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Measuring the effect of pro-cognitive light on the performance of secondary school students in comparison to a control student group

Research report – brief version

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1 MOTIVATION

Natural daylight and sunlight have a significant effect on the human body. Periodic alternation of light and dark on the Earth has always reliably informed living organisms about whether it is day or night and hence, if they should be prepared for activity or rest. The high proportions of the blue and azure components in the daylight spectrum synchronise the body's internal clock [1, 2], thereby supporting attention and the ability to concentrate and learn things, and helping people achieve high productivity. Towards the evening then, the warmer colour and low evening light intensity stimulate the body to produce the hormone melatonin. A high night melatonin level in the body promotes quality sleep and better body recovery. If, however, the amount of bright daylight is inadequate, the contrast between the day and night is low. The clock inside the human body may then be imprecise and the signals sent by it to the body unclear, weak and chaotic, and the 24-hour internal clock, called the circadian rhythm, may be disturbed. With people today staying inside buildings 90% of their time, with limited access to natural daylight, the inadequate amount of bright light may adversely affect sleep, mood, cognition, work performance and human health, both physical and mental [3, 4]. Scientific studies also document the greater importance of synchronisation of the internal biological clock in adolescents, whose bodies are undergoing many hormonal changes during that age [5].

Legislation stipulates [6] that daylight must be the primary source of illumination in workplaces and classrooms. Frequently, however, daylight cannot be provided during the entire time the area is used. It is, in particular, during the morning hours and during the winter months that daylight is unavailable. Or conversely, sunlight may be so intense that it disturbs visual or thermal comfort and must be shielded and augmented with artificial light. Common light systems, however, do not always attain the required intensity and/or spectral quality of illumination. For artificial light to efficiently replace natural light, it should include all wavelengths of the effective region of the visible spectrum so that all photoreceptors in the eye are uniformly stimulated. Of special importance in support of wake and circadian synchronisation are adequate proportions of the blue and azure spectral components, which control the timing of body activity and body recovery. Light with such parameters can be referred to as pro-cognitive (cognition-supportive).

2 RESEARCH OBJECTIVES

This study examined the difference in the action on the human body between common artificial lights and the light of specific pro-cognitive light panels manufactured by Spectrasol, s.r.o.

The primary endpoint was the effect of light in the classroom on the visual comfort and cognitive abilities of the students and teachers and the long-term effect on the study results and students' absence from school lessons. The research was aimed at testing the hypothesis that students exposed to pro-cognitive light will have better study results and will be healthier and more satisfied than students in the control group. All the parameters were measured both during summer and during winter, i.e., during periods of sufficient and insufficient amounts of light, respectively. The effect of the artificial light quality was expected to be more significant during winter than during summer. The subjective feeling of satisfaction and visual comfort were also investigated in the teachers. The secondary goal of this research was to use the information thus obtained to set up documents serving the future education of students and teachers regarding the effect of light on humans and the importance of light hygiene. This research is also expected to provide a basis for future continuing research in this area.

3 EXPERIMENT DESIGN

This research project was designed and implemented by the Platform for Healthy Light, University Centre of Energy-Efficient Buildings, Technical University in Prague. Two general upper secondary schools were engaged in the project: the Na Pražačce Grammar (NPG) and another grammar school in Prague where the parameters matched those of the NPG and whose students constituted the control group (CON). Spectrasol, s.r.o. installed their pilot pro-cognitive LED light panels in 13 NPG classrooms and in one teacher's room in summer 2018. The original common fluorescent lighting was replaced with pro-cognitive LED panels, which emit light with uniform proportions of all wavelengths across the central region of 450-650 nm, with a maximum deviation of ±15% (full spectral light). The chromaticity temperature was chosen to be 4,500 K as the areas were solely used during the day. The illuminance level in the classrooms was also increased (about 800 lx on a reference horizontal plane). The original linear fluorescent tubes within CON were retained, whereby the light was similar to that in the majority of Czech secondary schools. In order to avoid the placebo effect, the students and employees of both schools were told that the lights in the rooms had been replaced.

The measurements were made in normal classrooms (for 30 students, approximately 7 x 11 m in size) and in small language-teaching classrooms (for 15 students, approximately 4 x 7 m in size), ceiling height 4 m, windows facing the south and fitted with interior shading systems (Venetian blinds in the NPG and curtains in CON). 50 students were engaged in each of the two schools. The groups contained students of comparable age (16 to 17 years) and none of the students was in the first or last grades. The NPG students were exposed to the pro-cognitive light for a minimum of 40% of the time they spent in the school. The measurements (testing) were always made in the second teaching hour in the same week at the two schools, at the end of the winter semester and the summer semester, i.e., at times when grading is being completed and hence, the students are exposed to a high mental burden. The light conditions were measured in parallel and the biological effectiveness of the light was determined. In order to evaluate the long-term effects, the research was completed with year-on-year comparison of the study results at the NPG (n = 500) and short-term absences from / late arrivals at the school (n = 200). Furthermore, a questionnaire survey was organised among the teachers of both schools (n = 60).

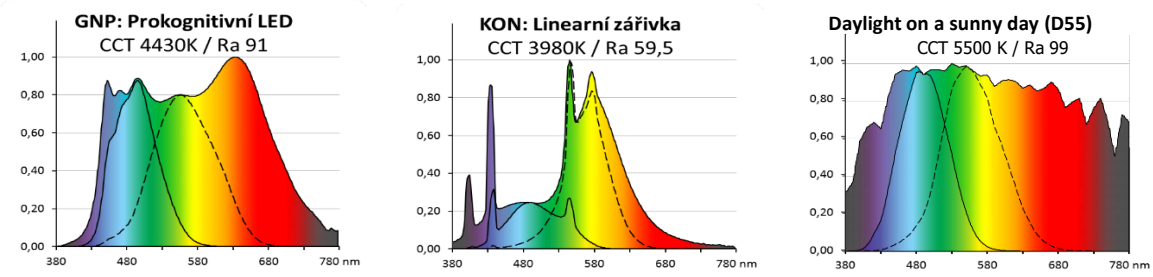
Data was evaluated in cooperation with the University of Economics in Prague, Department of Statistics and Probability. The results were analysed, in particular, by using descriptive characterisation and, where appropriate, by comparison of the observations in the relevant parameters. No complex regression models were used. Statistical significance was determined by non-parametric Wilcox paired tests (differences in the time for the same students) and two-sample tests (between different students at the same time). For a comparison between the groups, the confidence intervals were processed with Bonferroni correction with multiple comparisons (4 pairs). The mean (median) data was completed with variabilities (fluctuation, volatility).

4 MEASUREMENT RESULTS

The effect of the environment on a human must be assessed from the physical aspect (light quality and quantity, light distribution in the area, air quality, etc.) and with respect to the objective performance parameters (current cognitive performance, study results) and to the subjective assessment by the users, students and employees.

4.1 Colour rendering quality and the light spectrum

The standard governing the illumination of areas for long-term residence requires the colour rendering index to be Ra 80 as a minimum. The initial light source at the NPG and also the light sources at CON attained Ra 60, which actually fails to meet the requirements of the standard but is a situation commonplace in the classrooms of Czech school buildings. The new light system at the NPG attains Ra 91, the observed spectral composition is shown in Figure 1.



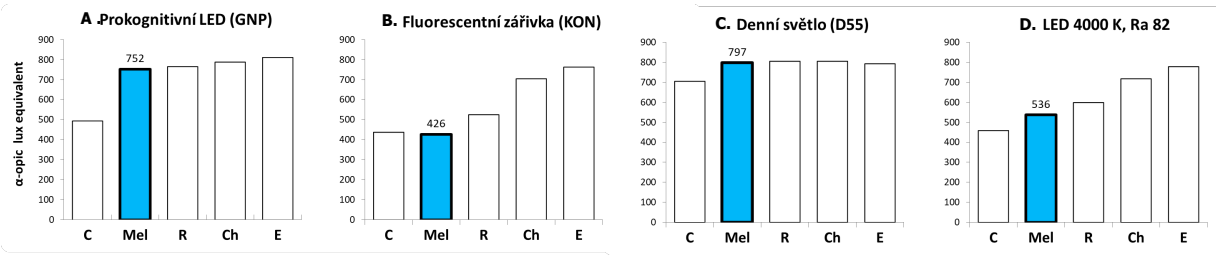
NPG: Pro-cognitive LED CON: Linear fluorescent tube Daylight on a sunny day

Figure 1: Spectral composition of the light in the classrooms, measured on the horizontal plane of a bench during the testing; solid line = CIE melanopic illumination, dashed line = photopic curve – vision

The quality colour rendering by the newly installed system is enabled by the good uniformity of the light colour spectrum. The **deviation** in the proportions of the **450-650 nm wavelengths does not exceed ±13.5%** at the NPG. This approaches daylight nicely. For a comparison, the relevant wavelength deviation at CON in the given interval is ±65%.

4.2 Biological effectiveness

Spectral measurements made during the winter months, when artificial light is predominantly used, showed that despite the comparable illuminance level of Ev = 800 lx (measured on the horizontal plane of a student's bench) the melanopic illuminance at the height of a sitting student on a vertical plane $s_{mel(\lambda)}$ is 405 melanopic lux at the NPG and a mere 245 melanopic lux at CON. **Hence, when compared to the biological effectiveness of daylight on a sunny day** (D55 standard) the **pro-cognitive illuminance at the NPG attains 94% of the natural light efficiency**, while the matching figure at CON (at the same horizontal illuminance) is a mere 53%, and the commercially available LED sources (4,000 K, Ra>80) typically lie at levels ≤70%, see the blue column in Figure 2 showing the sensitivity of the melanopsin receptors, dominant in non-visual light perception, e.g., for synchronisation of the circadian rhythms. A well-balanced spectral light composition of a pro-cognitive light source, with **high proportions of the blue and azure spectral components**, is a **key parameter** for attaining the desired favourable effect on **cognitive performance** and **endurance** and, particularly during early morning lessons, for good **synchronisation of the circadian system**.



Pro-cognitive LED (NPG) Fluorescent tube (CON) Daylight (D55)

Figure 2: Relative α-opic efficiencies of the light sources on the various photoreceptors in the eye (left to right: cyanopic, melanopic, rhodopic, chloropic, erythropic illuminance) at the school tested (NPG) (A), at the control school (CON) (B), daylight on a sunny day (C), and an example of a typical common LED source (D).

4.3 Subjective assessment of the light environment

Subjective assessment of the light environment was obtained through questionnaires in which the students and teachers showed the score (on a line between two extreme points) of their current mental and physical status and the score of the room in which they were currently present. Based on the results, small classrooms were exempt from the analysis. The poorer air quality due to the smaller room volume and the darker wall colour created a less comfortable environment and potentially distorted the results of the subjective assessment, which was primarily aimed at the illumination. The **pro-cognitive light** in the NPG classrooms during the winter months was **subjectively assessed as more pleasant** than the light in the CON classrooms. Although the illuminance of the surfaces was comparable between the NPG and CON classrooms, the CON group assessed the area as over-illuminated more frequently than the NPG group. No significant difference between the NPG and CON was observed in the students' subjective assessment of their visual acuity. However, the age of the subjects appeared to be a significant factor in the visual acuity test (reading of consecutively smaller and smaller text): while no differences were detected in the age-homogeneous student group, the **visual acuity** (ability to read small-font text) **of the teachers was poorer the higher their age**. The smallest text was assessed as easily readable by 60% of students and by a mere 30% of teachers. The assessment of the natural colour rendering differed significantly between the male and female subjects. On the whole, females considered typical lighting during the winter months as less natural. This higher sensitivity to colour rendering is in accordance with the greater ability to discern between different colours which has been demonstrated in women.

4.4 Students' cognitive efficiency – memory/concentration tests

The objective efficiency of the students was tested by means of 2 cognitive test types. The sustained attention test was used to examine the speed of decision-making and the ability to concentrate on solving a time-limited problem requiring the subject's attention. The task for resolution by the students was, during limited periods of time, to repeatedly find signs possessing certain properties among a series of signs. The second test was used to assess short-time memory quality. The students were required to remember certain abstract graphical images and specific terms – words. Then they were invited to answer related questions.

The **season of the year appeared to be a significant factor.** In all the tasks the students in the control group had **markedly poorer results during the winter months** than during the summer months. The winter months constitute a period during which natural daylight is available at a lower intensity and for a limited time which, in addition, the students spend indoors, in classrooms. This is the time when the effect of artificial light plays a major role. This is apparent in comparison with the results of the NPG students exposed to the pro-cognitive light: there was nearly no decrease in the test results during the winter months, as demonstrated by Figure 3.

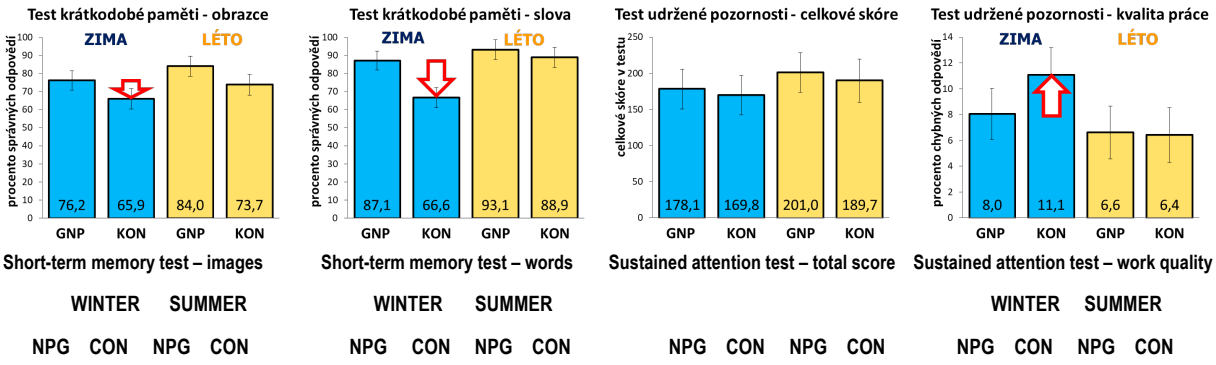


Figure 3: Comparison of the cognitive test results between the NPG and CON students The arrows point to a significant difference – performance decrease during the winter season occurring in classrooms with typical light from common sources, but not in classrooms with the pro-cognitive light.

Short-term memory tests

The memory tests were aimed at examining the ability to remember and recall simple terms and abstract signs. The results attained by CON students during the winter season, with the dominant effect of artificial light, were appreciably poorer than those attained during the summer season. This difference was far from being that marked in the NPG students. Specifically, the NPG students attained an average of 80% correct answers in an aggregated memory test during the winter season, compared to 65% correct answers attained by the CON students. By contrast, the results attained by the two groups in the summer season were comparable – 87% and 81% correct answers for the NPG and CON groups, respectively. This applied study thus supported in everyday practice the laboratory-proven fact that the human body perceives a deficit of daylight during the winter months. **Pro-cognitive light** is a **successful tool in the prevention** of this **deficit** and the **performance of students exposed to light of this type approaches that attained during the summer months**.

Concentration ability tests

The speed of work (percentage of signs processed) and the quality of work (percentage of errors) were independently evaluated from the concentration ability tests. The overall test result was evaluated using a validated methodology. The resulting score does not differ appreciably between the groups, if the quality of work is assessed (percentage of errors in the test), the situation is similar to that in the memory test. While the results are comparable between the groups during the summer testing, **in the winter season the NPG students made appreciably fewer errors and correctly recognised more signs than the CON students**. This once again implies the **favourable effect of the pro-cognitive light,** which is able to replace daylight during the periods of natural daylight deficit.

4.5 Year-on-year comparison – classification and absences from school

The statistical year-on-year comparison used data sets from 2 consecutive years at the NPG. The data from the first of the two school years (2017/18) was regarded as reference data. The lights were replaced in roughly one-half of the classrooms during summer 2018. The data from the next school year was regarded as post-intervention data. The data of all NPG students was included.

Classification

The analysis encompassed data of over 500 students during 2 years. It was found that the **installation of the pro-cognitive lights** resulted in a **statistically significant year-on-year improvement in the overall student results during the winter months**, see Figure 4. This statistically significant improvement in the mean achievements was found for mathematics, history, civics, physics and German/French. No significant change was observed in the Czech or English language.

The year-on-year change was less marked in the summer semester, but it was statistically significant in mathematics. i.e., in a subject with a higher engagement of the logical functions.

Pololetí	n	Průměrný prospěch	
		průměr	SD
ZS_2017/2018	515	2,35	0,651
LS_2017/2018	515	2,33	0,650
ZS_2018/2019	510	2,22	0,604
LS_2018/2019	517	2,30	0,638

*

Term	n	Mean study result	
		Mean	SD
Winter term 2017/2018	515	2.35	0.651
Summer term 2017/2018	515	2.33	0.650
Winter term 2018/2019	510	2.22	0.604
Summer term 2018/2019	517	2.30	0.638

Figure 4: Mean study results of the NPG students The asterisk marks a statistically significant difference.

Total missed classes and late arrivals

The documented late arrivals were compared before and after installation of the new lights and a year-on-year decrease was found for the NPG students during summer. The difference in the winter season was not significant. This result can be interpreted as a consequence of a better ability to concentrate in the early morning after waking up. This is believed to be a long-term effect of better-quality light during the day and its better availability during the preceding months. So, this observation can be considered to constitute another indicator of the favourable effect of the new light system.

4.6 Feedback from the teachers

The teachers contributed feedback to the research. They considered the new light system in the NPG rooms a commendable contribution in aspects such as the legibility of text on the blackboard and the presence of disturbing light reflections/flashes. Those teachers who spend more time teaching in classrooms with pro-cognitive lights have a tendency to assess the light as more pleasant overall. Teachers who wore glasses were also appreciably more satisfied with the new lights. So, the pro-cognitive light system offers greater visual comfort, which is especially appreciated by people with poorer vision.

5 CONCLUSION

It has been demonstrated by a number of research studies that natural daylight supports students' current attention, working performance, mood, ability to concentrate and to learn new things and, in the long term, also the quality of sleep and well-being [8]. A new light system was installed in the classrooms of the Na Pražačce Grammar school in summer 2018. This system emits full-spectrum, pro-cognitive light with well-balanced proportions of all wavelengths within the spectral region of 450-650 nm and with specific emphasis on the biologically activating blue and azure components of the spectrum, similar to natural daylight. Owing to this, the relative melanopic efficiency of this light approaches that of natural daylight and is able to provide a high-quality light environment in areas where there is a deficit of natural light. Despite the significantly increased sustained illuminance and improved light quality, the power consumption of this new system was 15% lower than that of the original system.

The effect of the pro-cognitive light on the secondary school students and teachers was monitored for a whole year after the installation. A number of factors were evaluated by the research team: subjective assessment via questionnaires, objective results of cognitive efficiency and endurance tests, study results, students' missed classes and late arrivals, and students' and teachers' chronobiological data. In parallel, the team monitored the light environment, air quality in the classrooms and certain other parameters. For unbiased evaluation of the effect of the light, the data of the students of the Na Pražačce Grammar school, where the pro-cognitive light system had been installed, was compared to those of a control student group at a reference (comparable) grammar school. Available statistical data showed that the study results attained by students at the two schools before initiating the project was comparable.

The results of this research study provided unambiguous evidence of the favourable effect of pro-cognitive light. The students in the control group, who had normal commercial light systems in their classrooms, showed a significant worsening of most of the assessed parameters during the winter months, i.e., at a time of natural daylight deficit. This daylight deficit brought about poorer cognitive performance and endurance. The subjective assessment of the light environment quality was also lower. This adverse effect was not observed in the students of the Na Pražačce Grammar (NPG) where the daylight deficit was effectively made up for by the artificial pro-cognitive light. Compared to the situation before the installation, the NPG students also exhibited statistically significant improvements in their study results and lower numbers of late arrivals at the school. This can be interpreted as a result

of stabilisation of the biological body clock rhythm, accomplished owing to the better everyday system stimulation by the high-quality bright light.

Teachers particularly appreciated the greater visual comfort in the classrooms with the pro-cognitive light system. They pointed to the better legibility of text on the blackboard and fewer disturbing light reflections. The beneficial effect of the higher illuminance and better light spectrum was marked particularly in individuals with poorer vision, either due to greater age or to a vision defect. The teachers also reported that those of them who did not have this pro-cognitive light system installed in their teachers' rooms, transferred (as far as possible) their activities to rooms with the new lights.

This study provided evidence that where there is a deficit of natural daylight, installation of a pro-cognitive light system is an advisable approach. The system used is currently the most suitable substitute for natural daylight. This system mitigates the adverse consequences affecting students during the winter months of the year because of their isolation from the natural synchronisers of the circadian rhythm – in this case high-intensity daylight.

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