Advances in Social Sciences Research Journal – Vol. 11, No. 5
Publication Date: May 25, 2024
DOI:10.14738/assrj.115.16943.
Nosko, M. (2024). The Effect of Bio-Optimised Light In the School Environment on The Cognitive Functions of Pupils. Advances in Social Sciences Research Journal, 11(5). 236-253.

The Effect of Bio-Optimised Light In the School Environment on The Cognitive Functions of Pupils

Martin Nosko
Faculty of Psychology, Pan-European University

ABSTRACT

The article discusses the impact of bio-optimised lighting in school environments on the cognitive functions and abilities of pupils. The article presents the results of foreign research in the field, as well as the initial findings of the authors' research conducted in a school. The research findings confirm a statistically significant relationship in the context of light and cognitive functions such as attention, thinking, problem-solving, and personal pace. The results suggest that in today's schools, more attention needs to be paid to the quality of lighting in classrooms. This is crucial if we want future generations to have the opportunity to spend time in a wholesome school environment and to be provided with a comprehensive, supportive, and developmental educational process.

Keywords: school environment, pupil education, bio-dynamic light, cognitive functions

INTRODUCTION

Assessing the performance or mental health of pupils and teachers in schools requires knowledge. This is only possible once we understand the influence of all the components and factors present in and interacting with the school environment. In psychology, we focus on the mental health levels of pupils and school staff, taking into account cognitive, emotional, and social aspects.

Children spend more time at school than anywhere else, even more than they do at home environment. Pupils attend school for approximately 200 days a year, with 70% of this time spent in classrooms. In Europe, there are more than 64 million pupils and almost 4.5 million teachers who spend many hours a day in kindergarten, primary, and secondary schools (Baloch et al., 2021). Breaking the phrase 'many hours' down to its smallest words, pupils and teachers are in classrooms for approximately 1,120 hours, which is equivalent to 67,200 minutes, during a school year. In reality, teachers and especially children spend almost 16 years of their lives on school premises from the start of kindergarten to the end of secondary school, which is approximately 17 920 hours or 1 075 200 minutes. Therefore, understanding and equipping the school environment, especially the classroom setting, is crucial to ensuring the well-being and success of future generations. It is well known that the indoor classroom environment has an impact on the performance and social relationships of pupils. The indoor environment includes the classroom's equipment with teaching aids, as well as its size, sufficient oxygen, and high-quality lighting. From this perspective, lighting receives the least attention. This article aims to emphasise the significance of light and illumination for all individuals in schools, particularly focusing on its impact.

Light Sources and Their Parameters

The Sun as The Primary Source of Light:

Several components are necessary for life as we know it to exist. These include water, air, and the Sun or light. Light is considered to be biologically active and to impact all life on Earth's surface, including humans. The Sun, as its primary source, contains several physical components. These consist of wavelengths measured in nanometres (hereafter referred to as nm) and are perceived by the general public as colours (rainbow). The Kelvin (K) unit is used to measure the temperature of these colours, while the Lux (lx) unit indicates the intensity of the illumination. These three quantities are sufficient for us to understand the difference between outdoor and indoor environments (Solt et al., 2017). Lighting companies work in a similar manner when developing artificial lighting.

It should be remembered that the primary source of light throughout the evolution of mankind has been the Sun. Based on the Earth's rotation, diurnal and nocturnal species have evolved. As a diurnal species, humans have always been and will always be attracted to light. Without it, individuals will never be able to perform to their maximum potential and utilize the capabilities that our bodies offer us.

Daylight under clear skies contains all wavelengths, making it full-spectral (Figure 1). The colour temperature of the light is typically around 5000 to 5500 Kelvin, and its radiant power varies depending on the season. In the bright part of the year (spring-summer), it is around 100,000 lux (Aarts et al., 2017).

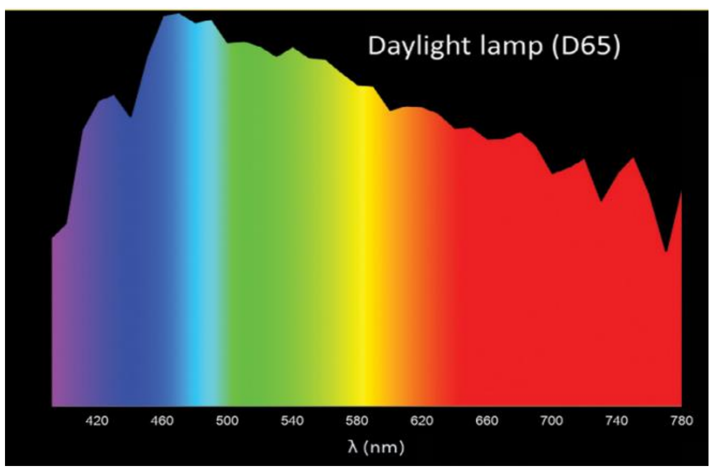

Figure 1: Spectral colour composition of daylight measured in nm

Source: Adapted by the author from Aarts et al. (2017).

The Rise of Modern Society: The First Source of Artificial Light:

The first major breakthrough in human history was the invention of Edison's light bulb and the onset of the industrial period. Thanks to this discovery, humans were able to access the interiors of buildings. The colour spectrum of this light is similar to that of the newer halogen bulb (Figure 2) (Aarts et al., 2017).

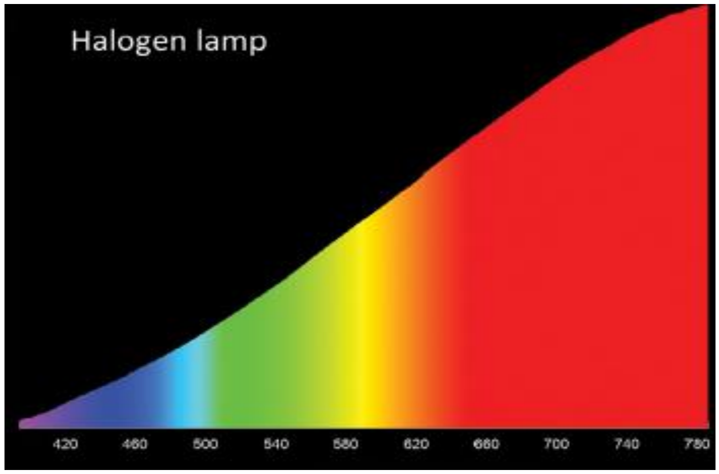

Figure 2: Halogen bulb

Source: Adapted by the author from Aarts et al. (2017).

Fluorescent Lighting - The Technology of the 20th Century:

In the 1930s, fluorescent lighting began to be used and is still commonly used in most interiors, including Slovak schools today. The colour composition of this is reduced compared to the solar one (Figure 3). The temperature of the light source ranges between 3000-4000 Kelvin, and its intensity is approximately 500 lux (Aarts et al., 2017).

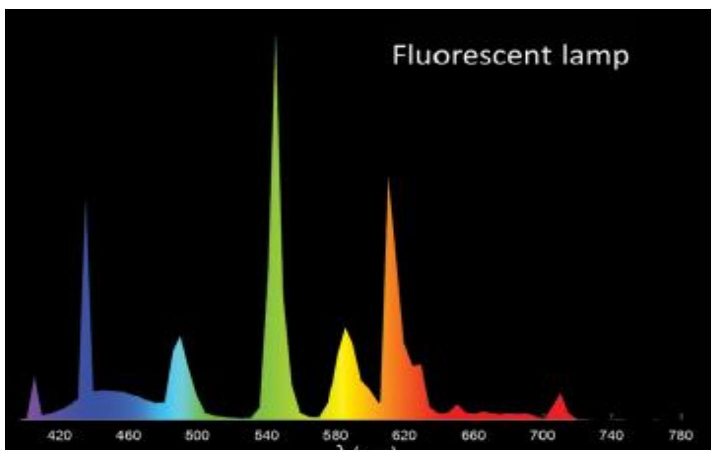

Figure 3: Fluorescent lamp

Source: Adapted by the author from Aarts et al. (2017).

LED Technology in the 21st Century:

As the 21st century begins, so does the rise of the best lighting technology that humanity has yet created - LED technology. It is the most energy-efficient light source and it also manages to combine the physical units of the Sun to our advantage. The lighting industry has not considered it necessary to address this issue, and thus, only a single type of "office" LED white lighting is produced (Figure 4). The colour composition of LED lighting is superior to fluorescent lighting, which is gradually starting to replace it. However, it still has some shortcomings in terms of the essential colours for humans. Azure blue, the same colour we see in the sky, is absent, while most of the red and near-infrared are not present at all. The colour temperature is 6500 Kelvin (Morrow et al., 2018), and the illumination power is around 500 lux at the desktop (Aarts et al., 2017).

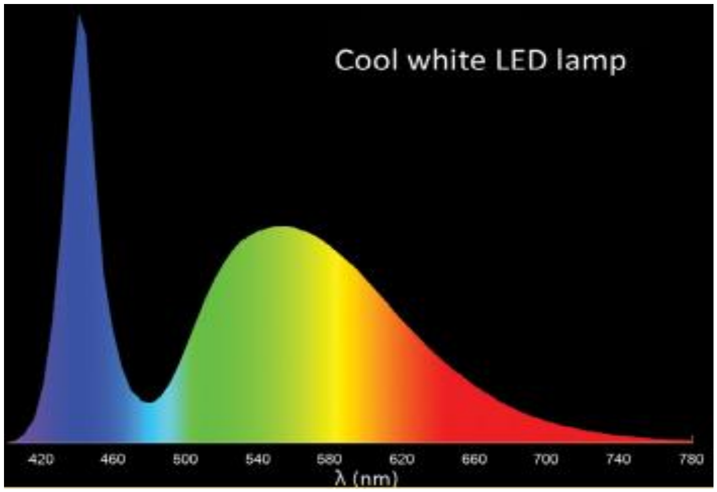

Figure 4: Cold white LED lamp
Source: Adapted by the author from Aarts et al. (2017).

Light-Dependent Organs - Circadian Rhythm

The Eye Is Our Primary Sensory Organ and Provides A Direct Connection to The Brain:

During our lives, we primarily perceive most external stimuli and information through our eyes. The eye thus becomes not only a gateway to the soul but also a gateway to the world around us. At the back of the eye is the retina, which comprises millions of receptors for both day and night vision. During the day, photoreceptors process the energy received in the form of light, whether from natural or artificial sources. These receptors are divided into three types: red, green, and blue, known as RGB. For a long time, it was thought that we only had these receptors in the eye. Still, the discovery and description of their direct function have added to this theory the newly discovered receptors in the eye - the ipRGCs, called intrinsic photosensitive ganglion cells (Hattar et al., 2002). This complex of receptors cannot distinguish which light source is involved; their role is to process the light information and transmit it to the brain. This process occurs through the optic nerves, and the point where they intersect is where our internal biological clock is located. This is a paired structure - the suprachiasmatic nuclei (SCN). This clock subsequently regulates hormone release, energy levels, and mood. It is the main regulator of our circadian system, which also determines whether our body should function in day or night mode. They are part of the hypothalamus and are therefore directly linked to the pituitary and pineal glands. In other words, they determine when cortisol and melatonin will be secreted (Fernandez et al., 2018; Münch et al., 2017). Melatonin is our most powerful antioxidant and is needed by every organ for repair during sleep (Ferlazzo et al., 2020). As a nocturnal hormone, it is also associated with sleep quality and its structure. Without sufficient amounts of it, the sleep architecture will not function properly, and thus the ideally long deep sleep phase followed by the REM phase will not take place. In addition to other functions, it also contributes to emotional balance (Walker, 2019). Melatonin is formed from serotonin, and serotonin is derived from light.

The Eye and Serotonin:

Serotonin, an important neurotransmitter for humans, begins to form in the eye, from where it subsequently has a direct effect on brain centres in the hypothalamus. The level of serotonin is linked to emotions and the motivational aspect of human behaviour, including anxiety, depression, impulsivity, and more. A growing body of evidence indicates that serotonin plays a crucial role in learning and memory (Fenandez et al., 2018; Meneses and Liy, 2012; Münch et al., 2017).

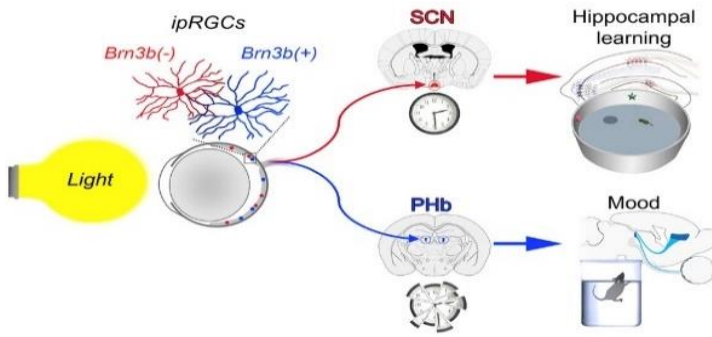

Figure 5: Light affects mood and learning through distinct retinal-brain pathways
Source: Adapted by the author from Fernandez et al. (2018).

Light has a direct effect on the activity of neural circuits and on the function of neurotransmitters. Serotonin shows both diurnal and seasonal variations. Its deficiency can be felt especially during the winter months because it is stimulated by sunlight (Münch et al., 2017). In such cases, a higher level of anxiety occurs, which, in some instances, progresses to disease states. In the case of the disease Seasonal Affective Disorder (SAD), its official treatment is through light therapy, which has a success rate of 70-90% (Prashko et al., 2008). Serotonin is a prosocial neurotransmitter, making us more social beings.

Research Findings Abroad

All-European Research on The Impact of Lightning Conditions on The Learning Performance of Pupils:

Demographic research across Europe can be considered the most extensive research into the effect of light on pupils' learning performance (Baloch et al., 2020). It was attended by 2837 pupils in 54 primary schools, across 148 classes in 13 European countries. The average age of the children ranged from 8 to 12 years. The aim of the research was to determine whether there are performance differences based on the geographical location of the country. The resulting lightning conditions vary between the southern and northern parts of Europe. The school environment and its parameters were taken into account, such as: ceiling height, class size, size and position of windows in relation to the cardinal points, as well as the subsequent view from the windows of nature or a specific part of the city. The lighting conditions in the classroom were also taken into account, as well as whether the classroom was illuminated by direct sunlight or was dependent on artificial light, or a combination of both. The authors of the study also analysed the part of the year the test was carried out, and the location receives sunlight for most of the day or other way around. Based on these parameters, the authors evaluated that they consider the overall lighting condition in the classrooms to be a beneficial of both natural and artificial light. The test consisted of tasks aimed at the pupils' cognitive abilities, such as logic and memory. They found differences in scores across all variables, with the smallest difference recorded in the comparison between urban and greenery outdoor environments. The biggest difference in scores was related to the size of the windows. Pupils in classrooms with smaller windows achieved worse results than those in classrooms with large windows. The size of the windows proved to be the strongest indicator of pupil performance, with a coefficient of 10.673 (P=0.001). Somewhat better results were obtained among pupils whose classrooms had windows facing south, which only confirm the importance of sunlight for the biology of our bodies. A certain difference was also noted in terms of the season, with better results achieved in the autumn months than in the winter months. The summary and conclusion from the authors of this all-European research support the hypothesis that light is an important indicator for the ability to learn and subsequent performance.

A Comparison of The Effect of Colour Temperature on The Mental and Physiological Performance of The Pupils:

In another foreign research, the authors focused on whether light can influence not only the mental performance of pupils but also the health of individuals. This research was conducted by experts in the field of biological psychology (Lasakujte and Cajochen, 2018). Their hypothesis about the influence of light on selected health parameters was confirmed, and they reached similar results to previous research. The research was also interesting because it included a variable - the temperature of the light and its effect on heart rate. The previous hypothesis that the effort-related cardiac response decreased with increasing light colour temperature was confirmed. These research results show that the characteristics of artificial lighting can affect the mobilisation of mental effort in individuals and also increase their heart rate. Thus, the lower the colour temperature (kelvin unit), the greater the physical exertion of a person. However, not only at the level of the brain and eyes. The old fluorescent lighting emits from 3000 K to 4000 K, while the new LED white lighting 4500 K to 6500 K.

New Bio-Optimised and Pro-Cognitive Light in Research:

In the Prague grammar school, experts installed full-spectrum artificial lighting, which was supposed to simulate sunlight. The aim of the researchers and scientists was to determine whether such light can affect the academic results and performance of pupils. Two working groups of pupils were formed. In one monitored group pupils (N -50) worked under the old type of lighting, while in the second, experimental group (N-50) pupils worked under the so-called cognitive lighting. The learning outcomes demonstrated a significant improvement in the concentration test scores of students who had the chance to work in classrooms with lighting that simulated sunlight. This effect is mainly attributed to the azure-blue colour, which is not present in common types of lighting. This colour stimulates receptors in the eye called ipRGCs (intrinsic photosensitive ganglion cells). The light blue colour (the same as the colour of the sky) increases the motivation of individuals exposed to this colour. The conclusions of the study underline that students who worked under full-spectrum light (qualitatively similar to real daylight) achieved much better results in memory tests as well as in tests aimed at concentrating knowledge. In the research, students' cognitive performance, chronobiologic factors, students' late arrivals at school, and their subjective assessment of the indoor environment were statistically evaluated. It turned out again that the real lighting environment regulates our internal biological clock (SCN), which influences the quality of sleep. In memory tests, pupils with pro-cognitive light made fewer mistakes ($p < 0.05$) and their short-term memory was significantly better ($p < 0.02$) than pupils in the control group. The median percentage of errors was higher in the control group during the concentration test. The experiment reveals an important insight that the learning outcomes and performances of pupils are statistically significantly higher with bio-optimised lighting (Maierová, 2020). From these results, it can be clearly pointed out that full-spectral pro-cognitive light can effectively substitute natural sunlight, especially during periods of significant sunlight deficiency. This

URL: http://dx.doi.org/10.14738/assrj.115.16943

lighting is full-spectral in colour (Figure 6), similar to solar, the colour temperature is 4800 Kelvin, and the lighting power is around 1000 lux.

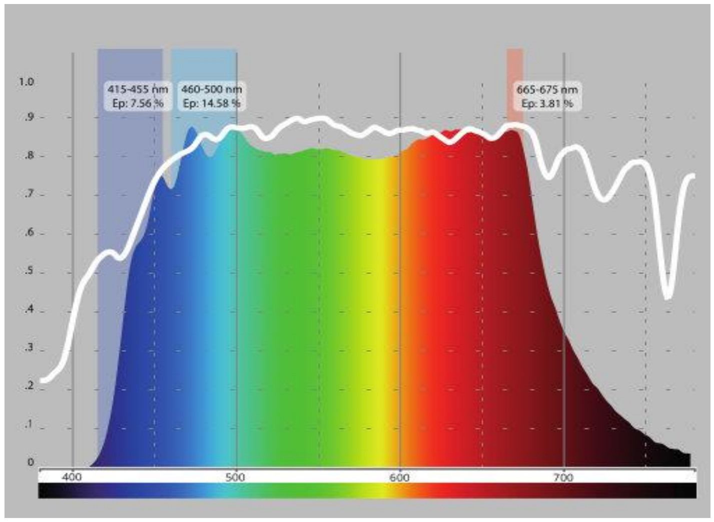

Figure 6: Colour spectrum of bio-optimised light
Source: lighting manufacturer

How the European Commission Sees the Issue of LED Lighting and Its Impact on the Human Body:

More and more experts are beginning to point out the potential risks associated with commercially produced LED technology. This is why the European Commission has requested an opinion on the subject from the Scientific Committee on Health, the Environment, and Emerging Risks. The conclusion of this work is that it remains important to closely monitor the risk of adverse health effects due to long-term use of LEDs in the general population (European Commission, 2018).

RESEARCH ON THE EFFECTS OF BIO-OPTIMISED LIGHTING ON THE COGNITIVE FUNCTIONS OF PRIMARY SCHOOL PUPILS

Cognitive Functions

Cognitive functions are one of the main areas of the human psyche, their centres are stored in different parts of the brain. Through cognitive functions, a person perceives the world around them, acts, reacts, and copes with various tasks. These are mental processes that allow us to receive, process, and utilize information. There are several key cognitive functions:

- Attention - is the ability to focus on a particular stimulus while ignoring others. Attention is fundamental to most other cognitive functions because it allows us to focus on the information we want to process.
- Memory - is the cognitive function that enables us to store and later retrieve information. There are several types of memory, including short-term memory (or working memory), long-term memory, and procedural memory.
- Language - language skills enable us to communicate with others and interpret linguistic information. This cognitive function involves understanding vocabulary, grammar, and the social rules of language use.
- Visual-spatial processing - this function allows us to comprehend and interpret visual information and spatial relationships. This involves not only visual object recognition

and orientation in space but also the ability to mentally manipulate visual and spatial information.

- Executive functions - are the set of cognitive processes that control and direct our thoughts and behaviour. These functions include planning, organizing, impulse control, flexibility of thought, and the ability to multitask.
- Emotional regulation - is the process by which we control and manage our emotions. This cognitive function is closely linked to our executive functions and is the key to our ability to adapt to changing circumstances and respond to stressful situations.

These cognitive functions also play a crucial role in students' academic performance at school, as they form the basis of their attention, perception, memory, thinking, and understanding of the world around them.

Research Aim, Research Questions and Hypotheses

Aim of the Research:

The primary aim of the pilot research, conducted using an experimental method in natural school conditions, was to determine the extent to which long-term exposure to bio-optimised light in a primary school classroom would affect the level of selected cognitive functions of pupils. We aimed to determine if there were statistically significant differences in the observed cognitive variables (pre-test/post-test) in the experimental group exposed to bio-optimised light after the end of the experiment, and what would be the situation in this sphere in the control group, which was educated in a classroom with classical artificial lighting. A secondary aim was to investigate the strength of the relationship/effect of variables from a range of cognitive functions.

Research Questions:

- VO1: What is the level of selected cognitive functions (attention, perception, mental speed, theoretical-computational thinking, logical thinking and problem-solving) of pupils in the experimental and control groups before and after the implementation of the experiment?
- VO2: What is the relationship/correlation between the investigated cognitive variables/cognitive abilities in the pre-test and post-test of the experimental and control groups of pupils?
- VO3: What is the strength of the relationship/effect between the cognitive variables?

Research Hypotheses:

- H1: We assumed that long-term exposure to bio-optimised lighting in the experimental classroom would significantly increase the levels of selected cognitive functions (attention, thinking, problem-solving) of pupils (Baloch et al.,2020, Maier, 2020).
- H2: We assumed that the correlations between the cognitive variables under study would be strong. (Baloch et al., 2020, Maier, 2020).

Methods

Research Sample:

The research sample consisted of a total of 43 pupils in two classes of grade 8, of which 26 pupils were in the experimental group and 17 pupils formed the control group. These were pupils of a standard primary school in Bratislava. The classes and the pupils in them were balanced in terms of the required indicators, such as school grades and intellectual level.

The participants were informed about the purpose of the research, they participated in the research voluntarily and anonymously. This was an intended, exhaustive selection. Data collection was conducted in October 2022 in two selected 8th grade classes (pre-test) and repeated in May 2023 in both experimental and control classes.

Operationalisation

The indicator of cognitive development was the summative index in the CHIPS test - in Part 3, which primarily looks at abstract logical thinking and logical problem-solving, secondary perception, especially spatial and area perception, and attention. (Hansen, Hansen, & Kreiner, 2016). The indicators of cognitive ability were summative indices representing the total number of correctly solved problems within the specified time frame in the intelligence test IST-70, in the Number Series subtest of NU (Amthauer, 1993). In the Disjunctive Reaction Time DRT, it was a summative index representing the total number of problems solved and the error rate within the specified time during the attention test.

Research Methods:

Experiment:

The primary method employed in our research was the experimental method conducted in the natural settings of the school and classroom. It is widely known that experiment, as the only research method, can determine whether the independent variable is the cause. Therefore, experiments typically exhibit high external (ecological) validity. The natural conditions are adjusted to suit the research objective. In general, the experimenter cannot control undesirable variables to the same extent as in a laboratory experiment, which lowers its internal validity.
In our case, we were introducing a new type of lighting - biodynamic lighting in one of the 8th grade classes of an elementary school. The pupils worked under this lighting in the classroom for the entire school year, including the autumn and winter months, while the pupils of another 8th grade class were working under traditional artificial lighting of the traditional type. The pupils of the experimental and control groups were balanced in terms of age, knowledge, and intellectual level. At both the beginning of the experiment and at the end of the experiment, the pupils were examined by the same psychodiagnostic methods aimed at determining the level of their cognitive functions. These were the CHIPS, DRT, and NU methods.

CHIPS (Children's Problem Solving) - Test of Children's Cognitive Development and Problem-Solving (Hansen, Kreiner, Hansen, 1993):

The authors of the CHIPS test are the Danish psychologists Hansen, Kreiner, and Hansen in 1993. It is a non-verbal psychological diagnostic method used to determine the cognitive development level of children aged 5-14 years. The test is based on Piaget's theory of cognitive development. The test is currently also used internationally. It consists of 40 items/problem tasks compiled based on difficulty. The first set of problem tasks is aimed at monitoring the fundamental level of thinking typical of children under 6 years of age. The second set of tasks monitors analytical-synthetic thinking in children, while the third set detects the application of logical and abstract thinking when dealing with problems. This most complex type of thinking is characteristic of children aged 10/11 and above.

Subtest of the Intelligence Structure Test IST Numerical Unit (NU) (Amthauer, 1993):

Amthauer focused on the overall capacity of intelligence and its structure in terms of the profile of results in individual subtests. The IST consists of 9 subtests, of which the Numerical Unit (NU) subtest specifically designed to assess the ability of inductive thinking related to numbers and theoretical numerical thinking. It evaluates the capacity to establish logical relationships between numbers. It contains 20 numerical rows sorted by difficulty, with time duration of 10 minutes. It is used by children aged 12 and older.

Disjunctive Reaction Time DRT II (Vonkomer, 1992):

This is a non-verbal performance method aimed at the diagnosis of attention and reaction time. More specifically, it is a test of rapid discrimination (perceptual alertness) according to the model, which detects the concentration of attention during an activity focused on achieving maximum speed and alertness in simple spatial orientation. The DRT II test is a modification of the DRT I test.

In this version, there was a change in the location of the presented stimuli on one double page, and the exact order of the items was determined. In the pencil-paper version, the test has 60 items. The individual items contain a square with a white and black circle positioned differently from each other. Next to each item, the client records the relative position of the circles according to the instructions given in advance within 55 seconds.

Research Plan:

The research was quantitative and correlational in nature as we examined the relationships between selected variables. Since we were seeking answers to research questions and empirical evidence for hypotheses, our research was exploratory-verified.

Data Analysis Methods

Statistical data analysis was performed using SPSS software. From the primary data, we calculated means, medians, standard deviations, interquartile range, skewness, and kurtosis for the raw scores. We used the Shapiro-Wilk test for normality of data distribution, testing the null hypothesis and determining the significance value of "p" for this test. If this value is greater than 0.05, we accept the null hypothesis, indicating that the data are not significantly different from a normal distribution, thus they are normally distributed. If this value is less than 0.05, we reject the null hypothesis, indicating that the data are different from a normal distribution, and therefore, the data are non-normally distributed. The strength of the relationship between the variables was assessed using Spearman's rank correlation coefficient r_s. Spearman's rank correlation coefficient is a relatively robust method that is not dependent on the normality of the data distribution. It is not dependent on the linearity of the relationship between the variables and is not biased by any outliers (Rabušic, Soukup, and Mareš, 2019).

Comparisons between groups were conducted using the Kruskal-Wallis test. The substantive significance of the differences was detected by the correlation measure of r_m size. We interpreted the degree of tightness/strength of the relationship between the variables as follows (Cohen, 1988): 0.00 - 0.30 - low/weak relationship/effect, 0.31 - 0.50 - medium relationship/effect, and strong relationship/effect - 0.51 or higher.

RESEARCH RESULTS

The Level of Cognitive Function in The Experimental Group Before and After the Experiment

There were 25 pupils in the experimental group at the beginning of the research, i.e. before the long-term exposure to bio-optimised light (1 pupil did not participate in the testing), 22 pupils participated in the post-test (6 pupils were absent due to family and health reasons). The results of three applied psychological tests aimed at monitoring cognitive functions, including - selected dimensions of cognitive development and cognitive abilities (problem-solving, logical thinking, theoretical numerical thinking, attention, perception, personal work pace), showed that long-term exposure to a new type of lighting in the classroom during the winter months of the school year has a positive effect on the cognitive functions of pupils. The study indicated that pupils' cognitive abilities and processes are improved as a result.

It was confirmed that in the applied subtest of the IST Numerical Unit Intelligence Test (NU), which primarily monitors students' theoretical numerical reasoning and logical thinking (20 items, duration 10 min), there was an increase in performance by an average of 2 correct answers after the experiment. Pupils improved from an average of 13 correct answers in the pre-test to 15 correctly solved items in the post-test. Even 45% of the pupils achieved 19/20 score of correctly solved problems in the post-test, compared to the pre-test where no pupils achieved such number. The situation was equally positive in the DRT - Disjunctive Reaction Time test, which is aimed at monitoring the attention, concentration of attention and speed of the pace of work. This test only takes 55 seconds to complete. On average, the pupils in the experimental group improved from solving 56 problems correctly in the pre-test to 59 problems correctly in the post-test, out of a total of 60 problems. However, the purpose of this test was to demonstrate the seasonal variations between the tested groups in the winter and summer seasons. In winter, pupils in the experimental group achieved scores as high as 83% of the maximum score compared to less than 30% for the control group. In the post-test, which was conducted during the summer months (June), and no artificial light was required in the classrooms, the anticipated improvement in the control group was expected to be primarily influenced by the season (longer days = more energy). This improvement occurred from 30% to 66%. On the CHIPS test of cognitive development and problem-solving, which measures multiple cognitive processes such as logical thinking, problem-solving, perception and attention, and measures overall cognitive development - the experimental group showed improvement in the third set of items on the test, which examines global abstract and logical thinking, by 2.5 items correctly solved, from 8 to 10.5 items in this set.

Table 1: Level of pupils in the experimental group in selected dimensions of cognitive development (problem-solving, theoretical numerical reasoning, attention) in pre-test and post-test after several months of exposure to bio-dynamic light.

Descriptive Statistics								
	NU pre-test (winter)	NU post-test (summer)	DRT pre-test (winter)	DRT post-test (summer)	DRT the number of errors pre-test (winter)	DRT the number of errors post-test (summer)	CHIPS pre-test (winter)	CHIPS post-test (summer)
	Experimental (8. B)	Experimental (8. B)	Experimental (8. B)	Experimental (8. B)	Experimental (8. B)	Experimental (8. B)	Experimental (8. B)	Experimental (8. B)
Valid	26	22	26	22	26	22	21	21
Missing	1	5	1	5	1	5	6	6

Median	14,000	15,500	60,000	60,000	0	0	10,000	11,000
Mean	13,500	15,273	56,615	59,227	346	727	9,714	10,571
Std. Deviation	3,421	4,474	8,247	3,624	689	2,979	2,686	3,010
IQR	4,250	6,000	0	0	0	0	4,000	5,000
Skewness	-426	-721	-2,592	-4,690	1,795	4,618	-211	-127
Std. Error of Skewness	456	491	456	491	456	491	501	501
Kurtosis	-829	-400	5,872	22,000	1,843	21,509	-1,060	-882
Std. Error of Kurtosis	887	953	887	953	887	953	972	972
Shapiro-Wilk	888	893	478	221	549	264	950	959
P-value of Shapiro-Wilk	9	21	< ,001	< ,001	< ,001	< ,001	337	496
Minimum	8,000	5,000	30,000	43,000	0	0	5,000	5,000
Maximum	18,000	20,000	60,000	60,000	2,000	14,000	14,000	15,000

Cognitive Function in The Control Group Before and After the Experiment

In the control group, which worked in the classroom during the school year with conventional artificial lighting, 17 pupils were present at the beginning of the experiment (3 pupils did not take part in testing), and 18 pupils were present in the post-test (2 pupils did not take part in the testing). The results of three applied psychological tests showed that in the control group, there was an improvement of the observed cognitive functions after the experiment. Specifically, in the DRT test, the pupils correctly solved an average of 45 tasks aimed at attention and mental speed at the beginning, 53 tasks out of 60 at the end of the experiment, in the set time of 55 seconds. In the other two tests, cognitive performance remained unchanged in both the pre-test and post-test (12 items in the NU and 11 items in the CHIPS before and after the experiment). Therefore, there was no improvement in pupils' performance in these tests.

Table 2: Level of pupils in the control group in selected dimensions of cognitive development (problem-solving, theoretical numerical reasoning, attention) in pre-test and post-test.

Descriptive Statistics								
	NU pre-test (winter)	NU post-test (summer)	DRT pre-test (winter)	DRT pre-test (summer)	DRT the number of errors pre-test (winter)	DRT the number of errors post-test (summer)	CHIPS pre-test (winter)	CHIPS post-test (summer)
	control. (8. A)	control. (8. A)	control. (8. A)	control. (8. A)	control. (8. A)	control. (8. A)	control. (8. A)	control. (8. A)
Valid	17	18	17	18	17	18	15	15
Missing	3	2	3	2	3	2	5	5
Median	13,000	11,500	48,000	60,000	0	0	12,000	10,000
Mean	12,824	12,667	45,294	53,389	1,176	3,778	11,467	11,000

Std. Deviation	4,019	4,615	14,061	10,971	2,007	7,084	1,995	1,813
IQR	6,000	6,500	25,000	14,000	2,000	2,750	1,000	2,000
Skewness	-338	414	-573	-1,243	2,722	2,017	-691	747
Std. Error of Skewness	550	536	550	536	550	536	580	580
Kurtosis	-59	-1,067	-1,037	-228	8,669	3,033	1,401	-736
Std. Error of Kurtosis	1,063	1,038	1,063	1,038	1,063	1,038	1,121	1,121
Shapiro-Wilk	957	913	870	638	633	609	894	850
P-value of Shapiro-Wilk	567	99	22	< ,001	< ,001	< ,001	77	17
Minimum	4,000	6,000	20,000	30,000	0	0	7,000	9,000
Maximum	19,000	20,000	60,000	60,000	8,000	23,000	15,000	14,000

Correlations and Strength of Relationship/Effect Between Cognitive Variables in The Pre-Test and Post-Test in The Experimental and Control Groups

We observed the relationship/correlation between the experimental group pupils' performance on cognitive functions before and after the application of bio-dynamic lighting in the classroom. Thus, we were interested in determining the strength of the relationship (strong, moderate, or weak) between the performance of the experimental group pupils on the cognitive variables in the pre-test and post-test. Additionally, we aimed to assess the strength of this relationship/effect between the variables. The results of the research confirmed significantly strong relationships/correlations between the variables. Specifically, in the CHIPS Cognitive Development Test r_s =0.777 and in the Number Unit Test r_s =0.549, and also highlighted a moderately strong relationship between the variables in the Disjunctive Reaction Time DRT r_s =0.491. These relationships between cognitive variables in the pre-test and post-test are statistically important at the significance level of p=0.001 in the NU subtest, p=0.002 in the DRT test, and p=0.001 in the CHIPS test of cognitive development. The control group showed a significant relationship only in DRT p=0.01, there was no significant relationship found between the other variables studied.

Table 3: Correlations between pre-test and post-test levels of the observed dimensions of cognitive development of pupils in the experimental group taught under the influence of bio-optimised lighting.

Spearman's Correlations					
Variable		NU pre-test (winter)	DRT pre-test (winter)	DRT the number of errors pre-test (winter)	CHIPS pre-test (winter)
NU post-test (summer)	Spearman's rho	0,549***	313	-100	259
	p-value	< ,001	63	562	126
DRT pre-test (summer)	Spearman's rho	114	0,491**	-85	-93
	p-value	507	2	621	591

DRT the number of errors post-test (summer)	Spearman's rho	182	-117	259	33
	p-value	289	498	128	849
CHIPS post-test (summer)	Spearman's rho	187	37	104	0,777***
	p-value	275	831	548	< ,001
* p < .05, ** p < .01, *** p < .001					

Significance of Differences in The Observed Variables Between the Pre-Test and Post-Test in The Experimental and Control Groups

In the experimental group, it was confirmed that long-term exposure to bio-dynamic lighting during the school year plays a significant role in the increase in the level of students' attention span and their personal work rate, as well as in the increase in the level of cognitive development, with an emphasis on logical thinking and problem-solving at abstract and logical level. The results of both tests are indicated by the statistically significant difference between the pre-test and post-test variables at the significance level of p=0.05, i.e. This signifies a notable change in the observed abilities of the pupils of the experimental group from the start to the end of the experiment. This also confirms our stated research hypotheses.

In the control group of pupils, we found a statistically significant difference between the pre-test and post-test only in the attention tested in the DRT test (p=0.01).

Table 4: Descriptive statistics

Descriptive Statistics																
	NU pre-test (winter)		NU post-test (summer)		DRT pre-test (winter)		DRT post-test (summer)		DRT the number of errors pre-test (winter)		DRT the number of errors post-test (summer)		CHIPS pre-test (winter)		CHIPS post-test (summer)	
	control. (8. A)	experi. (8. B)	control. (8. A)	experi. (8. B)	control. (8. A)	experi. (8. B)	control. (8. A)	experi. (8. B)	control. (8. A)	experi. (8. B)	control. (8. A)	experi. (8. B)	control. (8. A)	experi. (8. B)	control. (8. A)	experi. (8. B)
Valid	17	26	18	22	17	26	18	22	17	26	18	22	15	21	15	21
Missing	3	1	2	5	3	1	2	5	3	1	2	5	5	6	5	6
Median	13,000	14,000	11,500	15,500	48,000	60,000	60,000	60,000	0	0	0	0	12,000	10,000	10,000	11,000
Mean	12,824	13,500	12,667	15,273	45,294	56,615	53,389	59,227	1,176	346	3,778	727	11,467	9,714	11,000	10,571
Std. Deviation	4,019	3,421	4,615	4,474	14,061	8,247	10,971	3,624	2,007	689	7,084	2,979	1,995	2,686	1,813	3,010
IQR	6,000	4,250	6,500	6,000	25,000	0	14,000	0	2,000	0	2,750	0	1,000	4,000	2,000	5,000
Skewness	-338	-426	414	-721	-573	-2,592	-1,243	-4,690	2,722	1,795	2,017	4,618	-691	-211	747	-127
Std. Error of Skewness	550	456	536	491	550	456	536	491	550	456	536	491	580	501	580	501

Kurtosis	-59	-829	-1,067	-400	-1,037	5,872	-228	22,000	8,669	1,843	3,033	21,509	1,401	-1,060	-736	-882
Std. Error of Kurtosis	1,063	887	1,038	953	1,063	887	1,038	953	1,063	887	1,038	953	1,121	972	1,121	972
Shapiro-Wilk	957	888	913	893	870	478	638	221	633	549	609	264	894	950	850	959
P-value of Shapiro-Wilk	567	9	99	21	22	< ,001	< ,001	< ,001	< ,001	< ,001	< ,001	< ,001	77	337	17	496
Minimum	4,000	8,000	6,000	5,000	20,000	30,000	30,000	43,000	0	0	0	0	7,000	5,000	9,000	5,000
Maximum	19,000	18,000	20,000	20,000	60,000	60,000	60,000	60,000	8,000	2,000	23,000	14,000	15,000	14,000	14,000	15,000

Table 5: Significance of differences in pre-test and post-test variables in the control group

The control group (8. A)							
Wilcoxon signed-rank test							
Measure 1		Measure 2	W	z	p	Rank-Biserial Correlation	SE Rank-Biserial Correlation
NU pre-test (winter)	-	NU post-test (summer)	59,000	0,943	0,360	0,297	0,305
DRT pre-test (winter)	-	DRT pre-test (summer)	2,000	-2,599	0,011	-0,927	0,342
DRT the number of errors pre-test (winter)	-	DRT the number of errors post-test (summer)	11,000	-0,980	0,360	-0,389	0,377
CHIPS pre-test (winter)	-	CHIPS post-test (summer)	46,000	1,156	0,253	0,394	0,328

Table 5: Significance of differences between pre-test and post-test variables in the experimental group

The experimental group (8. B)							
Wilcoxon signed-rank test							
Measure 1		Measure 2	W	z	p	Rank-Biserial Correlation	SE Rank-Biserial Correlation
NU pre-test (winter)	-	NU post-test (summer)	64,000	-1,531	0,13	-0,390	0,250
DRT pre-test (winter)	-	DRT pre-test (summer)	0,000	-2,023	0,050	-1,000	0,458
DRT the number of errors pre-test (winter)	-	DRT the number of errors post-test (summer)	22,000	0,560	0,62	0,222	0,377
CHIPS pre-test (winter)	-	CHIPS post-test (summer)	41,500	-1,916	0,050	-0,515	0,262

Based on the results of the first pilot experiment with a new progressive type of lighting in the school environment, it can be concluded that the long-term use of bio-optimised lighting in the classroom throughout the school year, but especially in the winter months, has a positive effect on the level of cognitive abilities and processes of the pupils studied. Consequently, the performance of cognitive functions significantly improves.

DISCUSSION

Interpretation of the Results

The primary purpose of our research was to determine whether long-term exposure to a new type of classroom lighting has a positive effect on pupils' cognitive function. In our research, we decided to use a natural experiment in an 8th grade elementary school classroom. One class was randomly selected as the experimental group and worked/operated under bio-optimised lighting during class time throughout the school year (October-May). Another class became the control group, where instruction took place in standard conventional school conditions under artificial lighting during the fall and winter months. The two classes were matched based on basic variables such as school performance and intellectual level. Performance in selected psychological tests and observed variables was almost equal at the beginning of the experiment. In the NU subtest, both the experimental and control groups correctly solved 13 tasks out of 20. In the CHIPS test, the experimental group solved 10 tasks while the control group solved 11 tasks. However, in the DRT, there was a discrepancy with 56 correctly completed tasks in the experimental group compared to 45 tasks in the control group.

From October 2022 to May 2023, the teaching process was conducted in the experimental group with bio-optimised classroom lighting and in the control group with conventional artificial lighting. After the completion of the experiment, processing, and analysing the results along with the tests used to monitor the cognitive abilities of the pupils, it was confirmed that the pupils of the experimental group showed a statistically significant improvement in test performance. This improvement is believed to improve the level of concentration of attention, perception, spatial and surface imagination, logical and abstract thinking, and problem-solving.

Interesting information that also supports the improvement in the cognitive functions of the pupils, as pointed out by the headmaster of the primary school, is that the class that became the experimental group in the research for one year, and thus the pupils worked under the influence of the progressive bio-optimised lighting of the learning space, most pupils (up to 10) made the entrance interviews, among all the classes of the 8th grade, to the bilingual high schools where they are successfully studying at that time. This is a rare occurrence in the school's existence.

Theoretical and Methodological Implications

Future Research Objectives:

The topic of the effect of bio-optimised light in schools on pupils' cognitive function and positive cognitive development is fascinating and very topical. We believe that studying cognitive abilities and cognitive processes is highly beneficial and stimulating for enhancing pupils' school performance and learning achievement. We are pleased to address this topic as our research contributes to optimising cognitive indicators of youth development in Slovakia. We believe that conducting a comparative study on the cognitive development of pupils in various types of primary schools, as well as in secondary and higher education across different regions of Slovakia, would be very interesting.

CONCLUSION

If we consider how much time pupils spend in the school environment, the importance of light and lighting as one of the parameters of the school environment becomes extremely significant. In order to better grasp the importance of the Sun, we need to be aware of its influence on the human body and its impact on behaviour and functioning in personal, family, and work environments.

References

Aarts, M. P. J., Brown, S. A., Bueno, B. et al. (2017). Reinventing daylight. In Sanders, S. & Oberst, J. (Eds.): Changing perspectives on daylight: Science, technology, and culture [online]. The American Association for the Advancement of Science. 33-37. Dostupné na: https://www.science.org/content/resource/changing-perspectives-daylight-science-technology-and-culture

Albertová-Majerčáková, S. (2019). Sociálno-emocionálne zdravie žiakov v rannej adolescencii: vzťahy so školskou začlenenosťou, prosociálnym správaním a osobnosťou žiaka. In Psychológia inkluzívnej školy. Zborník príspevkov z medzinárodnej vedeckej konferencie z 22.10.2019, 93-100.

Baloch, M. R., Maesano, N. C., Christoffersen, J., Mandin, C., Csobod, E., de Oliviera Fernandes, E., Annesi-Maesano, I., & SINPHONIE Consortium (2021). Daylight and School Performance in European Schoolchildren. International Journal of Environmental Research and Public Health, 18(1), 258-270.

Cohen, J. (1988). Statistical Power Analysis for the Behavioral Sciences (2nd Edition) (2nd ed.). Routledge.

Ferlazzo, N., Andolina, G., Cannata, A., Costanzo, G. M., Rizzo, V., Currò, M., Ientile, R., & Caccamo, D. (2020). Is Melatonin the Cornucopia of the 21st Century? Antioxidants, 9(11), 1088.

Fernandez, D. C., Fogerson, P. M., Ospri, L. L., Thomsen, M. B., Layne, R. M., Severin, D., Zhan, J., Singer, J. H., Kirkwood, A., Zhao, H., Berson, D. M., & Hattar, S. (2018). Light Affects Mood and Learning through Distinct Retina-Brain Pathways. Cell, 175(1), 71-84.

Found My Fitness. (2019, February 28). Dr. Matthew Walker on Sleep for Enhancing Learning, Creativity, Immunity, and Glymphatic System [online]. Dostupné na: https://www.youtube.com/watch?v=bEbtf7uS6P8&t=17s

Gajdošová, E. (2023). Pozitívny model slovenskej školy v kontexte aplikácie pozitívnej psychológie a podpory duševného zdravia. In: Podpora a rozvoj duševného zdravia v školách. Zborník z medzinárodnej vedeckej konferencie, Inštitút priemyselnej výchovy, s.261-269.

Gross-Sampson, A. M. (2020). Statistical Analysis in JASP. A Guide for Students. 4th Edition, JASP.

Nosko, M. (2023) Duševné zdravie v školskom prostredí v kontexte svetla. In: Podpora a rozvoj duševného zdravia v školách. Zborník z medzinárodnej vedeckej konferencie, Inštitút priemyselnej výchovy, s.167-177

Hattar, S., Liao, H. W., Takao, M., Berson, D. M., & Yau, K. W. (2002). Melanopsin-Containing Retinal Ganglion Cells: Architecture, Projections, and Intrinsic Photosensitivity. Science, 295(5557), 1065-1070.

Lasauskaite, R., & Cajochen, Ch. (2017). Influence of lighting color temperature on effort-related cardiac response. Biological Psychology, 132, 64-70.

Maierova, L., & Kytka, I. (2020). Vyhodnocení vlivu pro-kognitivního osvětlení v budově Gymnázia Na Pražačce (Závěrečná výzkumná zpráva). České vysoké učení technické v Praze, Univerzitní centrum energeticky efektivních budov.

Meneses, A., & Liy, G. (2012). Serotonin and emotion, learning and memory. Reviews in the Neurosciences, 23(5-6), 543-553.

Münch, M., Brondsted, A. E., Brown, S. A. et al. (2017). The effect of light on human. In Sanders, S. & Oberst, J (Eds.), Changing perspectives on daylight: Science, technology, and culture [online]. The American Association for the Advancement of Science. 16-23. Dostupné na: https://www.science.org/content/resource/changing-perspectives-daylight-science-technology-and-culture

Nosko, M. (2023). Duševné zdravie v školskom prostredí v kontexte svetla. In: Podpora a rozvoj duševného zdravia v školách. Zborník z medzinárodnej vedeckej konferencie, Inštitút priemyselnej výchovy, s.167-177.

Nosko, M. (2023). Vplyv svetla na zdravie a učebný výkon žiakov. Prevencia, 1, CVTI, s. 21-27.

Praško, J., Brunovský, M., Závěšická, L., & Doubek, P. (2008). Sezónní afektivní porucha a léčba jasným světlem. Psychiatrie pro praxi, 9(2), 72-76.