0
	Total	09:50 a.m.	250	6.0	1.0	20.0
		11:45 a.m.	247	5.0	4.0	19.0
		02:45 p.m.	242	5.0	5.0	20.0
		Total	739	6.0	1.0	20.0

Table 4.6 The results regarding the effects of the classrooms, dates, hours and interaction of these three factors

Factors	*p* values
A	0.7686
C	0.4236
T	***0.0008***
AC	0.5326
AT	0.0853
CT	0.4430
ACT	0.7549

In order to investigate whether participants' self-report-based evaluations of their negative affective experience had significantly differed among the classrooms over the course of the study, F1-LD-F2 design was deemed the most appropriate one. In this design, the effects of the classrooms (*i.e.*, Factor A), dates (*i.e.*, Factor C), hours (*i.e.*, Factor T) and interactions of these three factors (*i.e.*, Factor AC, Factor AT, Factor CT and Factor ACT) were evaluated. The results regarding the effects of these seven factors are presented in Table 4.6.

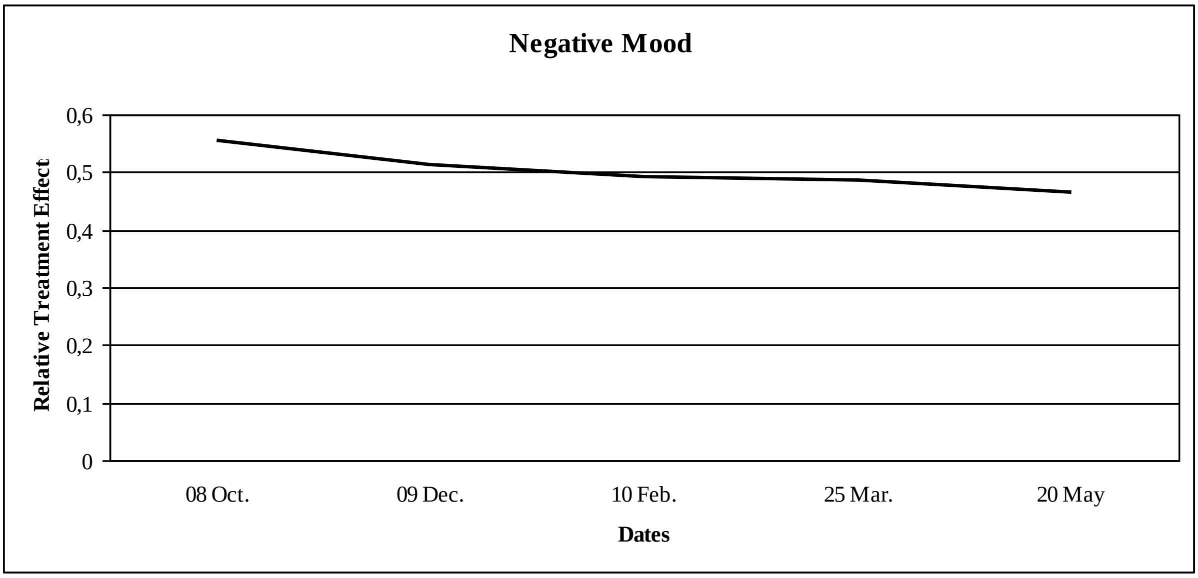

Figure 4.6 The relative treatment effects of the dates

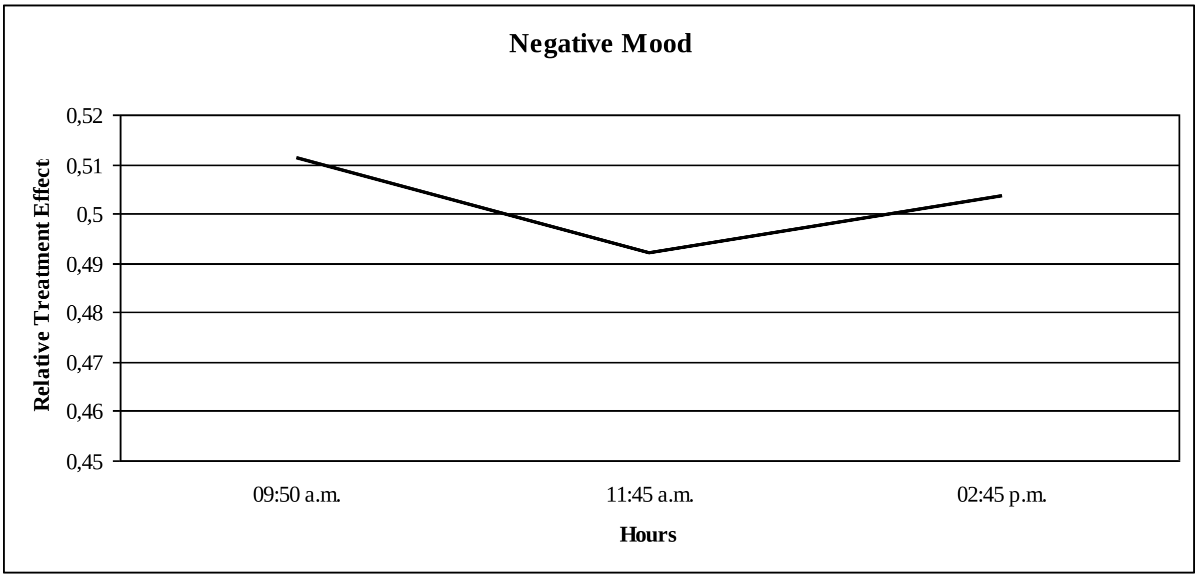

Figure 4.7 The relative treatment effects of the hours

It can be inferred from Table 4.6 that the participants' ratings differ significantly neither among the classrooms (p=0.7686) nor among the dates (p=0.4236). However, it should be noted from Figure 4.6 that the participants' negative mood improved gradually, but not markedly, from the 8th of October to the 20th of May. In addition, it can be deduced from the table that the hours differ significantly with respect to the participants' evaluations of their negative mood (*p*=0.0008). It is evident from Figure 4.7 that the participants were in a more distressed mood state at 09:50 a.m. ($\hat{p}_{09:50} = 0.5113$) than at 11:45 a.m. ($\hat{p}_{11:45} = 0.4920$) and 02:45 p.m. ($\hat{p}_{02:45} = 0.5036$) throughout the study. It can also be inferred from the table that the effects of Factor AC, Factor AT, Factor CT and Factor ACT are insignificant (*p*=0.5326, *p*=0.0853, *p*=0.4430 and *p*=0.7549, respectively).

4.3 Daytime sleepiness:

The descriptive statistics of the study population regarding their self-report-based evaluations of their daytime sleepiness are presented in Table 4.7. The results are based on a total number of 840 observations, of which 53 (*i.e.*, 6.3%) are missing. It can be inferred from Table 4.7 that the medians of the participants' ratings differ considerably neither among the classrooms and neither among the dates. However, it can be inferred from the table that there are modest differences in the medians among the hours. In addition, it can be deduced from the table that the participants were feeling active and vital over the course of the study.

Table 4.7 The descriptive statistics regarding participants' evaluations of their daytime sleepiness

Classrooms	Dates	Times	N	Medians	Minimums	Maximums
C03	08 Oct.	09:50 a.m.	14	2.0	1.0	5.0
		11:45 a.m.	13	2.0	1.0	5.0
		02:45 p.m.	14	2.0	1.0	5.0
		Total	41	2.0	1.0	5.0
	09 Dec.	09:50 a.m.	14	3.0	1.0	5.0
		11:45 a.m.	12	2.0	1.0	4.0
		02:45 p.m.	14	2.0	1.0	5.0
		Total	40	2.0	1.0	5.0
	10 Feb.	09:50 a.m.	13	2.0	1.0	4.0
		11:45 a.m.	12	2.0	1.0	3.0
		02:45 p.m.	13	2.0	1.0	3.0
		Total	38	2.0	1.0	4.0
	25 Mar.	09:50 a.m.	12	2.0	1.0	3.0
		11:45 a.m.	14	2.0	1.0	3.0
		02:45 p.m.	14	2.0	1.0	2.0
		Total	40	2.0	1.0	3.0
	20 May	09:50 a.m.	14	2.0	1.0	3.0
		11:45 a.m.	14	2.0	1.0	30
		02:45 p.m.	14	1.5	1.0	3.0
		Total	42	2.0	1.0	3.0
	Total	09:50 a.m.	67	2.0	1.0	5.0
		11:45 a.m.	65	2.0	1.0	5.0
		02:45 p.m.	69	2.0	1.0	5.0

		Total	201	2.0	1.0	5.0
C04	08 Oct.	09:50 a.m.	10	2.0	1.0	5.0
		11:45 a.m.	10	1.5	1.0	5.0
		02:45 p.m.	8	1.5	1.0	5.0
		Total	28	2.0	1.0	5.0
	09 Dec.	09:50 a.m.	10	1.5	1.0	5.0
		11:45 a.m.	10	2.0	1.0	5.0
		02:45 p.m.	9	2.0	1.0	5.0
		Total	29	2.0	1.0	5.0
	10 Feb.	09:50 a.m.	11	2.0	1.0	5.0
		11:45 a.m.	10	2.0	1.0	5.0
		02:45 p.m.	11	2.0	1.0	5.0
		Total	32	2.0	1.0	5.0
	25 Mar.	09:50 a.m.	9	2.0	1.0	5.0
		11:45 a.m.	10	1.0	1.0	5.0
		02:45 p.m.	8	2.0	1.0	5.0
		Total	27	2.0	1.0	5,0
	20 May	09:50 a.m.	11	1.0	1.0	5.0
		11:45 a.m.	11	1.0	1.0	5.0
		02:45 p.m.	11	2.0	1.0	5.0
		Total	33	2.0	1.0	5.0
	Total	09:50 a.m.	51	2.0	1.0	5.0
		11:45 a.m.	51	2.0	1.0	5.0
		02:45 p.m.	47	2.0	1.0	5.0
		Total	149	2.0	1.0	5.0
C09	08 Oct.	09:50 a.m.	15	2.0	1.0	4.0
		11:45 a.m.	13	2.0	1.0	4.0
		02:45 p.m.	12	2.0	1.0	5.0
		Total	40	2.0	1.0	5.0
	09 Dec.	09:50 a.m.	14	2.5	1.0	5.0
		11:45 a.m.	14	2.0	1.0	5.0
		02:45 p.m.	14	2.0	1.0	5.0
		Total	42	2.0	1.0	5,0
	10 Feb.	09:50 a.m.	16	2.0	1.0	5.0
		11:45 a.m.	16	2.0	1.0	5.0
		02:45 p.m.	16	2.0	1.0	5.0

		Total	48	2.0	1.0	5.0
	25 Mar.	09:50 a.m.	16	2.0	1.0	5.0
		11:45 a.m.	15	2.0	1.0	5.0
		02:45 p.m.	16	2.0	1.0	5.0
		Total	47	2.0	1.0	5.0
	20 May	09:50 a.m.	16	2.0	1.0	5.0
		11:45 a.m.	16	2.0	1.0	5.0
		02:45 p.m.	16	2.5	1.0	5.0
		Total	48	2.0	1.0	5.0
	Total	09:50 a.m.	77	2.0	1.0	5.0
		11:45 a.m.	74	2.0	1.0	5.0
		02:45 p.m.	74	2.0	1.0	5.0
		Total	225	2.0	1.0	5.0
C10	08 Oct.	09:50 a.m.	15	2.0	1.0	3.0
		11:45 a.m.	15	1.0	1.0	3.0
		02:45 p.m.	13	1.0	1.0	4.0
		Total	43	1.0	1.0	4.0
	09 Dec.	09:50 a.m.	14	2.5	1.0	4.0
		11:45 a.m.	13	2.0	1.0	4.0
		02:45 p.m.	13	2.0	1.0	5.0
		Total	40	2.0	1.0	5.0
	10 Feb.	09:50 a.m.	15	2.0	1.0	3.0
		11:45 a.m.	14	1.0	1.0	4.0
		02:45 p.m.	15	2.0	1.0	5.0
		Total	44	1.0	1.0	5.0
	25 Mar.	09:50 a.m.	13	2.0	1.0	3.0
		11:45 a.m.	15	1.0	1.0	3.0
		02:45 p.m.	15	1.0	1.0	4.0
		Total	43	1.0	1.0	4.0
	20 May	09:50 a.m.	14	2.0	1.0	3.0
		11:45 a.m.	14	1.0	1.0	3.0
		02:45 p.m.	14	1.0	1.0	4.0
		Total	42	1.0	1.0	4.0
	Total	09:50 a.m.	71	2.0	1.0	4.0
		11:45 a.m.	71	1.0	1.0	4.0
		02:45 p.m.	70	1.0	1.0	5.0

		Total	212	2.0	1.0	5.0
Total	08 Oct.	09:50 a.m.	54	2.0	1.0	5.0
		11:45 a.m.	51	2.0	1.0	5.0
		02:45 p.m.	47	2.0	1.0	5.0
		Total	152	2.0	1.0	5.0
	09 Dec.	09:50 a.m.	52	2.5	1.0	5.0
		11:45 a.m.	49	2.0	1.0	5.0
		02:45 p.m.	50	2.0	1.0	5.0
		Total	151	2.0	1.0	5.0
	10 Feb.	09:50 a.m.	55	2.0	1.0	5.0
		11:45 a.m.	52	2.0	1.0	5.0
		02:45 p.m.	55	2.0	1.0	5.0
		Total	162	2.0	1.0	5.0
	25 Mar.	09:50 a.m.	50	2.0	1.0	5.0
		11:45 a.m.	54	2.0	1.0	5.0
		02:45 p.m.	53	2.0	1.0	5.0
		Total	157	2,0	1.0	5.0
	20 May	09:50 a.m.	55	2.0	1.0	5.0
		11:45 a.m.	55	2.0	1.0	5.0
		02:45 p.m.	55	2.0	1.0	5.0
		Total	165	2.0	1.0	5.0
	Total	09:50 a.m.	266	2.0	1.0	5.0
		11:45 a.m.	261	2.0	1.0	5.0
		02:45 p.m.	260	2.0	1.0	5.0
		Total	787	2.0	1.0	5.0

Table 4.8 The results regarding the effects of the classrooms, dates, hours and interaction of these three factors

Factors	*p* values
A	0.3021
C	0.1882
T	***0.0017***
AC	0.4767
AT	0.1423
CT	0.3172
ACT	0.6227

In order to investigate whether participants' self-report-based evaluations of their daytime sleepiness had significantly differed among the classrooms over the course of the study, F1-LD-F2 design was deemed the most appropriate one. In this design, the effects of the classrooms (*i.e.*, Factor A), dates (*i.e.*, Factor C), hours (*i.e.*, Factor T) and interactions of these three factors (*i.e.*, Factor AC, Factor AT, Factor CT and Factor ACT) were evaluated. The results regarding the effects of these factors are presented in Table 4.8.

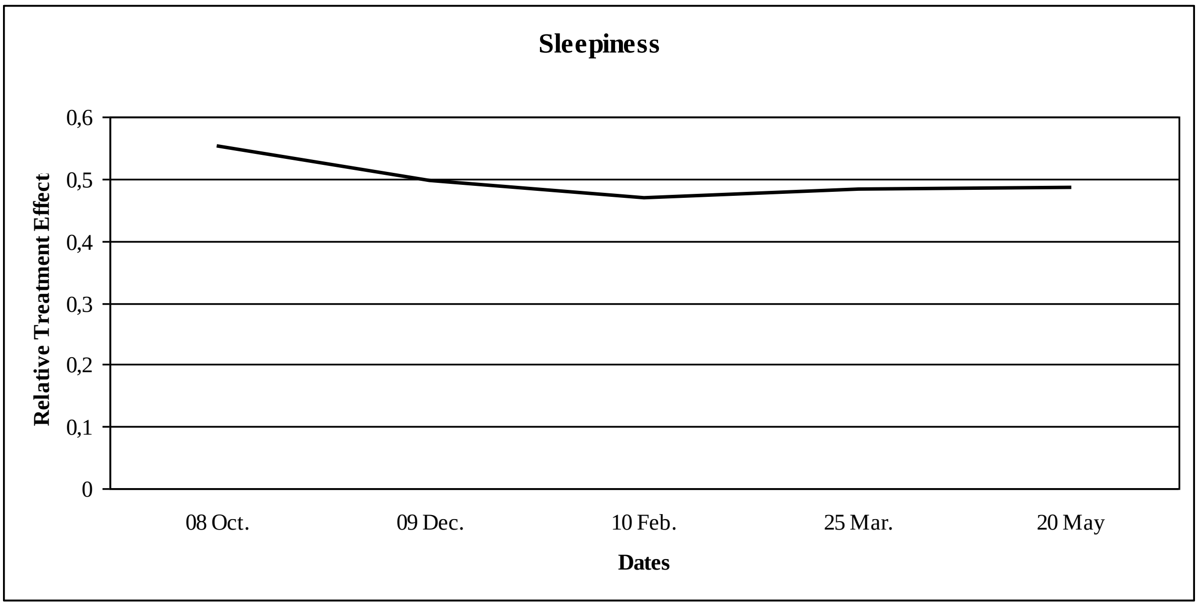

Figure 4.8 The relative treatment effects of the dates

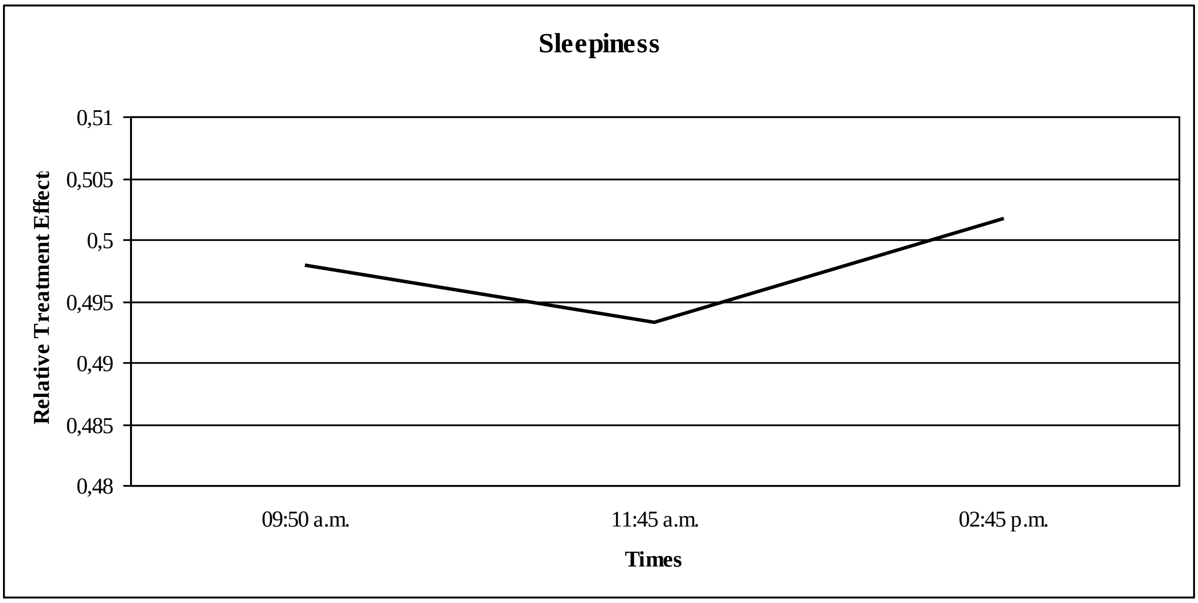

Figure 4.9 The relative treatment effects of the times

It can be inferred from Table 4.8 that the participants' ratings differ significantly neither among the classrooms (*p*=0.3021) nor among the dates and (*p*=0.1882). However, it should be noted from Figure 4.8 that the participants' sleepiness reduced gradually, but not markedly, from the 8^{th} of October to the 10^{th} of February and remained almost unchanged until the 20^{th} of May. In addition, it can be deduced from the table that the hours differ significantly with respect to the participants' evaluations of their sleepiness (*p*=0.0017). This reduction in daytime sleepiness seems to be consistent with the changes in participants' mood throughout the study. It is evident from Figure 4.9 that the participants were in a more active and vital state at 09:50 a.m. ($\hat{p}_{09:50} = 0.4979$) and 11:45 a.m. ($\hat{p}_{11:45} = 0.4937$) than at 02:45 p.m. ($\hat{p}_{02:45} = 0.5017$) throughout the study. It can also be inferred from the table that the effects of Factor AC, Factor AT, Factor CT and Factor ACT are insignificant (*p*=0.4767, *p*=0.1423, *p*=0.3172 and *p*=0.6227, respectively).

4.4 Cortisol:

The descriptive statistics of the study population regarding their salivary cortisol concentrations are presented in Table 4.9. The results are based on a total number of 840 observations, of which 69 (*i.e.*, 8.2%) are missing. It can be inferred from Table 4.9 that the medians of the participants' cortisol concentrations differ considerably neither among the dates and neither among the hours. However, it can be inferred from the table that there are modest differences in the medians among the classrooms.

Table 4.9 The descriptive statistics regarding participants' salivary cortisol concentrations (nmol/L)

Classrooms	Dates	Times	N	Medians	Minimums	Maximums
C03	08 Oct.	09:50 a.m.	14	2.35	0.90	5.00
		11:45 a.m.	14	2.85	0.50	4.90
		02:45 p.m.	14	2.00	0.70	6.40
		Total	42	2.55	0.50	6.40
	09 Dec.	09:50 a.m.	14	2.70	1.40	12.60
		11:45 a.m.	14	3.95	2.10	5.80
		02:45 p.m.	14	2.45	0.90	5.10
		Total	42	2.90	0.90	12.60
	10 Feb.	09:50 a.m.	13	4.20	2.40	7.60
		11:45 a.m.	13	3.30	2.00	6.90
		02:45 p.m.	13	2.90	1.20	4.00
		Total	39	3.50	1.20	7.60
	25 Mar.	09:50 a.m.	13	2.70	0.70	6.50
		11:45 a.m.	14	2.65	1.40	6.40
		02:45 p.m.	14	2.50	1.30	5.20
		Total	41	2.70	0.70	6.50
	20 May	09:50 a.m.	14	3.10	1.30	4.80
		11:45 a.m.	14	3.15	2.00	5.60
		02:45 p.m.	14	2.05	0.70	5.30
		Total	42	2.80	0.70	5.60
	Total	09:50 a.m.	68	2.85	0.70	12.60
		11:45 a.m.	69	3.30	0.50	6.90
		02:45 p.m.	69	2.40	0.70	6.40
		Total	206	2.80	0.50	12.60

C04	08 Oct.	09:50 a.m.	10	4.00	0.50	9.40
		11:45 a.m.	11	3.70	1.30	10.20
		02:45 p.m.	10	3.05	1.00	6.10
		Total	31	3.40	0.50	10.20
	09 Dec.	09:50 a.m.	10	3.70	1.70	21.70
		11:45 a.m.	10	2.60	1.20	12.80
		02:45 p.m.	10	2.35	0.30	4.30
		Total	30	3.05	0.30	21.70
	10 Feb.	09:50 a.m.	11	4.40	2.10	18.90
		11:45 a.m.	10	6.25	1.50	9.30
		02:45 p.m.	10	4.25	1.70	10.80
		Total	31	4.60	1.50	18.90
	25 Mar.	09:50 a.m.	9	3.00	1.40	10.20
		11:45 a.m.	9	4.00	1.10	14.40
		02:45 p.m.	7	2.00	1.50	12.40
		Total	25	3.00	1.10	14.40
	20 May	09:50 a.m.	10	3.25	1.10	6.70
		11:45 a.m.	10	4.85	1.90	8.60
		02:45 p.m.	11	3.80	2.30	15.10
		Total	31	3.80	1.10	15.10
	Total	09:50 a.m.	50	3.75	0.50	21.70
		11:45 a.m.	50	4.45	1.10	14.40
		02:45 p.m.	48	3.15	0.30	15.10
		Total	148	3.60	0.30	21.70
C09	08 Oct.	09:50 a.m.	15	3.2	0.30	20.20
		11:45 a.m.	15	4.20	0.90	20.10
		02:45 p.m.	14	2.75	1.40	4.40
		Total	44	3.20	0.30	20.20
	09 Dec.	09:50 a.m.	14	3.55	1.10	6.20
		11:45 a.m.	14	4.00	0.60	6.80
		02:45 p.m.	14	3.90	1.20	6.30
		Total	42	3.85	0.60	6.80
	10 Feb.	09:50 a.m.	15	3.60	1.00	6.00
		11:45 a.m.	16	4.55	1.10	9.90
		02:45 p.m.	16	3.55	0.90	6.10
		Total	47	4.10	0.90	9.90

	25 Mar.	09:50 a.m.	16	3.85	1.60	10.00
		11:45 a.m.	15	3.80	0.60	5.50
		02:45 p.m.	15	2.80	0.70	5.30
		Total	46	3.15	0.60	10.00
	20 May	09:50 a.m.	16	3.00	0.90	6.10
		11:45 a.m.	16	3.65	1,20	6.40
		02:45 p.m.	16	3.25	1.40	5.20
		Total	48	3.40	0.90	6.40
	Total	09:50 a.m.	76	3.35	0.30	20.20
		11:45 a.m.	76	4.00	0.60	20.10
		02:45 p.m.	75	2.90	0.70	6.30
		Total	227	3.5	0.30	20.20
C10	08 Oct.	09:50 a.m.	14	2.95	1.20	6.00
		11:45 a.m.	N/A	N/A	N/A	N/A
		02:45 p.m.	15	2.60	1.30	5.00
		Total	29	2.70	1.20	6.00
	09 Dec.	09:50 a.m.	14	2.80	0.70	4.70
		11:45 a.m.	13	1.80	0.30	6.90
		02:45 p.m.	13	2.40	0.90	4.80
		Total	40	2.40	0.30	6.90
	10 Feb.	09:50 a.m.	14	2.35	0.80	4.90
		11:45 a.m.	13	3.00	1.50	5.00
		02:45 p.m.	14	3.40	1.00	4.80
		Total	41	3.00	0.80	5.00
	25 Mar.	09:50 a.m.	14	2.50	0.60	6.50
		11:45 a.m.	13	2.30	0.80	6.50
		02:45 p.m.	14	2.35	1.10	5.90
		Total	41	2.40	0.60	6.50
	20 May	09:50 a.m.	13	2.80	0.50	4.20
		11:45 a.m.	14	3.65	1.20	8.30
		02:45 p.m.	12	2.10	1.40	4.30
		Total	39	2.80	0.50	8.30
	Total	09:50 a.m.	69	2.60	0.50	6.50
		11:45 a.m.	53	2.80	0.30	8.30
		02:45 p.m.	68	2.40	0.90	5.90
		Total	190	2.60	0.30	8.30

Total	08 Oct.	09:50 a.m.	53	3.00	0.30	20.20
		11:45 a.m.	40	3.75	0.50	20.10
		02:45 p.m.	53	2.60	0.70	6.40
		Total	146	2.90	0.30	20.20
	09 Dec.	09:50 a.m.	52	3.15	0.70	21.70
		11:45 a.m.	51	3.20	0.30	12.80
		02:45 p.m.	51	2.50	0.30	6.30
		Total	154	2.95	0.30	21.70
	10 Feb.	09:50 a.m.	53	3.70	0.80	18.90
		11:45 a.m.	52	3.55	1.10	9.90
		02:45 p.m.	53	3.40	0.90	10.80
		Total	158	3.60	0.80	18.90
	25 Mar.	09:50 a.m.	52	2.85	0.60	10.20
		11:45 a.m.	51	3.10	0.60	14.40
		02:45 p.m.	50	2.45	0.70	12.40
		Total	153	2.70	0.60	14.40
	20 May	09:50 a.m.	53	3.00	0.50	6.70
		11:45 a.m.	54	3.60	1.20	8.60
		02:45 p.m.	53	2.50	0.70	15.10
		Total	160	3.10	0.50	15.10
	Total	09:50 a.m.	263	3.10	0.30	21.70
		11:45 a.m.	248	3.50	0.30	20.10
		02:45 p.m.	260	2.65	0.30	15.10
		Total	771	3.00	0.30	21.70

Table 4.10 The results regarding the effects of the classrooms, dates, hours and interaction of these three factors

Factors	*p* values
A	***0.0015***
C	0.0557
T	0.2692
AC	0.4546
AT	0.3440
CT	0.6589
ACT	0.4082

In order to investigate whether participants' salivary cortisol concentrations had significantly differed among the classrooms over the course of the study, F1-LD-F2 design was deemed the most appropriate one. In this design, the effects of the classrooms (*i.e.*, Factor A), dates (*i.e.*, Factor C), hours (*i.e.*, Factor T) and interactions of these three factors (*i.e.*, Factor AC, Factor AT, Factor CT and Factor ACT) were evaluated. The results regarding the effects of these factors are presented in Table 4.10.

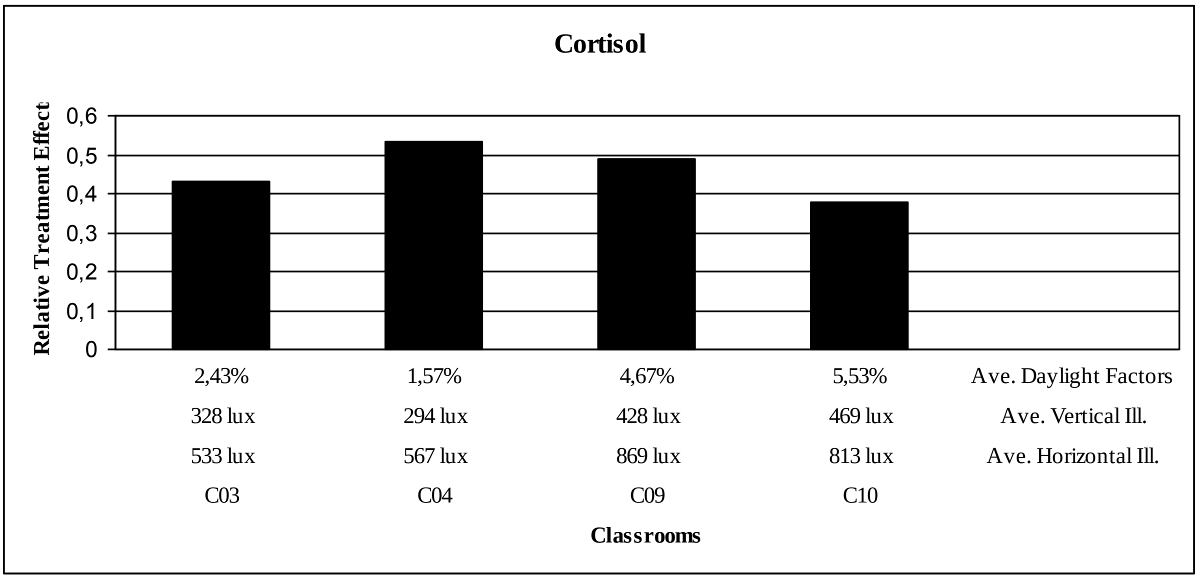

Figure 4.10 The relative treatment effects of the classrooms

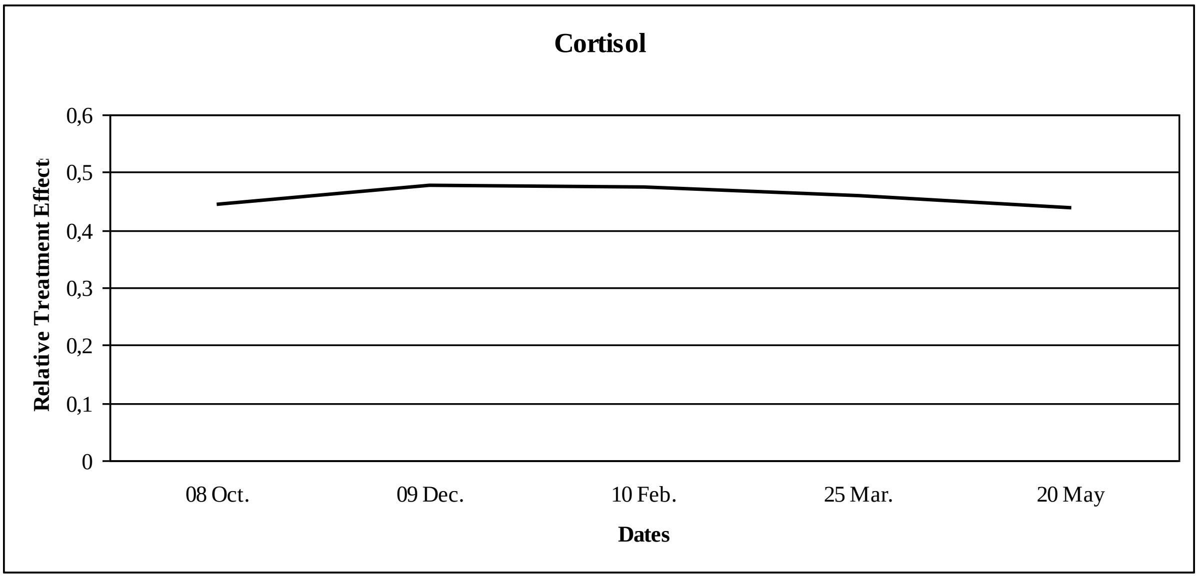

Figure 4.11 The relative treatment effects of the dates

It can be inferred from Table 4.10 that the participants' cortisol concentrations differ significantly among the classrooms (p=0.0015). It is evident from Figure 4.10 that the participants in C04 ($\hat{p}_{C04} = 0.5346$) and C09 ($\hat{p}_{C09} = 0.4879$) had higher concentrations than the participants in C03 ($\hat{p}_{C03} = 0.4317$) and C10 ($\hat{p}_{C10} = 0.3800$) over the course of the study. In addition, it can be deduced from the table that the concentrations differ significantly neither among the dates (p=0.0557) nor among the hours (p=0.2692). However, it should be noted from Figure 4.11 that the concentrations increased from the 8th of October to the 9th of December and decreased gradually until the 20th of May. It can also be inferred from the table that the effects of Factor AC, Factor AT, Factor CT and Factor ACT are insignificant (p=0.4546, p=0.3440, p=0.6589 and p=0.4082, respectively).

A critical review of the results on participants' cortisol concentrations may raise the question as to why there is not a link between the amount of natural light exposed at eye level and children's diurnal cortisol secretory patterns. The primary reason is likely to be the degradation of the saliva specimens during the time period between their shipment and analysis. In spite of collecting and storing the samples in accordance with the standard procedures outlined in Section 3.3.4, the daytime concentrations are worryingly low and stable in comparison with the levels observed by other researchers (see Table 4.11). Therefore, one should consider that the results may not be indicative of the actual effects of the lighting conditions.

Table 4.11 The diurnal variations of salivary cortisol levels (nmol/L) in healthy children

Studies	N*	Age ranges	Times	Means
The current study	56	8-9 years	09:50 a.m.	3.3
			11:45 a.m.	3.6
			02:45 p.m.	2.8
Groschl *et al*. (2003)	212	2-15 years	07:00 a.m.	24.7
			01:00 p.m.	8.0
			07:00 p.m.	1.7
Kiess *et al.* (1995)	82	8-18 years	08:00 a.m.	10.9
			01:00 p.m.	5.0
			06:00 p.m.	3.1
McCarthy *et al*. (2009)	98	4-10 years	10:00 a.m.	6.2
	91		12:00 p.m.	4.4
	18		03:00 p.m.	3.3

* N denotes the number of participants.

4.5 Melatonin:

The descriptive statistics of the study population regarding their salivary melatonin concentrations are presented in Table 4.12. The results are based on a total number of 560 observations, of which 231 (*i.e.*, 41.3%) are missing. It can be inferred from Table 4.12 that the medians of the participants' melatonin concentrations do not differ considerably among the dates. However, it can be inferred from the table that there are modest differences in the medians among the classrooms.

Table 4.12 The descriptive statistics regarding participants' salivary melatonin concentrations (pg/mL)

Classrooms	Dates	N*	Medians	Minimums	Maximums
C03	08 Oct.	10	5.20	0.50	13.60
	05 Nov.	13	3.20	0.50	17.50
	09 Dec.	8	1.40	1.00	5.10
	14 Jan.	9	1.00	0.50	4.00
	10 Feb.	10	1.15	0.40	4.10
	04 Mar.	7	1.20	0.60	2.60
	25 Mar.	4	3.10	0.60	6.30
	29 Apr.	7	1.50	1.40	7.50
	20 May	10	0.75	0.30	2.10
	10 Jun.	8	1.40	0.70	5.80
	Total	86	1.40	0.30	17.50
C04	08 Oct.	8	2.80	0.60	8.90
	05 Nov.	5	2.60	0.70	3.40
	09 Dec.	7	1.60	0.50	4.90
	14 Jan.	5	0.90	0.70	10.90
	10 Feb.	9	5.40	0.60	23.80
	04 Mar.	8	1.95	0.30	10.10
	25 Mar.	9	1.20	0.60	19.50
	29 Apr.	7	2.10	1.30	5.10
	20 May	9	5.20	0.50	8.30
	10 Jun.	6	1.75	0.70	6.80
	Total	73	2.10	0.30	23.80
C09	08 Oct.	11	0.70	0.30	9.80
	05 Nov.	10	1.40	0.50	8.70
	09 Dec.	6	1.70	0.80	14.50
	14 Jan.	8	0.70	0.50	1.90

	10 Feb.	8	0.85	0.50	24.70
	04 Mar.	11	1.50	0.80	17.10
	25 Mar.	11	1.80	0.80	22.60
	29 Apr.	10	1.45	0.60	15.80
	20 May	15	2.10	0.50	11.80
	10 Jun.	10	1.35	0.60	13.90
	Total	100	1.30	0.30	24.70
C10	08 Oct.	6	5.35	0.80	14.80
	05 Nov.	5	3.70	1.40	10.90
	09 Dec.	7	1.50	0.60	12.00
	14 Jan.	8	2.20	0.80	21.30
	10 Feb.	5	1.10	0.60	12.10
	04 Mar.	8	2.20	0.70	19.70
	25 Mar.	8	2.15	0.80	20.90
	29 Apr.	8	2.05	0.80	13.60
	20 May	6	3.30	1.00	6.20
	10 Jun.	9	3.10	1.00	9.90
	Total	70	2.40	0.60	21.30
Total	08 Oct.	35	2.20	0.30	14.80
	05 Nov.	33	2.60	0.50	17.50
	09 Dec.	28	1.60	0.50	14.50
	14 Jan.	30	0.95	0.50	21.30
	10 Feb.	32	1.15	0.40	24.70
	04 Mar.	34	1.35	0.30	19.70
	25 Mar.	32	1.90	0.60	22.60
	29 Apr.	32	1.85	0.60	15.80
	20 May	40	1.95	0.30	11.80
	10 Jun.	33	2.00	0.60	13.90
	Total	329	1.60	0.30	24.70

* N denotes the number of observations.

In order to investigate whether participants' salivary melatonin concentrations had significantly differed among the classrooms over the course of the study, F1-LD-F1 design was deemed the most appropriate one. In this design, the effects of the classrooms (*i.e.*, Factor A), dates (*i.e.*, Factor T) and interaction of these two factors (*i.e.*, Factor AT) were evaluated. The results regarding the effects of the three factors are presented in Table 4.13.

It can be inferred from Table 4.13 that the participants' melatonin concentrations differ significantly among the classrooms (p=0.0338). It is evident from Figure 4.12 that the participants in C04 ($\hat{p}_{C04} = 0{,}5212$) and C10 ($\hat{p}_{C10} = 0.5913$) had higher concentrations than the participants in C03 ($\hat{p}_{03} = 0{,}4621$) and C09 ($\hat{p}_{C09} = 0.4311$) throughout the study. In addition, it can be deduced from the table that the concentrations differ significantly neither among the dates (p=0.1346). It can also be inferred from the table that the interaction factor (*i.e.*, Factor AT) is insignificant (p=0.4001). It is important to note here that the same saliva specimens were used for measuring both cortisol and melatonin fluctuations. Besides, one should bear in mind that more than forty per cent of the samples could not be analysed for determining participants' melatonin levels because of their possible deterioration. Therefore, the results should be interpreted cautiously by the readers.

Table 4.13 The results regarding the effects of the classrooms, dates and interaction of these two factors

Factor	*p* value
A	***0.0338***
T	0.1346
AT	0.4001

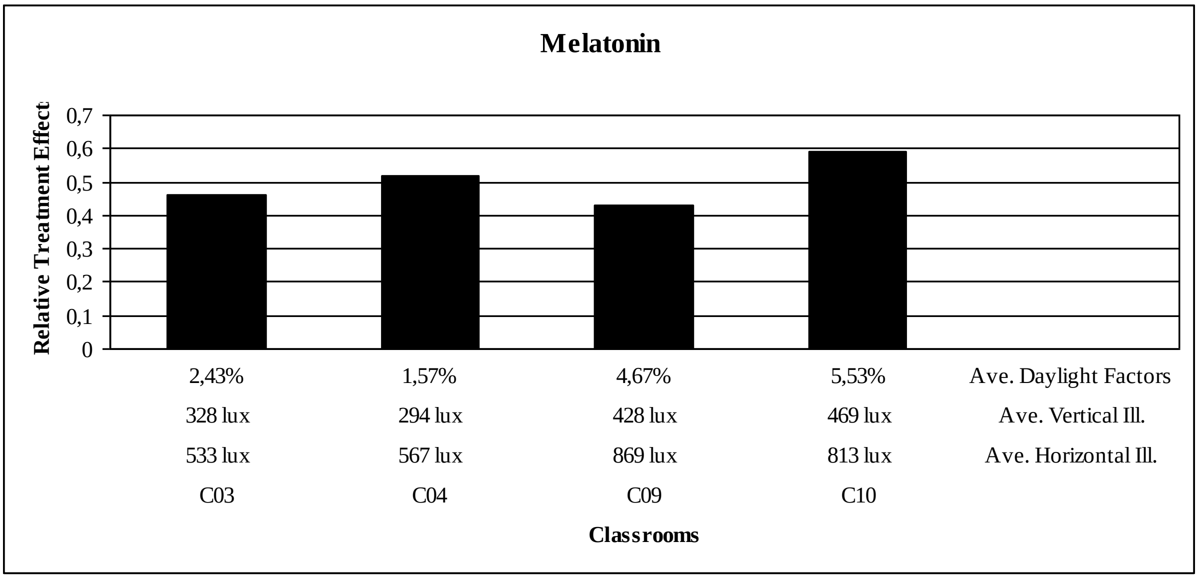

Figure 4.12 The relative treatment effects of the classrooms

4.6 Academic performance:

4.6.1 Reading:

The descriptive statistics of the study population regarding their reading performance are presented in Table 3.13. The results are based on a total number of 168 observations, of which 3 (*i.e.*, 1.8%) are missing. It can be inferred from Table 4.14 that the medians of the participants' scores do not differ considerably among the classrooms and that there are modest differences in the medians among the months. In addition, it can be deduced from the table that the participants' performance was satisfactory over the course of the study.

Table 4.14 The descriptive statistics regarding participants' reading performance

Skill	Classrooms	Months	N	Medians	Minimums	Maximums
Reading	C03	Sep.	14	4.5	1.0	7.0
		Jan.	13	6.0	1.0	8.0
		May	14	7.5	1.0	10.0
		Total	41	6.0	1.0	10.0
	C04	Sep.	10	4.5	1.0	7.0
		Jan.	11	7.0	3.0	8.0
		May	11	8.0	2.0	10.0
		Total	32	6.0	1.0	10.0
	C09	Sep.	16	6.0	2.0	8.0
		Jan.	16	7.0	4.0	9.0
		May	16	8.5	5.0	10.0
		Total	48	7.0	2.0	10.0
	C10	Sep.	15	6.0	1.0	8.0
		Jan.	15	8.0	1.0	10.0
		May	14	8.5	5.0	10.0
		Total	44	8.0	1.0	10.0
	Total	Sep.	55	5.0	1.0	8.0
		Jan.	55	7.0	1.0	10.0
		May	55	8.0	1.0	10.0
		Total	165	7.0	1.0	10.0

In order to investigate whether participants' reading performance had significantly differed among the classrooms over the course of the study, F1-LD-F1 design was deemed the most appropriate one. In this design, the effects of the classrooms (*i.e.*, Factor A), months (*i.e.*, Factor T) and interaction of these two factors (*i.e.*, Factor AT) were evaluated. The results regarding the effects of the three factors are presented in Table 4.15.

Table 4.15 The results regarding the effects of the classrooms, dates and interaction of these two factors

Factors	*p* values
A	0.0986
T	***0.0000***
AT	0.7928

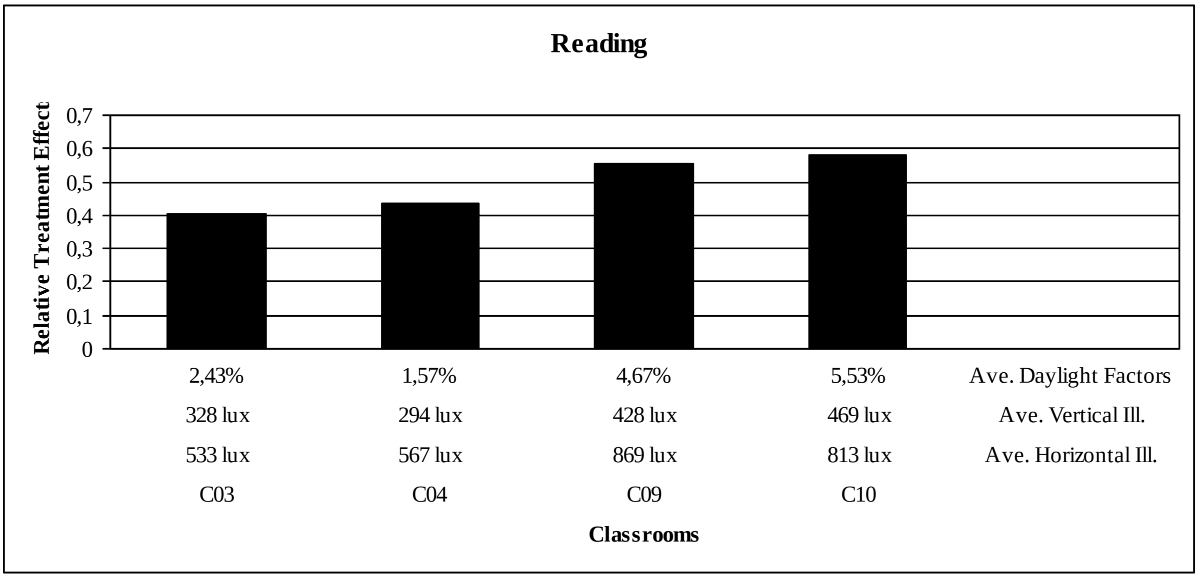

Figure 4.13 The relative treatment effects of the classrooms

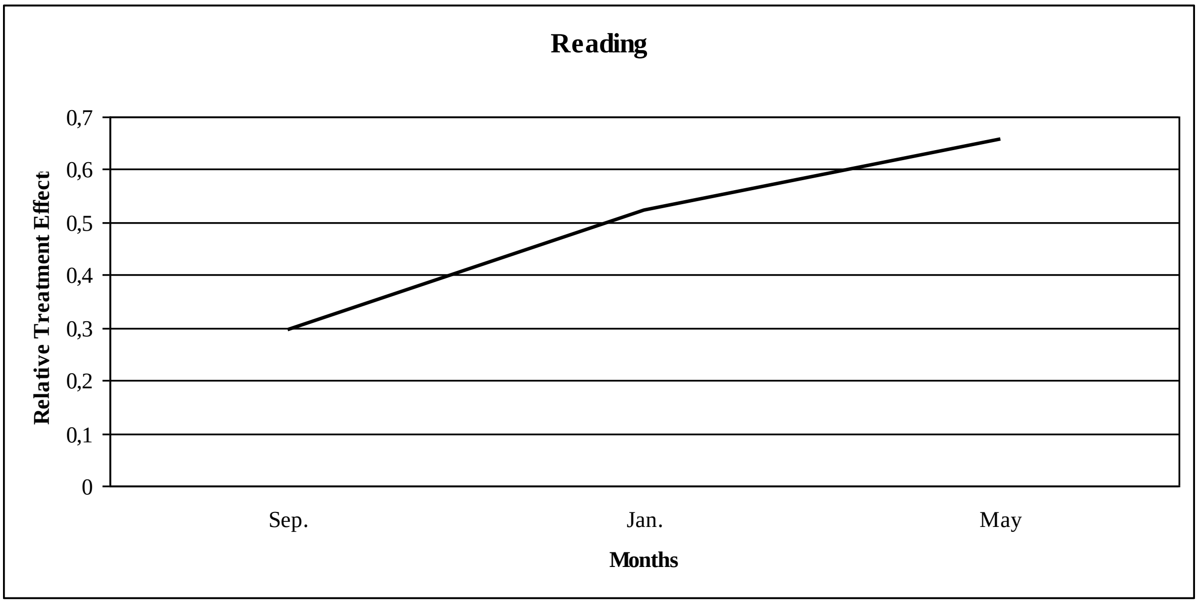

Figure 4.14 The relative treatment effects of the months

It can be inferred from Table 4.15 that the participants' scores do not differ significantly among the classrooms (p=0.0986). It is apparent from Figure 4.13 that the classrooms have similar relative treatment effects. However, it should be noted that the relative treatment effects of C09 ($\hat{p}_{C09} = 0.5533$) and C10 ($\hat{p}_{C10} = 0.5804$) are relatively higher than those of C03 ($\hat{p}_{C03} = 0.4030$) and C04 ($\hat{p}_{C04} = 0.4331$). More specifically, the occupants of C09 and C10 who were exposed to comparatively more daylight performed marginally better than the other students. In addition, it can be deduced from the table that the months differ significantly with respect to the participants' reading performance (p=0.0000). It is evident from Figure 4.14 that the participants' reading performance was better on May ($\hat{p}_{May} = 0.6575$) than their performance on January ($\hat{p}_{Jan} = 0.5234$) and September ($\hat{p}_{Sep} = 0.2964$). It can also be inferred from the table that the effect of the interaction factor (*i.e.*, Factor AT) is insignificant (p=0.7928).

4.6.2 Writing:

The descriptive statistics of the study population regarding their writing performance are presented in Table 4.16. The results are based on a total number of 168 observations, of which 2 (*i.e.*, 1.2%) are missing. It can be inferred from Table 4.16 that the medians of the participants' scores do not differ considerably among the classrooms and that there are modest differences in the medians among the months. In addition, it can be deduced from the table that the participants' performance was satisfactory over the course of the study.

Table 4.16 The descriptive statistics regarding participants' writing performance

Skills	Classrooms	Months	N	Medians	Minimums	Maximums
Writing	C03	Sep.	14	4.5	1.0	7.0
		Jan.	13	5.0	2,.0	7.0
		May	14	6.5	4.0	8.0
		Total	41	5.0	1.0	8.0
	C04	Sep.	11	3.0	1.0	8.0
		Jan.	11	4.0	1.0	8.0
		May	11	5.0	1.0	9.0
		Total	33	4.0	1.0	9.0
	C09	Sep.	16	4.0	2.0	6.0
		Jan.	16	5.0	3.0	9.0
		May	16	7.0	5.0	10.0
		Total	48	5.5	2.0	10.0
	C10	Sep.	15	4.0	1.0	6.0
		Jan.	15	5.0	1.0	8.0
		May	14	7.0	2.0	10.0
		Total	44	5.0	1.0	10.0
	Total	Sep.	56	4.0	1.0	8.0
		Jan.	55	5.0	1.0	9.0
		May	55	7.0	1.0	10.0
		Total	166	5.0	1.0	10.0

In order to investigate whether participants' writing performance had significantly differed among the classrooms over the course of the study, F1-LD-F1 design was deemed the most appropriate one. In this design, the effects of the classrooms (*i.e.*, Factor A), months (*i.e.*, Factor T) and interaction of these two factors (*i.e.*, Factor AT) were evaluated. The results regarding the effects of the three factors are presented in Table 4.17.

Table 4.17 The results regarding the effects of the classrooms, dates and interaction of these two factors

Factors	*p* values
A	0.2770
T	***0.0000***
AT	0.5806

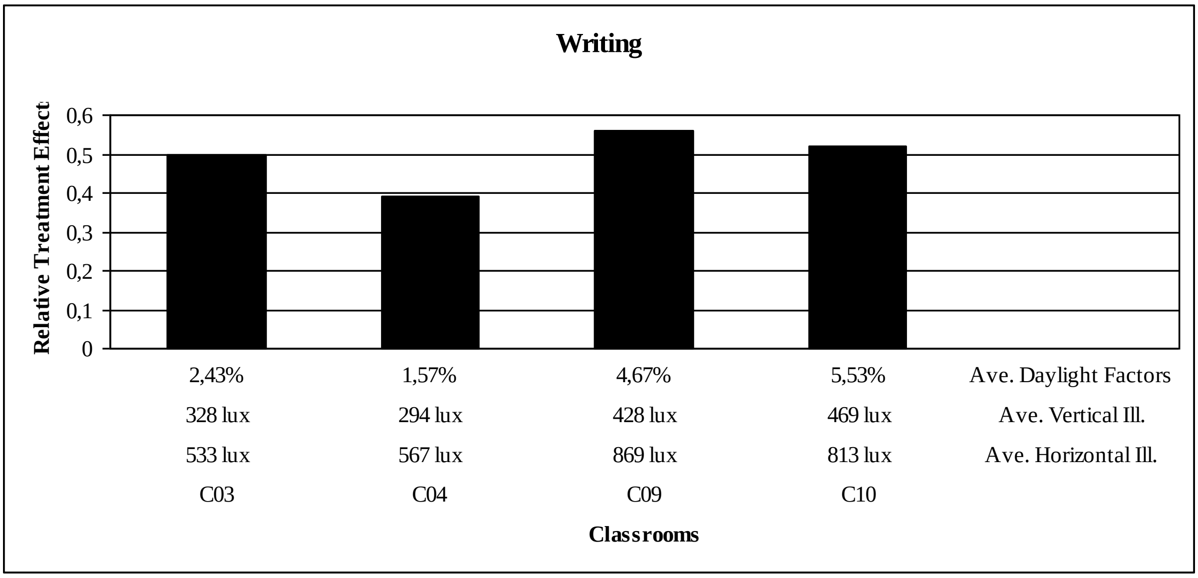

Figure 4.15 The relative treatment effects of the classrooms

It can be inferred from Table 4.17 that the participants' scores do not differ significantly among the classrooms (*p*=0.2770). It is apparent from Figure 4.15 that the classrooms have similar relative treatment effects. However, it should be noted that the relative treatment effects of C09 ($\hat{p}_{C09} = 0.5607$) and C10 ($\hat{p}_{C10} = 0.5188$) are relatively higher than those of C03 ($\hat{p}_{C03} = 0.4988$) and C04 ($\hat{p}_{C04} = 0.3931$). In other words, participants' writing performance was slightly better in the classrooms providing more natural light. In addition, it can be deduced from the table that the months differ significantly with respect to the participants' writing performance (*p*=0.0000). It is evident from Figure 4.16 that the participants' writing performance was better on May ($\hat{p}_{May} = 0.6723$) than their performance on January ($\hat{p}_{Jan} = 0.4737$) and September ($\hat{p}_{Sep} = 0.3327$). It can also be inferred from the table that the effect of the interaction factor (*i.e.*, Factor AT) is insignificant (*p*=0.5806).

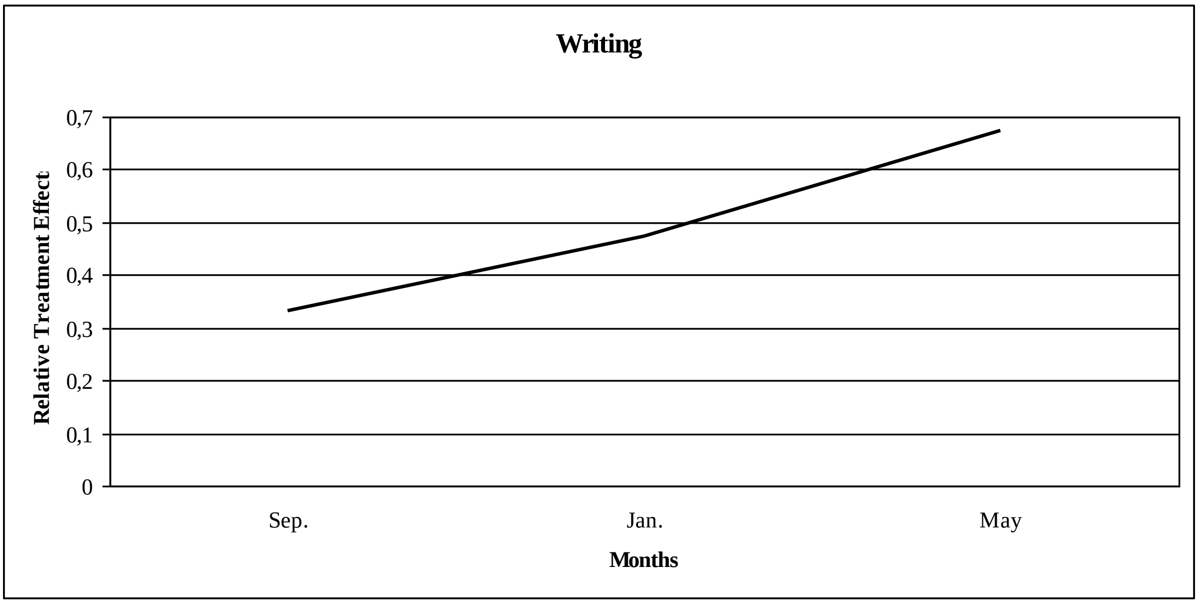

Figure 4.16 The relative treatment effects of the months

4.6.3 Mathematics:

The descriptive statistics of the study population regarding their mathematics performance are presented in Table 4.18. The results are based on a total number of 168 observations, of which 2 (*i.e.*, 1.2%) are missing. It can be inferred from Table 4.18 that the medians of the participants' scores do not differ considerably among the classrooms and that there are modest differences in the medians among the months. In addition, it can be deduced from the table that the participants' performance was satisfactory over the course of the study.

Table 4.18 The descriptive statistics regarding participants' mathematics performance

Skill	Classrooms	Months	N	Medians	Minimums	Maximums
Mathematics	C03	Sep.	14	5.5	1.0	8.0
		Jan.	13	6.0	1.0	8.0
		May	14	6.0	1.0	10.0
		Total	41	6.0	1.0	10.0
	C04	Sep.	11	3.0	1.0	9.0
		Jan.	11	5.0	1.0	9.0
		May	11	5.0	3.0	10.0
		Total	33	5.0	1.0	10.0
	C09	Sep.	16	6.0	2.0	10.0
		Jan.	16	7.0	4.0	10.0
		May	16	7.0	5.0	10.0
		Total	48	6.0	2.0	10.0
	C10	Sep.	15	5.0	1.0	9.0
		Jan.	15	6.0	3.0	10.0
		May	14	7.0	4.0	11.0
		Total	44	6.0	1.0	11.0
	Total	Sep.	56	5.0	1.0	10.0
		Jan.	55	6.0	1.0	10.0
		May	55	7.0	1.0	11.0
		Total	166	6.0	1.0	11.0

In order to investigate whether participants' mathematics performance had significantly differed among the classrooms over the course of the study, F1-LD-F1 design was deemed the most appropriate one. In this design, the effects of the classrooms (*i.e.*, Factor

A), months (*i.e.*, Factor T) and interaction of these two factors (*i.e.*, Factor AT) were evaluated. The results regarding the effects of the three factors are presented in Table 4.19.

Table 4.19 The results regarding the effects of the classrooms, dates and interaction of these two factors

Factor	*p* value
A	0.0539
T	***0.0000***
AT	0.5693

It can be inferred from Table 4.19 that the participants' scores do not differ significantly among the classrooms (*p*=0.0539). It is apparent from Figure 4.17 that the classrooms have similar relative treatment effects. However, it should be noted that the relative treatment effects of C09 ($\hat{p}_{C09} = 0.5376$) and C10 ($\hat{p}_{C10} = 0.5876$) are relatively higher than those of C03 ($\hat{p}_{C03} = 0.4879$) and C04 ($\hat{p}_{C04} = 0.3432$).More specifically, the occupants of C09 and C10 who were exposed to comparatively more daylight and, as a direct consequence, higher vertical illuminance levels performed marginally better than those of C03 and C04. In addition, it can be deduced from the table that the months differ significantly with respect to the participants' writing performance (*p*=0.0000). It is evident from Figure 4.18 that the participants' writing performance was better on May ($\hat{p}_{May} = 0.5761$) than their performance on January ($\hat{p}_{Jan} = 0.5293$) and September ($\hat{p}_{Sep} = 0.3618$). It can also be inferred from the table that the effect of the interaction factor (*i.e.*, Factor AT) is insignificant (*p*=0.5693).

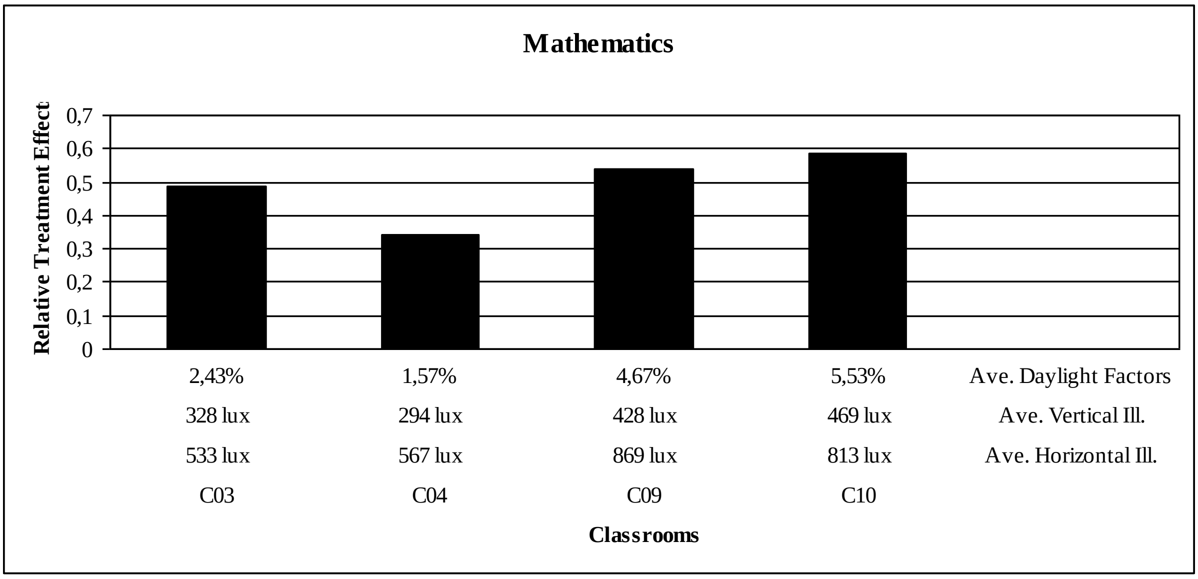

Figure 4.17 The relative treatment effects of the classrooms

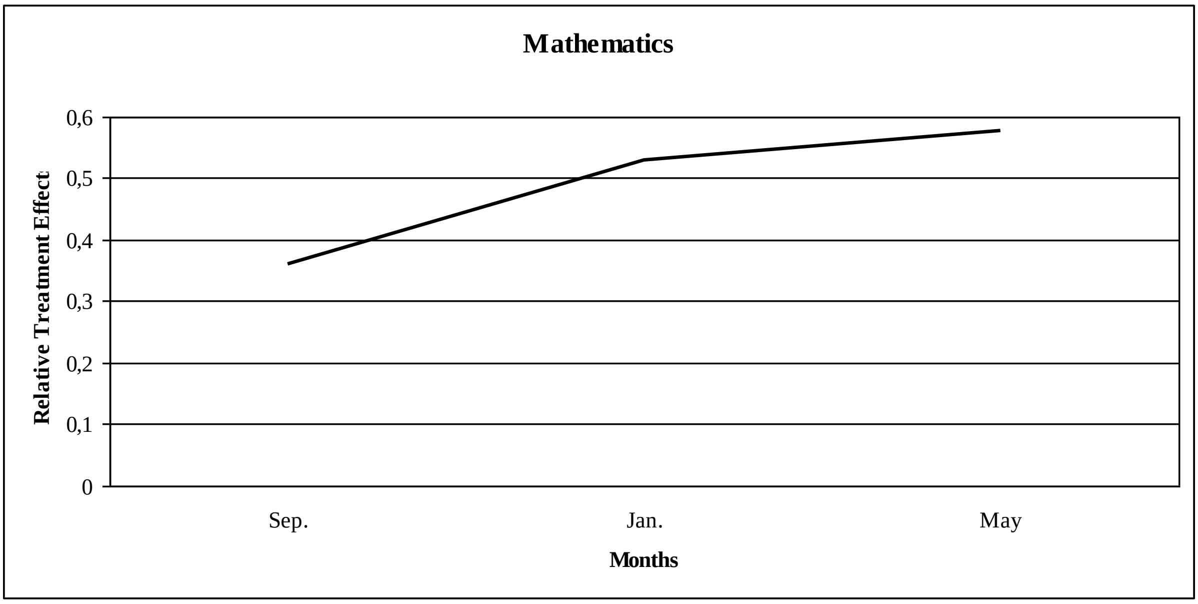

Figure 4.18 The relative treatment effects of the months

Chapter 5

Supplementary field study

Chapter 5 - Supplementary field study

The results of the main field study revealed that daylight itself might be a potent factor in promoting beneficial non-visual effects on children. Therefore, in an attempt to verify and further elucidate the findings, a similar field study was conducted at a lower latitude in winter. Because of time constraints, the second study spanned a shorter time period than that of the main study.

5.1 Setting:

The supplementary field study was carried out in the third-grade classrooms of a junior school in Ankara, Turkey. Ankara (39° 52' N; 32° 52' E) is a city centrally located in Anatolia. This region has a continental climate characterised by cold, snowy winters and hot, dry summers. The mean daily durations of sunshine vary between 2.4 and 4.5 hours in winter months (DMI, 2011). The classrooms, in which the study was conducted, were on the same floor of the school building (see Figure 5.1) and almost identical to each other (see Figure 5.2). In particular, they were quite similar in size and interior décor. Each classroom had a ceiling height of approximately 4 meters and floor area of 38 m^2. Classrooms' floors were covered with light grey mosaic tiles. Their walls and ceilings had been painted in light pink and off-white, respectively. However, in general, the windowless walls of the classrooms were used for displaying teaching materials and students' work. In spite of the similarity between the two classrooms, they were considerably different from each other with respect to the provision of daylight.

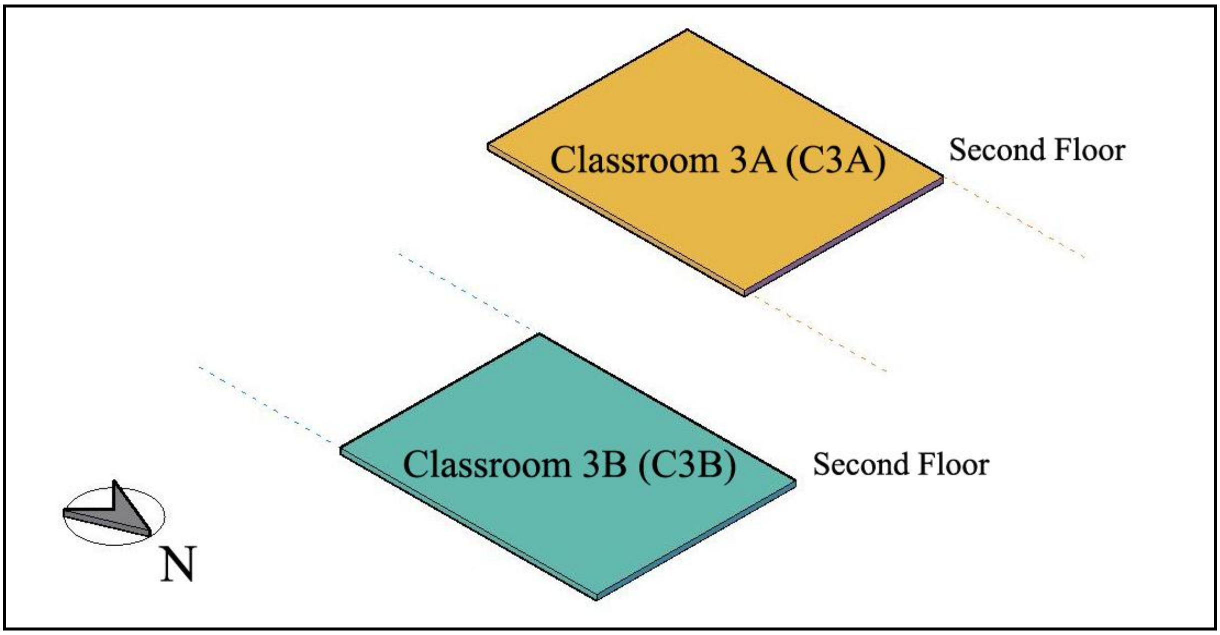

Figure 5.1 The locations and names of the classrooms

Figure 5.2 The images of the classrooms

Figure 5.3 The western and eastern windows of the classrooms

While C3A had four windows, covering an area of almost 11 m^2, on the west façade, C3B had the same amount of windows, covering the same surface area, on the east façade (see Figure 5.3). All windows with PVC frames were double-glazed in order to provide both sound and thermal insulation. It is relevant to mention here that adjacent structures, located approximately 20 meters away, were limiting the penetration of daylight through the western windows and that, during most of the study period, the curtains of each classroom were not used by the occupants for shading. Table 5.1, giving information on the measured average daylight factors in each classroom, indicates that the eastern windows could supply noticeably more natural light than the western windows.

Table 5.1 The measured average daylight factors expressed in percentages

The positions of the curtains	Classrooms	
	C3A	C3B
Completely open	1.05	3.86
Completely closed	0.01	0.02

In each classroom, an average horizontal illuminance level of approximately 200 lux at desktop height, or at 65 cm, and an average vertical illuminance of about 100 lux at sitting eye height*, or at 96 cm, were generated by the existent electrical lighting system consisting of daylight fluorescent lamps (*i.e.*, General Electric Standard Halophosphate) with a CCT of 6,500 K and ceiling-mounted luminaires with conventional ballasts and prismatic diffusers (see Table 5.2 for further information on illumination).

Table 5.2 The measured illuminance levels expressed in lux

Average levels	Classrooms	
	C3A	C3B
Horizontal illuminance level at desktop height	196	212
Vertical illuminance level at sitting eye height	105	97

In addition to the measurements performed for electrical lighting, the total illumination obtained from both the windows and electrical lighting systems were also determined horizontally and vertically over the course of the study. The total levels were measured on two different days at a single time point (see Table 5.3). It is evident from the table that the participants in C3B could expose themselves to substantial amounts of light, or more specifically, daylight, in comparison with those in C3A. All measurements regarding the illuminance levels and calculation of the average daylight factors were carried out with two portable illuminance meters (model T-10; Konica Minolta Inc., Osaka, Japan).

Table 5.3 The total illuminance levels expressed in lux

Classrooms	Dates	Time	Average horizontal levels	Average vertical levels
C3A	05 Jan.	12:10 p.m.	252	104
	20 Jan.		340	141
	Average		296	123
C3B	05 Jan.	12:10 p.m.	464	168
	20 Jan.		532	218
	Average		498	193

* Since students' main direction of gaze was towards the whiteboard in each classroom, the vertical illuminance measurements were carried out in the direction perpendicular to the board.

5.2 Participants:

In total, seventy-nine third-grade students or the ninety-three per cent of all third graders, aged between eight and nine years, voluntarily participated in the supplementary field study (see Table 5.4 for further information). It should be mentioned here that, in addition to the written consent of the parents, the informed consent of each participant was obtained. By utilising an appropriate and a simplistic language in order to ensure comprehension, each classroom teacher orally explained the study protocol* to their students and sought their consent. Even though all participants were free to withdraw from the research at any time, none of them expressed unwillingness to cooperate throughout the study period. For maintaining continuity, on each assessment day, the participants received a small carton of fruit juice as an honorarium in appreciation of their time. Furthermore, it is important to note that participants' names were transformed into code numbers by one of the classroom teachers. By assigning code numbers to the participants, their confidentiality and anonymity were protected both during and after the conduct of the research.

Table 5.4 Quantitative information on the third-grade students of the junior school in Turkey

Student numbers and participation percentages	Classrooms		Totals
	C3A	C3B	
The number of participating students (NPS)	38	41	79
The number of participating male students (NPMS)	16	23	39
The number of participating female students (NPFS)	22	18	40
The total number of students (TNS)	42	43	85
The total number of male students (TNMS)	19	23	42
The total number of female students (TNFS)	23	20	43
Total participation percentage (NPS×100/TNS)	91	95	93
Male participation percentage (NPMS×100/TNMS)	84	100	93
Female participation percentage (NFMS×100/TNFS)	96	90	93

* Although the students were thoroughly informed about their rights and responsibilities, no information on the possible outcomes of the study was given to them in order to minimise the confounding effects of prior knowledge or expectations on their responses (see Veitch, 1997; Veitch *et al.*, 1991 for further information). For the discussion of any issues arising out of or related to the research, a debriefing session was held with the classroom teachers approximately one week after the completion of the study protocol. The teachers provided any necessary information for the participants following the debriefing session.

Prior to the execution of the field work, the administrators of the elementary school were interviewed in order to gather information on the participants. They provided the following details about their students:

- All students were in good physical and psychological health. They did not suffer from any acute or chronic diseases that could influence the study outcomes, and none of them were not on any kind of medication.
- The students had normal or corrected-to-normal vision, and they had no colour vision deficiencies.
- There was no obvious mechanism or practice of allocating “better” classrooms or assigning “more experienced or skilful” teachers to “more successful or capable” students. In addition, the administrators assured that the scholastic achievements of the children in the classrooms under investigation had been even in the 2009-2010 school year. Moreover, they affirmed that all third-grade students were following the same educational programme.
- The parents or guardians of the students were similar in terms of their socioeconomic status. According to the administrators, there were not large or considerable differences in the education and income levels of the families that might affect the results.

Chapter 5 - Supplementary field study

5.3 Data acquisition:

5.3.1 Sleep quality:

Because of the convenience of the SSR-A (see Section 3.3.1), it was decided to administer this measure to the participants in spite of the fact it had been developed in English for the main field study. Therefore, the SSR-A was translated from English into Turkish and vice versa in order to ensure comparability[*].

Since research instruments must be valid and reliable in the culture being studied (Maneesriwongul and Dixon, 2004), the psychometric properties of the Turkish version of the SSR-A (SSR-AT) were investigated. Initially, the face validity of the SSR-AT was evaluated by a number of students from eight to nine years of age (N[†]=10) and their classroom teachers (N=2). The purpose of the instrument was explained to the classroom teachers. Then, they were asked to administer the self-report measure to some of their students and report on whether it was easily comprehensible to their students. Because the SSR-AT was considered to be an appropriate measure, no alterations were made to this abbreviated version.

In addition to the face validity, the construct validity of the SSR-AT was determined by conducting a CFA on the data from the first administration of the instrument. Specifically, a single-factor model was postulated and assessed the extent to which this factor model fitted the observed variables. It was revealed that no items had to be removed from the instrument due to satisfactory factor loadings. The goodness of fit between the sample data from the six items and conceptual model was evaluated by computing the aforementioned fit indices. The fit indices were in accordance with the commonly accepted ranges. The TLI, CFI and RMSEA values for the single-factor model were 0.98, 0.99 and 0.06, respectively.

In order to verify the reliability of the SSR-AT, the internal consistency of the items comprising the instrument was evaluated by means of the alpha coefficient. The internal consistency was found to be 0.90, indicating a high level. In other words, each of the items appears to measure a particular aspect of the same construct (*i.e.*, perceived sleep quality). All items were rated on the same three-point scale as the SSR. A total score[‡] was obtained by

[*] During the translation process, two independent translators were consulted. Firstly, one of the translators worked independently to produce a translated version. Secondly, this new version was translated back into the original language by the other translator. Finally, both versions were compared with each other for detecting and resolving any inconsistencies.
[†] N denotes the number of respondents.
[‡] The total score can vary from six to eighteen. The higher the score, the better the evolutions of perceived sleep experience.

adding up the scores for each item. The teachers of the participants were given written instructions on how to administer the sleep quality measure and help the participants (see Appendix 1.2 for the SSR-AT).

5.3.2 Mood:

Because of its brevity, simplicity and low cost in comparison with those of other methods and instruments, it was decided to administer the DPMS to the participants despite the fact that a Turkish version of the questionnaire was not available. Therefore, in the same manner as for the SSR-A, the DPMS was translated from French into Turkish and vice versa in order to ensure comparability.

Since research instruments must be valid and reliable in the culture being studied (Maneesriwongul and Dixon, 2004), the psychometric properties of the Turkish version of the DPMS (DPMS-T) were investigated. Initially, the face validity of the DPMS-T was evaluated by a number of students from eight to nine years of age (N=10) and their classroom teachers (N=2). The purpose of the instrument was explained to the classroom teachers. Then, they were asked to administer the self-report measure to some of their students and report on whether it was easily comprehensible to their students. Because the DPMS-T was considered to be an appropriate measure, no alterations were made to this English version.

In addition to the face validity, the construct validity of the DPMS-T was determined by conducting a CFA on the data from the first administration of the instrument. Specifically, a two-factor model was postulated and assessed the extent to which this factor model fitted the observed variables. It was revealed that no items had to be removed from the instrument due to satisfactory factor loadings. The goodness of fit between the sample data from the nine items and conceptual model was evaluated by computing the aforementioned fit indices. The fit indices were in accordance with the commonly accepted ranges. The TLI, CFI and RMSEA values for the two-factor model were 0.99, 0.99 and 0.05, respectively.

In order to verify the reliability of the DPMS-T, the internal consistencies of the items in two different item sets* were evaluated by means of the alpha coefficient. The internal consistencies of the items in the four-item and five-item sets were found to be 0.94 and 0.95, respectively. In other words, each set of items appears to reliably measure a particular aspect of the same construct (*i.e.*, either positive or negative mood). All items were rated on the same

* One of the sets consists of the four items regarding positive mood. The items are as follows: "Şu anda, kendimi neşeli hissediyorum."; "Şu anda, gülecekmiş gibi hissediyorum."; "Şu anda, mutluyum."; "Şu anda, çok eğleniyorum." The other set is comprised of the five items regarding negative mood. The items are as follows: "Şu anda, kötü bir ruh hali içerisindeyim."; "Şu anda, kendimi huysuz hissediyorum."; "Şu anda, kendimi üzgün hissediyorum."; "Şu anda, kendimi aksi hissediyorum."; "Şu anda, sinirliyim."

four-point scale as the DPMS. Two scores[*] were obtained for each factor by adding up the scores for appropriate items. The teachers of the participants were given written instructions on how to administer the mood scale and help the participants (see Appendix 2.2 for the DPMS-T).

[*] One of the scores is a positive mood score. It can vary from four to sixteen. The higher the score, the better the evolutions of positive mood states. The other score is a negative mood score. It can vary from five to twenty. The higher the score, the worse an individual's mood state.

5.3.3 Daytime sleepiness:

Since there was a need for a method that would be easy, convenient and inexpensive, it was decided to administer the pictorial scale of Maldonado *et al*. (2004), which had been proven to be a valid and sensitive measure of state sleepiness in an ethnically diverse population, was utilised (see Section 3.3.3). The teachers of the participants were given written instructions on how to administer the pictorial sleepiness scale and help the participants.

5.3.4 Academic performance:

By comparing the examination results of the participants, their scholastic performance or educational success, which was also indicative of their cognitive abilities and limitations (Thompson *et al*., 1991), was assessed. In order to evaluate the extent to which they were successful in learning mathematics, science and Turkish language, the students were examined by means of two tests on two separate days in January, 2011.

Chapter 5 - Supplementary field study

5.4 Protocol:

The study took place between the 5th of January 2011 and 20th of January 2011. In total, two data collection sessions were executed at an approximately two-week interval. In each session lasting for the entire school day (see Table 5.5), the students rated their mood and sleepiness on two different occasions subsequent to the retrospective evaluation of their sleep quality. At 08:40 a.m., data gathering was carried out promptly after the first morning break in order to determine the existence of possible group-related differences in the early hours. Before leaving school, the participants were assessed for a second time in order to appraise and compare the differential effects of the lighting conditions in the classrooms. It is important to note here that none of the data collection sessions were performed either on Monday or on Friday for minimising the possible confounding effects of weekends on the outcomes of the study.

Table 5.5 The daily routine of data collection sessions

Times	Operations
07:00-08:00 a.m.	Preparations
08:00 a.m.	The start of school day – Subjective sleep quality reports
08:45-08:50 a.m.	Break
08:50 a.m.	Subjective mood and sleepiness reports
09:35-09:40 a.m.	Break
10:25-10:35 a.m.	Break
11:20-11:25 a.m.	Break
11:25 a.m.	Subjective mood and sleepiness reports
12:10 p.m.	The end of school day

Chapter 5 - Supplementary field study

5.5 Statistics:

Because of the reported superiority of modern robust statistics, the same statistical methodology (see Section 3.5) was utilised, instead of the conventional techniques, for the main and supplementary field studies.

5.6 Results:

5.6.1 Sleep quality:

The descriptive statistics of participants' scores on the SSR-AT are presented in Table 5.6. The results are based on a total number of 158 observations, of which 10 (*i.e.*, 6%) are missing. It can be deduced from the table that the medians of the scores differ slightly among the classrooms and dates. Furthermore, it can be concluded from the table that the results do not indicate any difficulties involved in sleep initiation, maintenance and restoration over the course of the study.

Table 4.6 The descriptive statistics of the scores on the self-report measure of sleep quality

Classrooms	Dates	N*	Medians	Minimums	Maximums
C3A	05 Jan.	38	15.0	9.0	18.0
	20 Jan.	36	14.0	6.0	18.0
	Total	74	14.0	6.0	18.0
C3B	05 Jan.	41	16.0	7.0	18.0
	20 Jan.	33	15.0	10.0	18.0
	Total	74	16.0	7.0	18.0
Total	05 Jan.	79	15.0	7.0	18.0
	20 Jan.	69	15.0	6.0	18.0
	Total	148	15.0	6.0	18.0

* N denotes the number of observations.

In order to investigate whether the self-report-based evaluations of sleep quality had significantly differed among the classrooms over the course of the study, F1-LD-F1 design was deemed the most appropriate one. In this design, the effects of the classrooms (*i.e.*, Factor A), dates (*i.e.*, Factor T) and interaction of these two factors (*i.e.*, Factor AT) were evaluated. The results regarding the effects of all three factors are presented in Table 5.7.

Table 5.7 The results regarding the effects of the classrooms, dates and interaction of these two factors

Factors	*p* values
A	***0.0037***
T	0.3651
AT	0.4850

It can be inferred from Table 5.7 that the ratings of perceived sleep experience differ significantly only among the classrooms. It is apparent from Figure 5.4 that the classrooms have dissimilar relative treatment effects. The relative treatment effect of C3B ($\hat{p}_{C3B} = 0.5778$) is relatively higher than that of C3A ($\hat{p}_{C3A} = 0.4230$). More specifically, the occupants of C3B who were exposed to comparatively more daylight and, as a direct consequence, higher vertical and horizontal illuminance levels reported significantly better sleep quality. It is important to note here that, in comparison with the increase of 202 lux in horizontal illumination, the increase in vertical illumination, being almost three-fold smaller, seems to be equally effective in augmenting sleep quality.

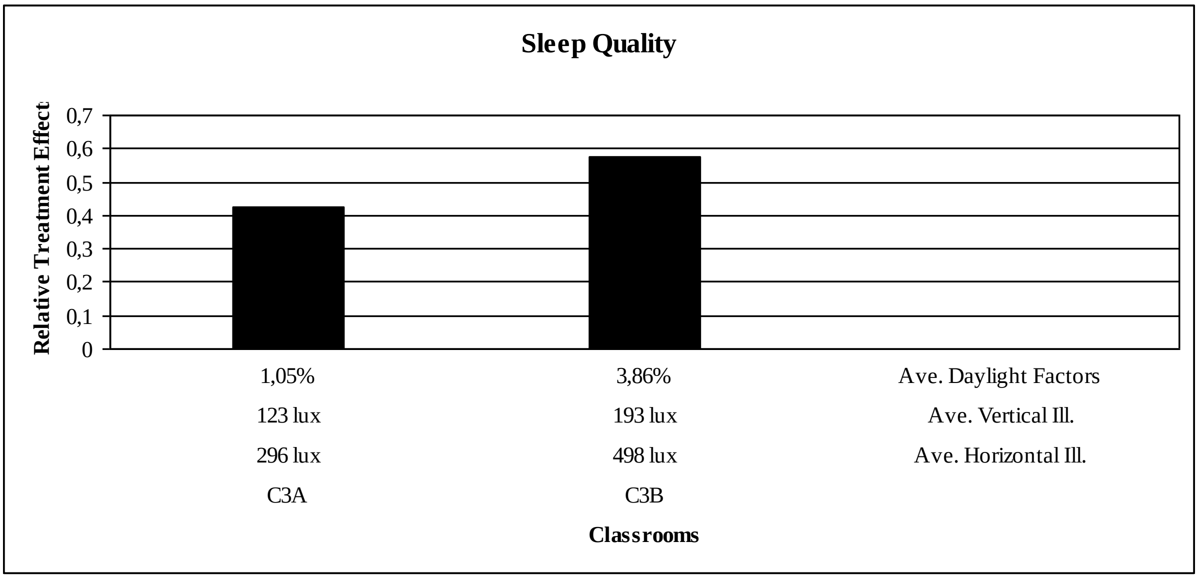

Figure 5.4 The relative treatment effects of the classrooms

5.6.2 Mood:

5.6.2.1 Positive mood:

The descriptive statistics of participants' scores on the DPMS-T are presented in Table 5.8. The results are based on a total number of 316 observations, of which 21 (*i.e.*, 7%) are missing. It can be deduced from the table that the medians of the scores differ modestly among the classrooms and times. Furthermore, it can be inferred from the table that the medians are indicative of an elated mood over the course of the study.

Table 5.8 The descriptive statistics of the scores on the self-report measure of positive mood

Classrooms	Dates	Times	N	Medians	Minimums	Maximums
C3A	05 Jan.	08:50 a.m.	38	12.0	4.0	16.0
		11:25 a.m.	37	15.0	6.0	16.0
		Total	75	14.0	4.0	16.0
	20 Jan.	08:50 a.m.	36	14.0	4.0	16.0
		11:25 a.m.	36	15.0	4.0	16.0
		Total	72	15.0	4.0	16.0
	Total	08:50 a.m.	74	12.0	4.0	16.0
		11:25 a.m.	73	15.0	4.0	16.0
		Total	147	14.0	4.0	16.0
C3B	05 Jan.	08:50 a.m.	41	15.0	7.0	16.0
		11:25 a.m.	41	15.0	4.0	16.0
		Total	82	15.0	4.0	16.0
	20 Jan.	08:50 a.m.	33	15.0	4.0	16.0
		11:25 a.m.	33	15.0	6.0	16.0
		Total	66	15.0	4.0	16.0
	Total	08:50 a.m.	74	15.0	4.0	16.0
		11:25 a.m.	74	15.0	4.0	16.0
		Total	148	15.0	4.0	16.0
Total	05 Jan.	08:50 a.m.	79	15.0	4.0	16.0
		11:25 a.m.	78	15.0	4.0	16.0
		Total	157	15.0	4.0	16.0
	20 Jan.	08:50 a.m.	69	15.0	4.0	16.0
		11:25 a.m.	69	15.0	4.0	16.0

		Total	138	15.0	4.0	16.0
	Total	08:50 a.m.	148	15.0	4.0	16.0
		11:25 a.m.	147	15.0	4.0	16.0
		Total	295	15.0	4.0	16.0

In order to investigate whether the self-report-based evaluations of positive mood had significantly differed among the classrooms over the course of the study, F1-LD-F2 design was considered to be the most appropriate one. In this design, the effects of the classrooms (*i.e.*, Factor A), dates (*i.e.*, Factor C), times (*i.e.*, Factor T) and interactions of these three factors (*i.e.*, Factor AC, Factor AT, Factor CT and Factor ACT) were evaluated. The results regarding the effects of all seven factors are presented in Table 5.9.

Table 5.9 The results regarding the effects of the classrooms, dates, times and interaction of these three factors

Factors	*p* values
A	***0.0073***
C	0.7293
T	***0.0005***
AC	0.7864
AT	0.0731
CT	0.1045
ACT	0.6827

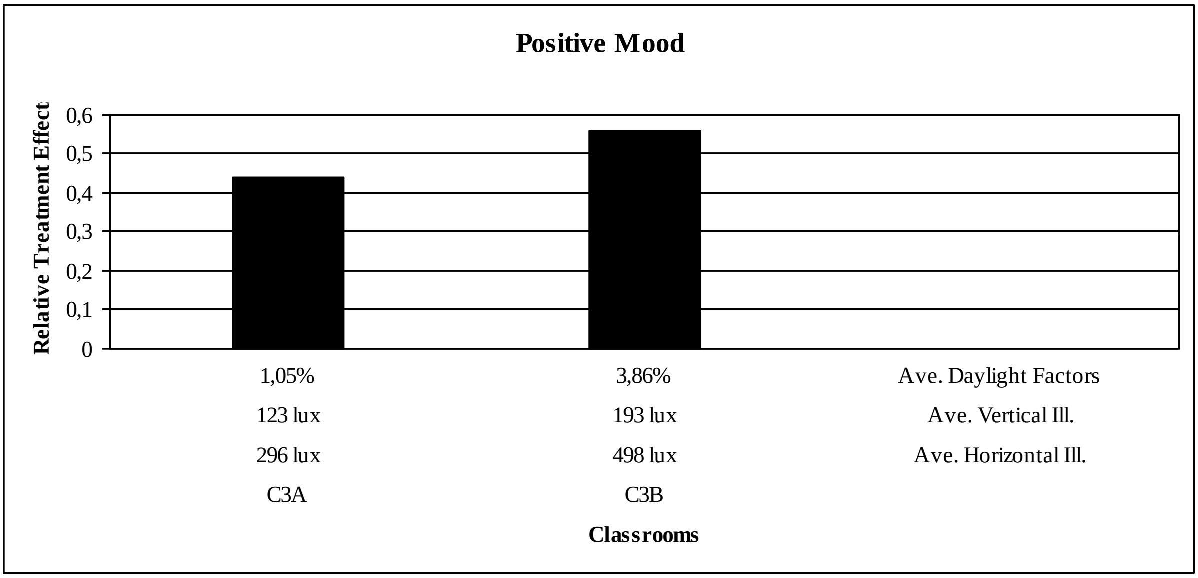

Figure 5.5 The relative treatment effects of the classrooms

It can be inferred from Table 5.9 that the ratings of perceived positive affect differ significantly only among the classrooms and times. It is apparent from Figure 5.5 that the classrooms have dissimilar relative treatment effects. The relative treatment effect of C3B ($\hat{p}_{C3B} = 0.5591$) is relatively higher than that of C3A ($\hat{p}_{C3A} = 0.4413$). In other words, participants' mood was significantly better in C3B providing more natural light at eye level. It appears that increasing vertical illumination is of critical importance. In addition, it is evident from Figure 5.6 that the study population was in a more elated mood state at 11:25 a.m. ($\hat{p}_{11:25} = 0.5055$) than at 08:50 a.m. ($\hat{p}_{08:50} = 0.4950$) throughout the study.

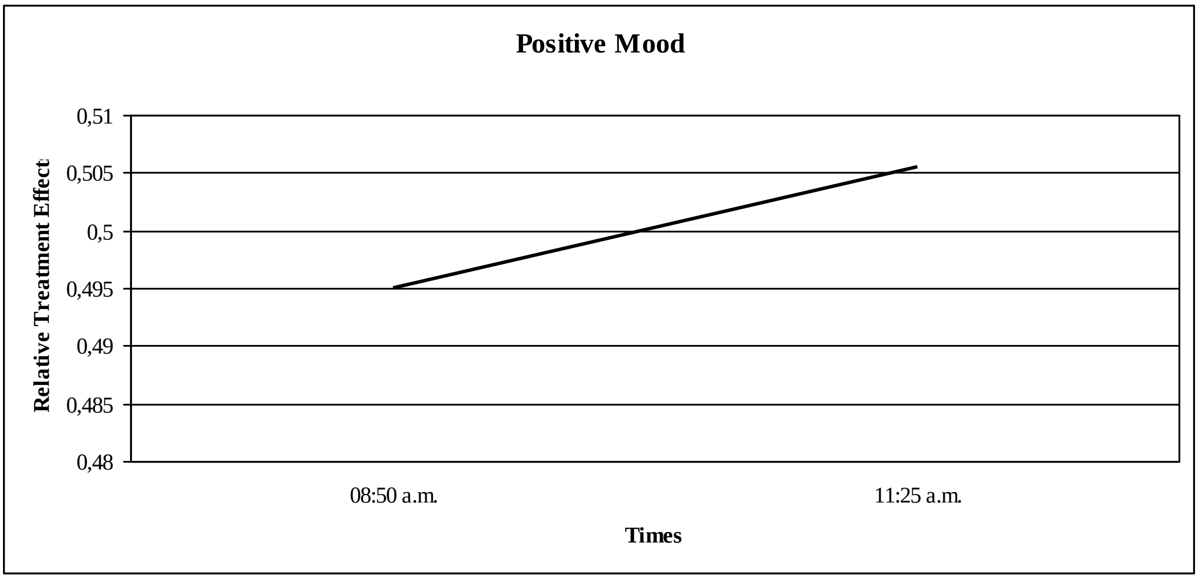

Figure 5.6 The relative treatment effects of the times

5.6.2.2 Negative mood:

The descriptive statistics of participants' scores on the DPMS-T are presented in Table 5.10. The results are based on a total number of 316 observations, of which 21 (*i.e.*, 7%) are missing. It can be deduced from the table that the medians of the scores do not differ among the classrooms, dates and times. Furthermore, it can be concluded from the table that the medians are not indicative of a distressed mood over the course of the study.

Table 5.10 The descriptive statistics of the scores on the self-report measure of negative mood

Classroom	Dates	Times	N	Medians	Minimums	Maximums
C3A	05 Jan.	08:50 a.m.	38	5.0	5.0	19.0
		11:25 a.m.	37	5.0	5.0	16.0
		Total	75	5.0	5.0	19.0
	20 Jan.	08:50 a.m.	36	5.0	5.0	17.0
		11:25 a.m.	36	5.0	5.0	17.0
		Total	72	5.0	5.0	17.0
	Total	08:50 a.m.	74	5.0	5.0	19.0
		11:25 a.m.	73	5.0	5.0	17.0
		Total	147	5,0	5.0	19.0
C3B	05 Jan.	08:50 a.m.	41	5.0	5.0	16.0
		11:25 a.m.	41	5.0	5.0	19.0
		Total	82	5.0	5.0	19.0
	20 Jan.	08:50 a.m.	33	5.0	5.0	15.0
		11:25 a.m.	33	5.0	5.0	15.0
		Total	66	5.0	5.0	15.0
	Total	08:50 a.m.	74	5.0	5.0	16.0
		11:25 a.m.	74	5.0	5.0	19.0
		Total	148	5,0	5.0	19.0
Total	05 Jan.	08:50 a.m.	79	5.0	5.0	19.0
		11:25 a.m.	78	5.0	5.0	19.0
		Total	157	5.0	5.0	19.0
	20 Jan.	08:50 a.m.	69	5.0	5.0	17.0
		11:25 a.m.	69	5.0	5.0	17.0
		Total	138	5.0	5.0	17.0

	Total	08:50 a.m.	148	5.0	5.0	19.0
		11:25 a.m.	147	5.0	5.0	19.0
		Total	295	5.0	5.0	19.0

In order to investigate whether the self-report-based evaluations of negative mood had significantly differed among the classrooms over the course of the study, F1-LD-F2 design was deemed to be the most appropriate one. In this design, the effects of the classrooms (*i.e.*, Factor A), dates (*i.e.*, Factor C), times (*i.e.*, Factor T) and interactions of these three factors (*i.e.*, Factor AC, Factor AT, Factor CT and Factor ACT) were evaluated. The results regarding the effects of all seven factors are presented in Table 5.11.

Table 5.11 The results regarding the effects of the classrooms, dates, times and interaction of these three factors

Factors	*p* values
A	***0.0498***
C	0.9831
T	***0.0006***
AC	0.6071
AT	0.6825
CT	0.6764
ACT	0.7057

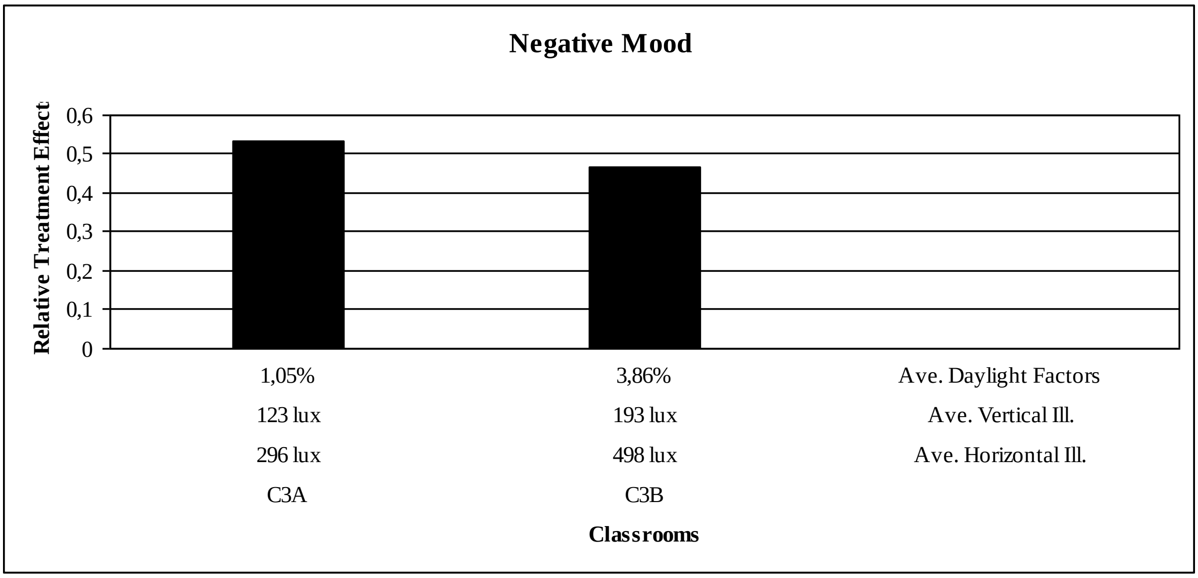

Figure 5.7 The relative treatment effects of the classrooms

It can be inferred from Table 5.11 that the ratings of perceived negative affect differ significantly only among the classrooms and times. It is apparent from Figure 5.7 that the classrooms have dissimilar relative treatment effects. The relative treatment effect of C3B

($\hat{p}_{C3B} = 0.4661$) is relatively lower than that of C3A ($\hat{p}_{C3A} = 0.5345$). More specifically, the occupants of C3B who were exposed to comparatively more daylight and, as a direct consequence, higher vertical and horizontal illuminance levels reported significantly better mood. It is important to note here that, in comparison with the increase of 202 lux in horizontal illumination, the increase in vertical illumination, being almost three-fold smaller, seems to be equally effective in improving mood. In addition, it is evident from Figure 5.8 that the study population was in a more negative mood state at 08:50 a.m. ($\hat{p}_{08:50} = 0.5006$) than at 11:25 a.m. ($\hat{p}_{11:25} = 0.5000$) throughout the study.

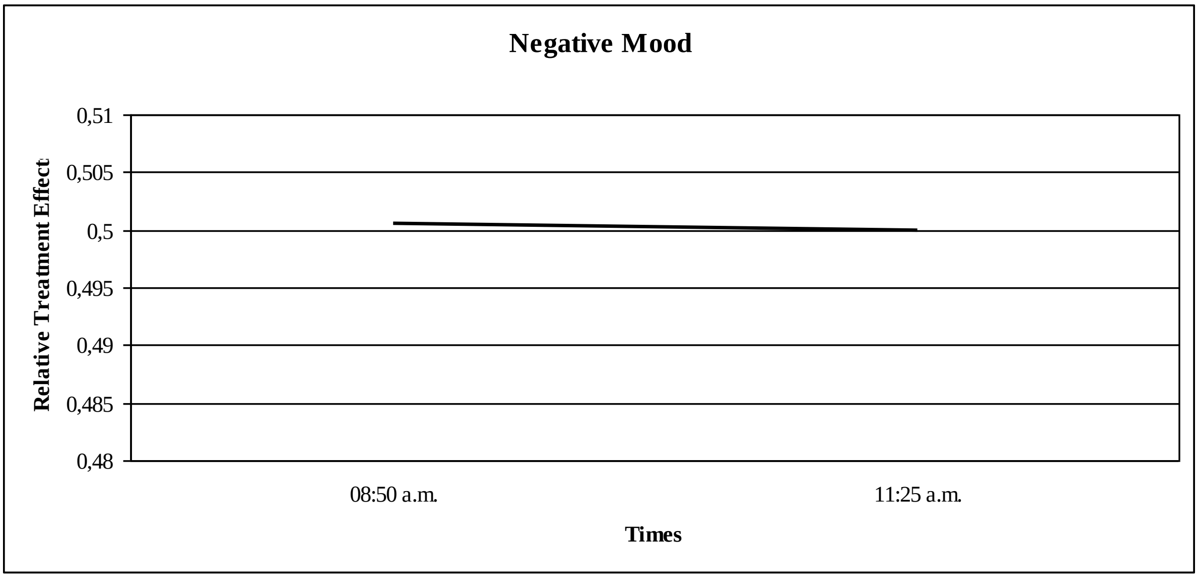

Figure 5.8 The relative treatment effects of the times

5.6.3 Daytime sleepiness:

The descriptive statistics of participants' scores on the pictorial sleepiness scale are presented in Table 5.12. The results are based on a total number of 316 observations, of which 21 (*i.e.*, 7%) are missing. It can be deduced from the table that the medians of the scores differ slightly among the classrooms and times. Furthermore, it can be inferred from the table that the results do not indicate any difficulties involved in maintaining alertness and vitality over the course of the study.

Table 5.12 The descriptive statistics of the scores on the self-report measure of daytime sleepiness

Classrooms	Dates	Times	N	Medians	Minimums	Maximums
C3A	05 Jan.	08:50 a.m.	38	2.0	1.0	5.0
		11:25 a.m.	37	3.0	2.0	5.0
		Total	75	3.0	1.0	5.0
	20 Jan.	08:50 a.m.	36	2.0	1.0	5.0
		11:25 a.m.	36	3.0	1.0	5.0
		Total	72	3.0	1.0	5.0
	Total	08:50 a.m.	74	2.0	1.0	5.0
		11:25 a.m.	73	3.0	1.0	5.0
		Total	147	3.0	1.0	5.0
C3B	05 Jan.	08:50 a.m.	41	1.0	1.0	5.0
		11:25 a.m.	41	2.0	1.0	4.0
		Total	82	2.0	1.0	5.0
	20 Jan.	08:50 a.m.	33	1.0	1.0	3.0
		11:25 a.m.	33	2.0	1.0	4.0
		Total	66	2.0	1.0	4.0
	Total	08:50 a.m.	74	1.0	1.0	5.0
		11:25 a.m.	74	2.0	1.0	4.0
		Total	148	2.0	1.0	5.0
Total	05 Jan.	08:50 a.m.	79	2.0	1.0	5.0
		11:25 a.m.	78	3.0	1.0	5.0
		Total	157	2.0	1.0	5.0
	20 Jan.	08:50 a.m.	69	2.0	1.0	5.0
		11:25 a.m.	69	3.0	1.0	5.0

		Total	138	2,0	1.0	5.0
	Total	08:50 a.m.	148	2,0	1.0	5.0
		11:25 a.m.	147	3,0	1.0	5.0
		Total	295	2,0	1.0	5.0

In order to investigate whether the self-report-based evaluations of daytime sleepiness had significantly differed among the classrooms over the course of the study, F1-LD-F2 design was considered to be the most appropriate one. In this design, the effects of the classrooms (*i.e.*, Factor A), dates (*i.e.*, Factor C), times (*i.e.*, Factor T) and interactions of these three factors (*i.e.*, Factor AC, Factor AT, Factor CT and Factor ACT) were evaluated. The results regarding the effects of all seven factors are presented in Table 5.13.

Table 5.13 The results regarding the effects of the classrooms, dates, times and interaction of these three factors

Factors	*p* values
A	***0.0000***
C	0.9004
T	***0.0000***
AC	0.6148
AT	0.8898
CT	0.7133
ACT	0.7859

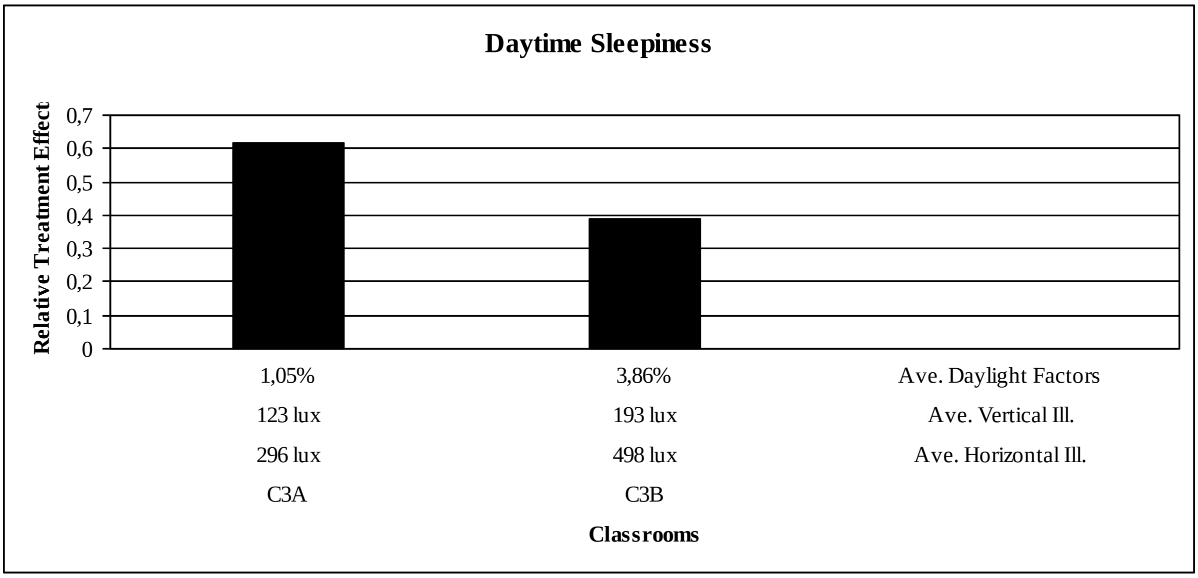

Figure 5.9 The relative treatment effects of the classrooms

It can be inferred from Table 5.13 that the ratings of perceived daytime sleepiness differ significantly only among the classrooms and times. It is apparent from Figure 5.9 that the classrooms have dissimilar relative treatment effects. The relative treatment effect of C3B ($\hat{p}_{C3B} = 0.3864$) is relatively lower than that of C3A ($\hat{p}_{C3A} = 0.6154$). In other words, participants' sleepiness was significantly lower in C3B providing more natural light at eye level. It appears that increasing vertical illumination is of critical importance. In addition, it is evident from Figure 5.10 that the study population was more alert and vital at 11:25 a.m. ($\hat{p}_{11:25} = 0.4990$) than at 08:50 a.m. ($\hat{p}_{08:50} = 0.5028$) throughout the study.

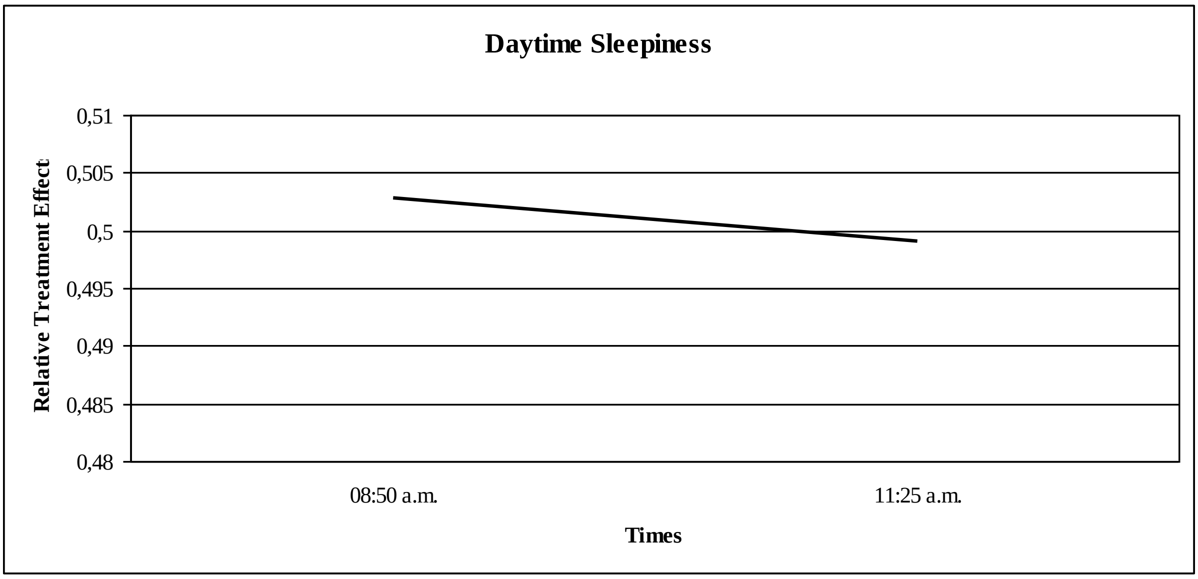

Figure 5.10 The relative treatment effects of the times

5.6.4 Academic performance:

5.6.4.1 Turkish:

The descriptive statistics of participants' marks in the Turkish examinations are presented in Table 5.14. The results are based on a total number of 158 observations, of which 11 (*i.e.*, 7%) are missing. It can be deduced from the table that the medians of the marks differ slightly among the classrooms and dates. Furthermore, it can be concluded from the table that the medians are indicative of a satisfactory performance over the course of the study.

Table 5.14 The descriptive statistics of the marks in the Turkish examinations

Classrooms	Dates	N	Medians	Minimums	Maximums
C3A	03 Jan.	37	26.0	10.0	38.0
	17 Jan.	35	27.0	11.0	40.0
	Total	72	26.0	10.0	40.0
C3B	03 Jan.	38	26.0	14.0	40.0
	17 Jan.	37	29.0	11.0	40.0
	Total	75	27.0	11.0	40.0
Total	03 Jan.	75	26.0	10.0	40.0
	17 Jan.	72	29.0	11.0	40.0
	Total	147	27.0	10.0	40.0

In order to investigate whether the evaluations of Turkish performance had significantly differed among the classrooms over the course of the study, F1-LD-F1 design was deemed the most appropriate one. In this design, the effects of the classrooms (*i.e.*, Factor A), dates (*i.e.*, Factor T) and interaction of these two factors (*i.e.*, Factor AT) were evaluated. The results regarding the effects of all three factors are presented in Table 5.15.

Table 5.15 The results regarding the effects of the classrooms, dates and interaction of these two factors

Factors	*p* values
A	0.4022
T	0.2323
AT	0.5239

It can be inferred from Table 4.15 that the marks of the participants do not differ significantly. However, it is apparent from Figure 5.11 that the classrooms have dissimilar relative treatment effects. The relative treatment effect of C3B ($\hat{p}_{C3B} = 0.5229$) is relatively higher than that of C3A ($\hat{p}_{C3A} = 0.4718$). More specifically, the occupants of C3B who were exposed to comparatively more daylight and, as a direct consequence, higher vertical and horizontal illuminance levels were marginally more successful. It is important to note here that, in comparison with the increase of 202 lux in horizontal illumination, the increase in vertical illumination, being almost three-fold smaller, seems to be equally effective in improving scholastic achievement.

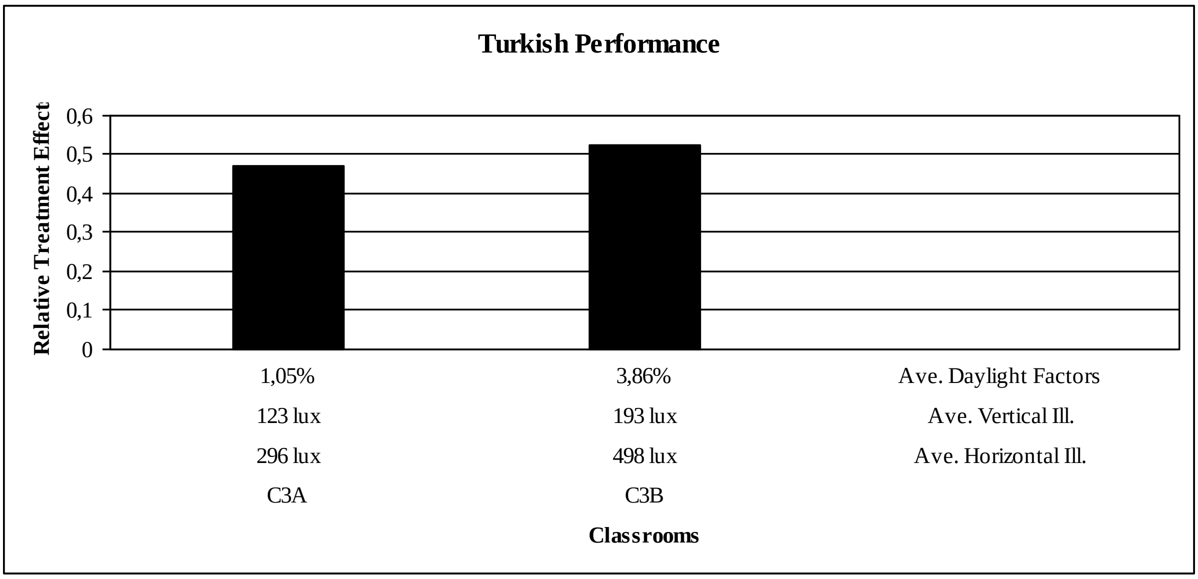

Figure 5.11 The relative treatment effects of the classrooms

5.6.4.2 Science:

The descriptive statistics of participants' marks in the science examinations are presented in Table 5.16. The results are based on a total number of 158 observations, of which 10 (*i.e.*, 6%) are missing. It can be deduced from the table that the medians of the marks differ slightly among the classrooms and dates. Furthermore, it can be inferred that the medians are indicative of a satisfactory performance over the course of the study.

Table 5.16 The descriptive statistics of the marks in the science examinations

Classroom	Dates	N	Medians	Minimums	Maximums
C3A	03 Jan.	38	32.0	18.0	40.0
	17 Jan.	35	24.0	13.0	37.0
	Total	73	29.0	13.0	40.0
C3B	03 Jan.	38	32.0	24.0	40.0
	17 Jan.	37	29.0	16.0	40.0
	Total	75	32.0	16.0	40.0
Total	03 Jan.	76	32.0	18.0	40.0
	17 Jan.	72	28.0	13.0	40.0
	Total	148	30.0	13.0	40.0

In order to investigate whether the evaluations of science performance had significantly differed among the classrooms over the course of the study, F1-LD-F1 design was deemed the most appropriate one. In this design, the effects of the classrooms (*i.e.*, Factor A), dates (*i.e.*, Factor T) and interaction of these two factors (*i.e.*, Factor AT) were evaluated. The results regarding the effects of all three factors are presented in Table 5.17.

Table 5.17 The results regarding the effects of the classrooms, dates and interaction of these two factors

Factors	*p* values
A	0.1386
T	***0.0000***
AT	***0.0009***

It can be inferred from Table 5.12 that the marks of the participants differ significantly among the dates. It is apparent from Figure 5.12 that the study population was more successful on the third of January ($\hat{p}_{J03} = 0.5812$) than on the seventeenth of January

($\hat{p}_{J17} = 0.4078$). It should be noted that there is also a significant interaction among the classrooms and dates. It is evident from Figure 5.13 that the initial relative treatment effects of C3A ($\hat{p}_{C3A} = 0.5878$) and C3B ($\hat{p}_{C3B} = 0.5746$) are very similar. Unlike the performance on the first day of examination, the performance of C3B ($\hat{p}_{C3B} = 0.4983$) was considerably better than that of C3A ($\hat{p}_{C3A} = 0.3173$) on the second day of examination.

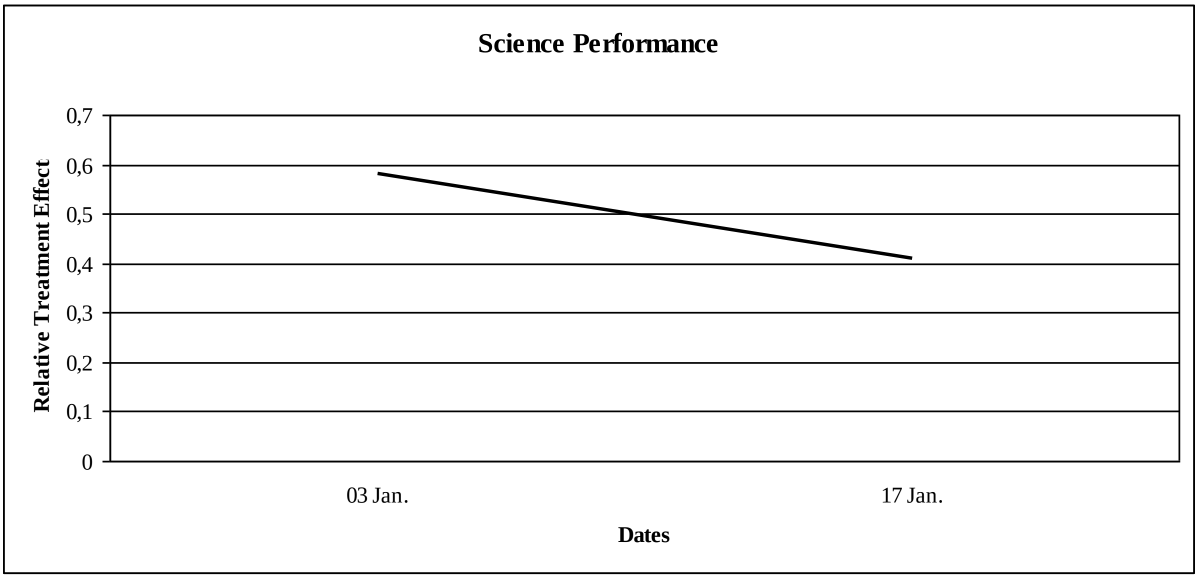

Figure 5.12 The relative treatment effects of the dates

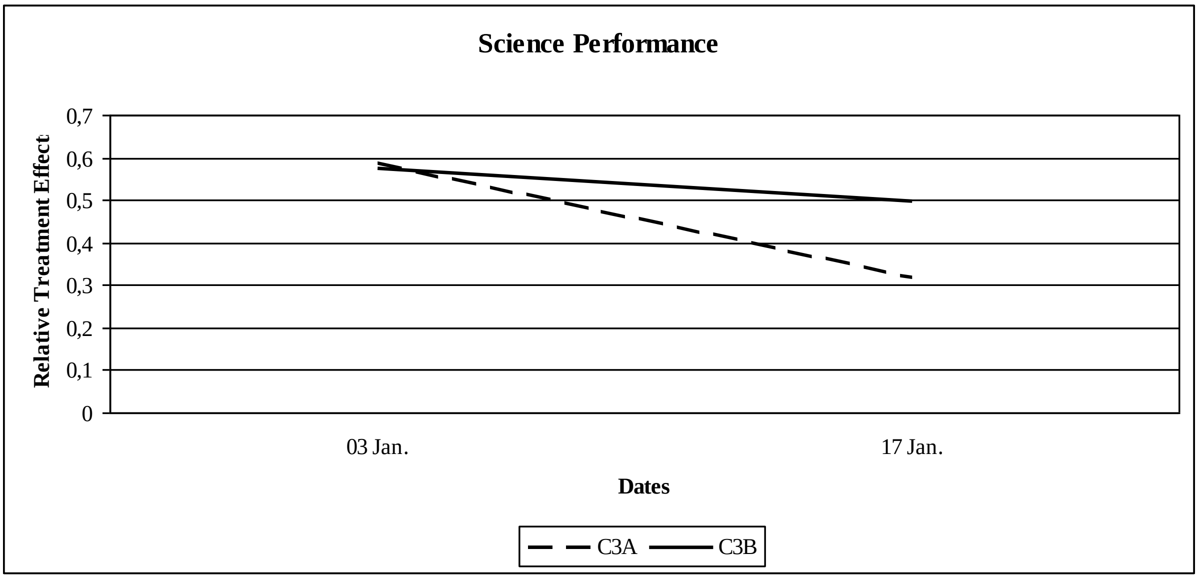

Figure 5.13 The relative treatment effects of the interactions among the classrooms and dates

5.6.4.3 Mathematics:

The descriptive statistics of participants' marks in the mathematics examinations are presented in Table 5.18. The results are based on a total number of 158 observations, of which 10 (*i.e.*, 6%) are missing. It can be deduced from the table that the medians of the marks differ slightly among the classrooms and dates. Furthermore, it can be concluded from the table that the medians are indicative of a satisfactory performance over the course of the study.

Table 5.18 The descriptive statistics of the marks in the mathematics examinations

Classrooms	Dates	N	Medians	Minimums	Maximums
C3A	03 Jan.	38	15.0	4.0	20.0
	17 Jan.	35	13.0	2.0	20.0
	Total	73	13.0	2.0	20.0
C3B	03 Jan.	38	14.0	10.0	20.0
	17 Jan.	37	14.0	6.0	20.0
	Total.	75	14.0	6.0	20.0
Total	03 Jan.	76	15.0	4.0	20.0
	17 Jan.	72	13.0	2.0	20.0
	Total	148	14.0	2.0	20.0

In order to investigate whether the evaluations of mathematics performance had significantly differed among the classrooms over the course of the study, F1-LD-F1 design was deemed the most appropriate one. In this design, the effects of the classrooms (*i.e.*, Factor A), dates (*i.e.*, Factor T) and interaction of these two factors (*i.e.*, Factor AT) were evaluated. The results regarding the effects of all three factors are presented in Table 5.19.

Table 5.19 The results regarding the effects of the classrooms, dates and interaction of these two factors

Factors	*p* values
A	0.4279
T	***0.0004***
AT	0.8961

It can be inferred from Table 5.19 that the marks of the participants do not differ significantly among the classrooms. However, it is apparent from Figure 5.14 that the classrooms have dissimilar relative treatment effects. The relative treatment effect of C3B ($\hat{p}_{C3B} = 0.5219$) is relatively higher than that of C3A ($\hat{p}_{C3A} = 0.4738$). In other words, participants' performance was slightly better in C3B providing more natural light at eye level. It appears that increasing vertical illumination is of critical importance. In addition, it is evident from Figure 5.15 that the study population was more successful on the third of January ($\hat{p}_{J03} = 0.5471$) than on the seventeenth of January ($\hat{p}_{J17} = 0.4486$).

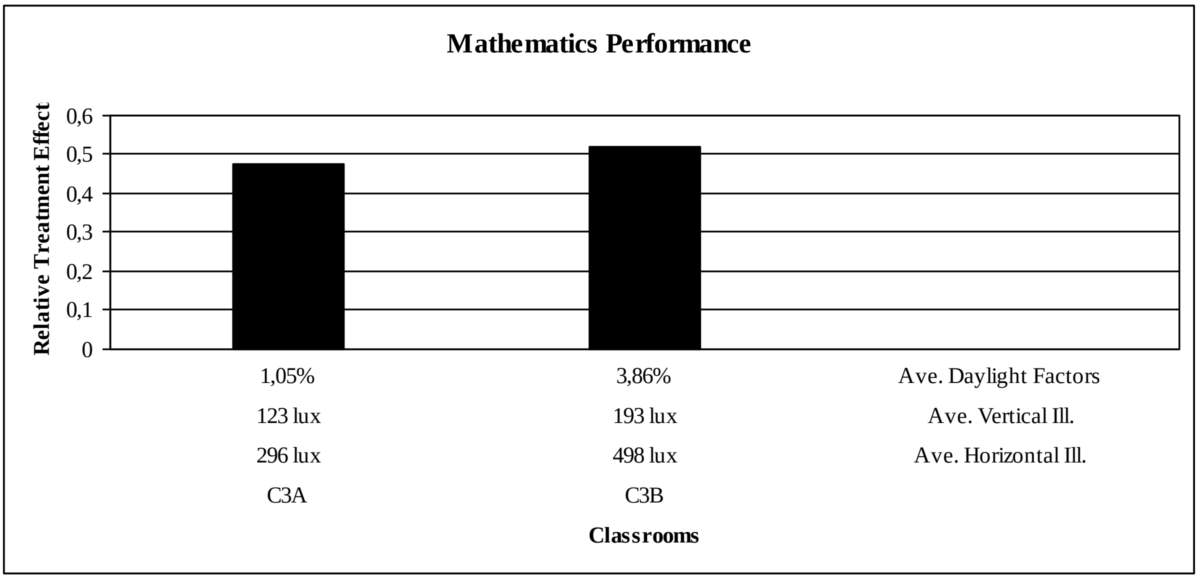

Figure 5.14 The relative treatment effects of the classrooms

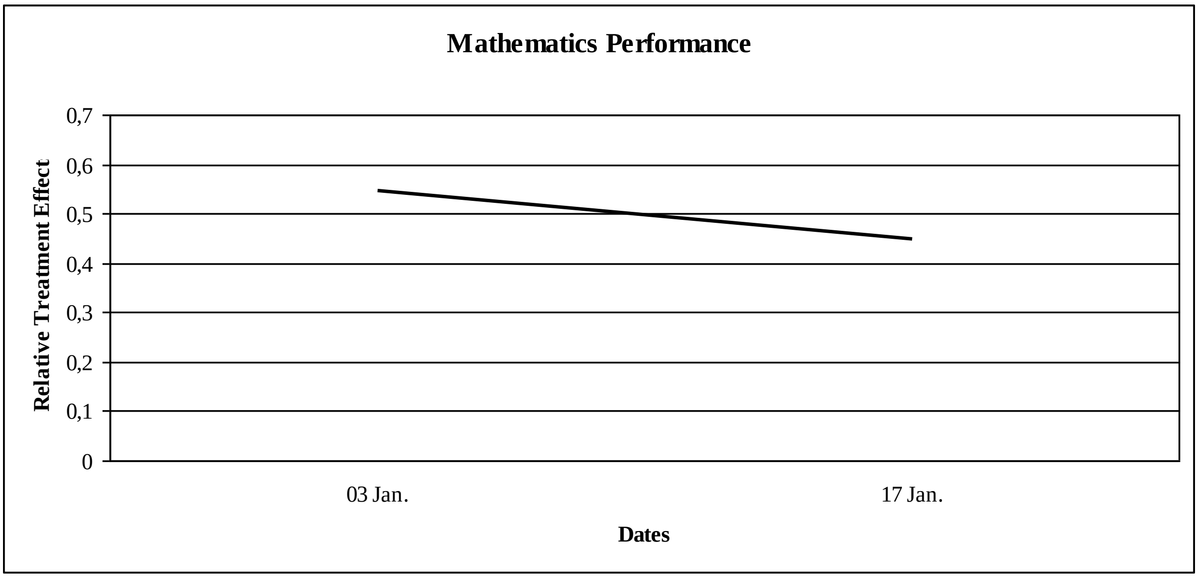

Figure 5.15 The relative treatment effects of the dates

Chapter 6

Discussion

From infancy we concentrate happily on ourselves and other organisms. We learn to distinguish life from the inanimate and move toward it like moths to a porch of light… To explore and affiliate with life is a deep and complicated process in mental development. To an extent still undervalued in philosophy and religion, our existence depends on this propensity, our spirit is woven from it, hope rises on its currents.

Edward O. Wilson, 1984

Chapter 6 - Discussion

While the effects of light on man have been mainly studied in terms of visibility and visual discomfort for many years (Boyce, 2004), the non-visual aspects of light, primarily electric lighting, have become an increasingly important concern for the community of lighting since late 1990s (Veitch, 2002; Veitch *et al*., 2004). Given the relative novelty of the research that has been devoted to light and our non-visual needs, it is evident that a number of relevant research questions still remain to be answered by lighting practitioners. With regard to these unanswered questions, the findings from my own field studies are of particular interest as they provide affirmative answers to the following questions: "Is there an optimal indoor lighting condition for sustaining or augmenting our general well-being and cognitive abilities?"; "*Is the illumination produced naturally, by the sun, superior to its artificial substitute?"* The findings suggest that daylight itself is a potent and unique photic stimulus influencing our physical and mental functioning in today's modern urban built environment housing most of us*. Concerning these deductions, two concepts, namely the Biophilia Hypothesis and Environment of Evolutionary Adaptedness, need to be explicated before discussing the results.

The idea or hypothesis that humans have an affinity to affiliate with natural systems and processes is called the Biophilia Hypothesis (Kellert and Wilson, 1993; Wilson 1984). According to the proponents of the idea, this affinity, which is known as biophilia, is an innate human characteristic. The reason for this genetic predisposition is presumably that, over the course of human evolution, biophilic tendencies have been instrumental in enhancing our physical, emotional and intellectual fitness and, as a direct consequence, the survival of our species. In addition, the proponents assert that our affection to contact with nature reflects the reality of having evolved in a largely natural, not in an artificial, world.

John Bowlby (1969, 1973) introduced the concept of the Environment of Evolutionary Adaptedness (EEA). Bowlby (1973) defined a species' EEA as "the environment in which a species lived while its existing characteristics, including behavioural systems, were being evolved, and… the only environment in which there can be any assurance that activation of a system will be likely to result in the achievement of its biological function…" (p. 82). According to Bowlby (1969), our species' EEA is the primeval, or natural, environment of our ancestors. Therefore, it seems reasonable to surmise that the evolutionary context for the

* Almost fifty per cent of all people in the world live in metropolitan areas, and this percentage has been projected to increase by fifteen per cent in less than twenty years (Charles and Louv, 2009).

development of the human mind and body was a mainly a sensory world dominated by critical environmental features such as animals, daylight, vegetation, water and wind. According to Wilson (1993, p. 32), it would be "quite extraordinary to find that all learning rules related to that world have been erased in a few thousand years*, even in the tiny minority of peoples who have existed for more than one or two generations in wholly urban environments." Thus, it is also plausible to surmise that an environment devoid of natural systems and processes may act like a deleterious deviation from the way of life for which we are genetically designed, or a "discord" (Grinde, 2002).

The invention of steam engine in the late eighteenth century massively increased human access to energy (Goudie, 1990), and this marked advance notably changed our species' long-standing contact with the natural environment. The emergence of a new era in manufacturing created both the demand and means of living and working indoors (Baker, 2004). It should be emphasised that this revolution in culture and technology not only gave rise to our separation from natural systems and processes but also encouraged the massive transformation and degradation of nature. For example, prior to the Clean Air Act of 1952, the average hours of sunshine during winter months was approximately one hour per day in central London because of the pollution emanating from domestic chimneys together with industrial smokestacks (Baker, 2004). In addition, the means to support indoor living and working had to be provided by unorthodox technologies. One of these technologies was incandescent lamp technology. By 1881, it was feasible to utilise electric lighting to illuminate indoors (Dilaura, 2008).

Since the end of the nineteenth century, electric lighting has become an integral part of our lives and a substitute for daylight. In addition to the above-mentioned fact that our daily exposure to daylight is no more than one and a half hours (Espiritu *et al.*, 1994; Savides *et al.*, 1986), another indication of our reliance upon electric lighting is that over ten per cent of all U.S. energy consumption is for lighting buildings during the day and at night (Loftness and Snyder, 2008). Therefore, in terms of light, we can be pretty sure that most of the environments in which modern humans live today do not conform to the environment to which we are genetically adapted. One should be aware of the fact that daylight was the primary source of illumination in our species' EEA and consider that electric lighting became available approximately four generations ago. Thus, in my view, it is very perplexing and

* Humans probably first appeared on earth roughly three million years ago, and they lived solely by hunting and gathering until the Agricultural Revolution (Goudie, 1990). A mere ten thousand years ago, humans began to create their own version of natural world by domesticating animals, cultivating crops, digging mines and forming settlements (Frumkin, 2001).

unfortunate that modern humans have become dependent on electric lighting. In terms of physical, affective and intellectual well-being of man, does it matter that we have been replacing daylight with electric lighting? Since the speed at which our environment has been diversified, especially the speed in the recent centuries, has far outstripped the pace at which our mind and body are able to adapt (Eaton *et al*., 1988), I suppose that it does matter. In order to support this provisional answer, my own findings and those of other researchers should be discussed.

Initially, I would like to ask rhetorically whether our estrangement from daylight is a reluctant concession. It seems that it is. Based on Bowlby's (1969) definition of man's EEA, it is tenable to infer that daylight was one of the salient features of that environment. If this inference is correct, we, as modern humans, should have a biophilic tendency to or, in other words, an inherent inclination to affiliate with daylight. In this regard, there is convincing evidence that the vast majority of us prefer daylight to electric lighting (*e.g.*, Heerwagen and Heerwagen, 1986; Roche *et al*., 2000; Wells, 1965). Furthermore, this general trend of preference for daylight is consistent with the finding that building occupants would rather be close to the windows, providing both full spectrum light and the changing cycles of light and darkness (*e.g.*, Kim and Wineman, 2005; Markus, 1967; Wang and Boubekri, 2009).

There is no doubt at all that, for many of us, it is a blessing or pure joy to feel the warmth of sun and be able to perceive the meaningful variations of daylight. Even if these were only aesthetic preferences, they would be of great value. But perhaps these are more than just simple preferences. From an evolutionary perspective, a deep-rooted connection with nature's light would be of no surprise. In the framework of the Biophilia Hypothesis and EEA concept, it is viable to deduce that, as a legacy of evolution, we are physically and mentally attuned to daylight. Therefore, it seems reasonable to suggest that our well-being is highly contingent upon the successful incorporation of daylight into the modern urban built environment, which is a necessity rather than a luxury, for avoiding discords and optimising our fitness. Not surprisingly, the results of various investigations and my own field studies provide supportive evidence that daylight undoubtedly contributes to our functioning and existence.

There is a close correspondence between the findings from both of my field studies and those of Mishima *et al*. (2001) concerning the consequential association between daylight indoors and the augmentation of nocturnal sleep. Since sleep is an essential or a prerequisite biological process that is known to play a key role in the restoration of physical and mental functioning (Stanley, 2005), it is very likely that the proper integration of daylight in building design is crucial to the overall quality of life in modern-day humans spending most of their time indoors and posit that the following observations are of particular interest. By means of the self-reports specifically developed for my field studies, it was demonstrated that difficulties with sleep initiation, maintenance and efficacy were more frequently reported by the children in C03 and C04 than by those in the other two classrooms admitting comparatively more daylight and, as a direct consequence, vertical illumination (see Figure 6.1). Although this difference did not attain a statistical significance, the difference between the classrooms investigated in the supplementary field study (see Figure 6.2) was statistically significant. The children in C3B, who could expose themselves to more natural light and vertical illumination at eye level, reported better sleep quality than those in C3A.

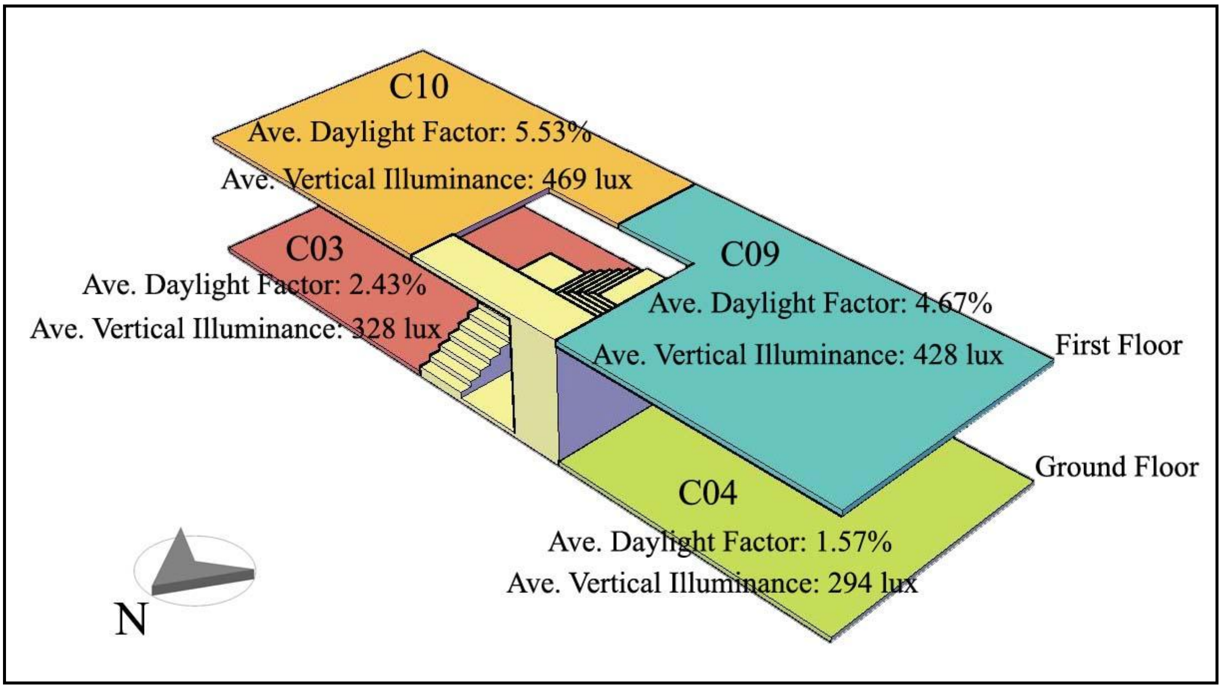

Figure 6.1 The locations, average daylight factors and average vertical illuminances of the classrooms in the main field study

Despite the fact that there is convergent evidence for the involvement of daylight in endogenous hormone production (*e.g.*, Mishima *et al*., 2001; Morita *et al*., 2002), the findings from my main field study, unfortunately, do not offer an empirical support for the likelihood of a relationship between natural light and the rhythmical secretion of melatonin and cortisol. Based on the previous research and my findings as regards sleep quality, it is very plausible to expect that there should be some degree of concordance between the availability of daylight and biochemical rhythm of melatonin having an impact on our nocturnal sleep. Regrettably, in stark contrast to my expectation, the differences in melatonin concentrations were not influenced by the amount of daylight. Throughout the entire study period, it was observed that the children in C10 had the highest diurnal melatonin levels by comparison with those in the other three classrooms. Unlike the others, the children in C09 had the lowest concentrations. Since the contribution of daylight to the lighting of C09 and C10 was comparatively more extensive, the accuracy of the results should be questioned and interpreted cautiously. It is important to emphasise that more than forty per cent of participants' saliva specimens could not be analysed for determining melatonin concentrations because of the possible storage-related deterioration of the samples during the period between their shipment and laboratory analysis. Although the salivary specimens were collected and stored in accordance with the recommendations of experts (see Section 3.3.4), the remaining percentage of the salivary samples might also be detrimentally affected by the adverse storage conditions. Therefore, the quantitative estimates of salivary melatonin are likely to be inaccurate and misleading.

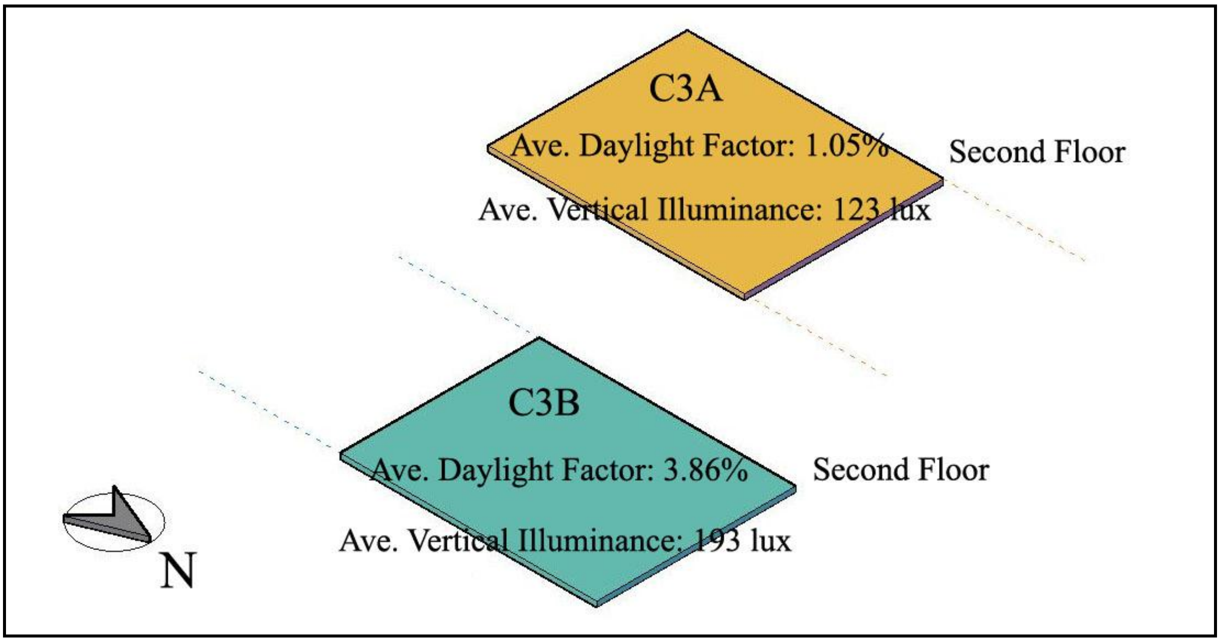

Figure 6.2 The locations, average daylight factors and average vertical illuminances of the classrooms in the supplementary field study

Drawing upon the fact that the activity of the HPA axis is regulated by the suprachiasmatic nucleus (Nicolson, 2008) and the prevailing opinion that melatonin is an endogenous synchroniser (Claustrat *et al*., 2005; Geoffriau *et al*., 1998), it is very plausible to think that there ought to be a detectable relationship between the presence of daylight and the physiological rhythm of cortisol. Surprisingly, in sharp contrast to my inference, there was not a notable or meaningful involvement of daylight and its quantity reaching participants' eyes in children's diurnal cortisol profiles. Even though the occupants of C09 and C10 could expose themselves to more daylight and vertical illumination, they had relatively lower cortisol levels during the entire study. While the children in C09 had concentrations comparatively higher than those in C03 and C10, the participants in C10 had the lowest levels. Since the same salivary specimens were utilised for measuring both melatonin and cortisol fluctuations, it is necessary to consider that the possible degradation of the samples may account for the peculiar cortisol findings. Compared with the normative data for preadolescent children from four to ten years of age (McCarthy *et al.*, 2009), the salivary cortisol levels of my study population are worryingly low and, thus, likely to be erroneous. An indication of the substantial difference is that the early morning levels of my participants are almost two-fold lower than the corresponding normative values.

Our innate preference for the natural environment which cradled us for over two million years should not be a revelation to us. Another likely role of our primeval environment is that most of the adaptive changes in the human species, including those of the mind, were in response to the features and demands of that environment. Therefore, it seems reasonable to infer that we need to adopt a design approach seeking reconciliation with daylight in order to assure our well-being in the modern urban built environment. Unsurprisingly, my own research findings, which parallel those of the preceding assessments (Kaida *et al.*, 2006; 2007), confirm my inference. In spite of the fact that there was not any remarkable difference regarding daytime sleepiness, it was revealed that the occupants of C09 and C10 were in a more positive mood state than those of C03 and C04, possibly because of the provision of some additional daylight illumination. As to the inference, the findings from the supplementary field study were more encouraging. The children in C3B, which had the advantage of receiving considerably more natural light at eye level, reported significantly better overall mood and less daytime sleepiness than the other group of children.

As it was discussed earlier in this chapter, the primeval, or natural, environment of our ancestors might be central to the development of our mind and cognitive tools. Therefore, it is equally possible to contemplate that the innate cognitive abilities of the human mind are heavily reliant upon perceiving and responding life and life-like processes, such as the continuous progression from light to darkness. In other words, living in intimate contact with nature, including natural light exposure, is essential to maintain or restore our mental capacity or performance. In the light of the findings of Wells (2000) concerning the favourable effects of living in a place with more natural or restorative resources on children's cognitive functioning, it is prudent to consider that the potential benefits of daylight may be substantial, especially during middle childhood[*], a period of immense cognitive growth and children's initial engagement with formal learning (Cincotta, 2008). In this regard, there is direct evidence that natural light undoubtedly contributes to preadolescent children's scholastic achievements (*e.g.*, Heschong *et al.*, 2002; Nicklas and Bailey, 1996).

Is daylight a potent stimulus for promoting our cognitive skills? On the basis of the currently available research results, it can be concluded that there is a certain connection between natural light and the cognitive abilities of school-age children. Unsurprisingly, the findings from both of my field studies affirm the general validity of this assumption. Despite the fact that the difference between the classrooms with and those without good access to daylight was not statistically significant, it was observed that the children in C09 and C10 were more successful in learning at school than those in the other two classrooms during the main field study. Correspondingly, the findings from the supplementary field study further support my assumption. The students in C3B were comparatively, but not significantly, more successful in mathematics and language learning than those in C3A, very likely due to copious amounts of natural light reaching their eyes. Additionally, a possible statistically significant effect of daylight on science achievement was detected. Unlike the performance of the children in C3B, the scholastic performance of the other group was considerably impaired throughout the study period.

A critical review of my results may raise the question whether the differences in school achievement are attributable to natural light or the assignment of comparatively more skilled teachers to the classrooms with better daylight availability. In an attempt to answer this question, the administrators of both schools were interviewed. They assured that there was no obvious mechanism or practice of assigning "better" teachers to the classrooms admitting more daylight and also stated that their students were not separated according to any performance-related criteria. Therefore, it seems that the teachers and students are less likely to account for the observed differences. Due to the inconclusive and contradictory research findings from both laboratory and field studies (*e.g.*, Knez and Enmarker, 1998), some may also question the validity of the general assumption that the lighting condition being experienced influences cognition via mood. However, based on the results with regard to mood and performance, it is tenable to think that natural light exposure can affect mental functioning via mood.

[*] Children from five years of age to the beginning of puberty are considered to be in middle childhood (Cincotta, 2008).

By considering biophilic needs as an adaptive end product of man's biological and mental evolution rather than as a vestige of our ancient past, we can argue that the satisfaction of our biophilic urges is closely related to the health and productivity of humankind. Unfortunately, the existing approach to the design of our new man-made environment has encouraged the massive transformation and degradation of the natural environment and provoked the alienation of humans from nature. According to my view, the possible assumption that human progress and civilisation is measured by our separation from nature is an erroneous and a dangerous illusion. We may think that we can jettison natural systems and processes with impunity, but we cannot. Although this statement is based on my interpretation of the indirect evidence from the aforementioned studies on daylight, a number of studies (*e.g.*, Hoffmann *et al.*, 2010; Kahn *et al.*, 2008; Wirz-Justice *et al.*, 1996), including my own work, have clearly shown that the technologically oriented world in which we are living today is very unlikely to substitute for nature and its components such as natural light.

Before our first introduction to incandescent lamps and electric lighting at the end of nineteenth century, daylight per se was an essential environmental component of human life for many centuries. Since the emergence of incandescent lamp technology, our species' long-standing contact with natural light has begun to change. Electric lighting has become an integral part of modern-day life and a substitute for daylight. However, we should not be fooled into thinking that artificial illumination is capable of simulating the basic characteristics of solar radiation, such as its variability over time, and equally effective in eliciting non-visual responses. In addition to the findings from the above-mentioned studies, those from my main field work provide further evidence for the uniqueness and significance of natural light. As opposed to my initial expectation that the dynamic lighting system in C09 could compensate the lack of solar exposure, especially in winter, and might influence both diurnal and seasonal patterns of various biological and non-biological processes, there was no measurable effect of the lighting system providing approximately ninety-six per cent more artificial light at eye level. In fact, the children in C10, the classroom admitting comparatively more daylight at eye level and containing a conventional electric lighting system, were more successful and reported better sleep quality and mood than those in C09 throughout the study. Therefore, in the light of these findings, it can be concluded that we, as human beings, need to live in intimate contact with nature and its features such as natural light at all times in order to assure our physical and mental well-being in the modern urban built environment.

In spite of the fact that there is not a discrepancy between my results and those of the other investigators, the reliance upon children's self-reports may seem to be a shortcoming of my research and obscure the true association between daylight and well-being. On the contrary, it is believed that it does not impose any limitation. Since the utilisation of children's own assessments for drawing empirical research conclusions presumes that children are able to be self-aware, understand the concept under investigation, comprehend the nature of their task and provide reliable reports (Rebok *et al*., 2001), one may expect that, due to their limited cognitive abilities (Cincotta, 2008), children are incapable of responding appropriately to self-report measures. Conversely, there is convincing evidence that school-aged children can reliably report on their own well-being. It has been demonstrated that children as young as eight years of age are able to give accurate information on their current and retrospective perceptions of their general health and emotional experience (Chambers and Johnston, 2002; Laerhoven *et al*., 2004; Rebok *et al*., 2001). Therefore, it is more than likely that the responses of the participants were truly reflective of their accurate beliefs and perceptions concerning their sleep quality, mood and sleepiness.

If we accept that humans possess a fundamental need to affiliate with natural systems and processes, including daylight, for avoiding discords and promoting survival, the question arises as to why we deforest, extinguish other species, beget pollution and create impoverished environments devoid of nature. A clear indication of this contradiction was given by Xueyuan and Yu (1988). They stated that, throughout the city of Shanghai, an area of approximately 2,000,000 m^2 was covered by various types of subterranean buildings in the 1980s. As regards lighting design and application, one of the possible explanations is that the non-visual aspects of light, primarily electric lighting, have caught lighting experts' and other specialists' attention only recently. Even though, for a long time, it has been known that there is a general trend of preference for natural light, the delineation or depiction of the effects of daylight on our physical and mental functioning is relatively new. In addition, given the relative novelty of the subject, both lighting design guidelines and lighting standards are not adequately or properly concerned with the association between natural light exposure and the non-visual responses of the human mind and body (Boubekri, 2004). For example, according to the authors of the SLL Lighting Handbook, daylight "is just another source of electromagnetic radiation… [that] may have benefits for human well-being" (Boyce and Raynham, 2009, p. 129). Therefore, the lack of solar exposure in urbanised societies and its deleterious non-visual effects on us can be attributed to the current recommendations based primarily on visual system requirements. It is evident from the preceding paragraphs that adequate natural light exposure is a necessity rather than an amenity. Accordingly, it is believed that lighting practitioners should not wait indefinitely for more robust research results and hesitate to make bold statements about daylight. They need to implement the existing findings and adapt the present-day recommendations for promoting our general well-being.

Despite the fact that there is a clear exigency for additional research in order to deepen our understanding of the systemic effects of daylight in humans, the research into the causal relationship between natural light and general well-being has generated sufficient scientific evidence supporting the following design recommendations:

- Since the vast majority of us prefer daylight to electric lighting and highly value having a window in the immediate vicinity, the design of subterranean and windowless environments should be avoided as far as possible.
- The evidence linking the adequacy of natural light exposure at eye level (*i.e.*, daylight reaching the human eye) to substantial improvements in physical and mental functioning underlines the importance of giving careful consideration to building orientation and site planning in architectural designs. Therefore, new buildings need to be designed and sited to ensure that they provide enough daylight for all building occupants and do not shade adjacent structures.
- In addition, designers should avoid deep floor plans reducing natural light penetration and increasing the dependence upon electric lighting for the benefit of building occupants. Moreover, the provision of daylight through fenestration systems needs to be maximised in buildings that are occupied mostly during the day (e.g., schools) without causing either discomfort or privacy issues. As in the current standards[*], recommending window areas or percentages is a misleading criterion since it does not necessarily indicate the actual presence of natural light within a building.
- It has been demonstrated that the technologically oriented world in which we are living today is a poor substitute for our EEA. Therefore, in order to meet our biophilic needs, we need to replace electric lighting with daylight whenever possible. It is very unlikely that new electric lighting technologies can benefit man as much as the sun and its light.

Taken overall, it can be concluded that we have to adequately expose ourselves to the natural cycles of light and darkness at all times for minimising the risk of discords and deduced that the beneficial effects of natural light exposure on the overall quality of our lives

[*] For example, in BS 8206: Part 2, it is recommended that the minimum window area should be the twenty per cent of a window wall for a room measuring less than 8 meters in depth and thirty-five per cent of a window wall for a room deeper than 14 meters.

are not confined to a specific time period. Furthermore, it is reasonable to infer that it is a fallacy to consider or provide electric lighting as a surrogate of natural light. There is ample evidence that, in comparison with electric lighting, daylight is very potent and unique stimulant to numerous physical and mental processes in humans. Since we spend most of our time indoors for producing, studying and working, it should be acknowledged that the proper integration of daylight in building design by means of thorough lighting recommendations is extremely important.

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Appendices

Appendix 1.1:

Date: ☐☐☐☐☐☐ . . . . ☐☐

Is it hard for you to go to bed?

Usually (5-7 times/week)	Sometimes (2-4 times/week)	Rarely (0-1 time/week)
☐	☐	☐

Do you fall asleep in about 20 minutes?

Usually (5-7 times/week)	Sometimes (2-4 times/week)	Rarely (0-1 time/week)
☐	☐	☐

Do you wake up at night when your parents think you're asleep?

Usually (5-7 times/week)	Sometimes (2-4 times/week)	Rarely (0-1 time/week)
☐	☐	☐

Do you have trouble falling back to sleep if you wake up during the night?

Usually	Sometimes	Rarely
☐	☐	☐

Do you have trouble waking up in the morning?

Usually (5-7 times/week)	Sometimes (2-4 times/week)	Rarely (0-1 time/week)
☐	☐	☐

Do you feel rested after a night's sleep?

Usually (5-7 times/week)	Sometimes (2-4 times/week)	Rarely (0-1 time/week)
☐	☐	☐

Appendices

Appendix 1.2:

Tarih: ☐ | Kod numarası: | Sınıf: ☐☐

Senin için yatağa gitmek zor mudur?

Genellikle	Ara Sıra	Nadiren
(Haftada 5-7 defa)	(Haftada 2-4 defa)	(Haftada 0-1 defa)
☐	☐	☐

Yaklaşık 20 dakika içinde uykuya dalar mısın?

Genellikle	Ara Sıra	Nadiren
(Haftada 5-7 defa)	(Haftada 2-4 defa)	(Haftada 0-1 defa)
☐	☐	☐

Ailen seni uykuda zannederken, geceleyin uyanır mısın?

Genellikle	Ara Sıra	Nadiren
(Haftada 5-7 defa)	(Haftada 2-4 defa)	(Haftada 0-1 defa)
☐	☐	☐

Eğer geceleyin uyanıyorsan, uykuya tekrar dalmakta zorluk çekiyor musun?

Genellikle	Ara Sıra	Nadiren
☐	☐	☐

Sabahleyin uyanmakta zorluk çekiyor musun?

Genellikle	Ara Sıra	Nadiren
(Haftada 5-7 defa)	(Haftada 2-4 defa)	(Haftada 0-1 defa)
☐	☐	☐

Gece uykusundan sonra, kendini dinlenmiş hissediyor musun?

Genellikle	Ara Sıra	Nadiren
(Haftada 5-7 defa)	(Haftada 2-4 defa)	(Haftada 0-1 defa)
☐	☐	☐

Appendices

Appendix 2.1:

Date:

☐☐☐☐☐☐ . . . . ☐☐ ☐

	YES	yes	no	NO
At the moment, I am feeling sad	☐	☐	☐	☐
At the moment, I feel like laughing	☐	☐	☐	☐
At the moment, I am having great fun	☐	☐	☐	☐
At the moment, I am in a bad mood	☐	☐	☐	☐
At the moment, I am feeling grouchy	☐	☐	☐	☐
At the moment, I am feeling grumpy	☐	☐	☐	☐
At the moment, I am feeling cheerful	☐	☐	☐	☐
At the moment, I am happy	☐	☐	☐	☐
At the moment, I am angry	☐	☐	☐	☐

Appendices

Appendix 2.2:

Tarih:	Kod numarası:	Sınıf:	Zaman:

7 Şu anda, kendimi üzgün hissediyorum	EVET	evet	hayır	HAYIR
2 Şu anda, gülecekmiş gibi hissediyorum	EVET	evet	hayır	HAYIR
4 Şu anda, çok eğleniyorum	EVET	evet	hayır	HAYIR
5 Şu anda, kötü bir ruh hali içerisindeyim	EVET	evet	hayır	HAYIR
6 Şu anda, kendimi huysuz hissediyorum	EVET	evet	hayır	HAYIR
8 Şu anda, kendimi aksi hissediyorum	EVET	evet	hayır	HAYIR
1 Şu anda, kendimi neşeli hissediyorum	EVET	evet	hayır	HAYIR
3 Şu anda, mutluyum	EVET	evet	hayır	HAYIR
9 Şu anda, sinirliyim	EVET	evet	hayır	HAYIR

Appendices

Appendix 3.1: