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C.R.O.M.A.: the impact of specific wavelenght on attentional processes in primary school children

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Abstract: CROMA is a research project aimed at creating optimal educational conditions to support students' learning processes. Based on the latest evidence in the field of Educational Neuroscience, the project has a dual objective: to identify the most effective combinations of light stimuli to be integrated into the school environment to enhance memory and attention processes in primary school children, and to determine the appropriate level of chromatic stimulation to use during lessons. The project involved a sample of 92 students from a school in the province of Rome. The students completed two tests under different experimental conditions, using light stimuli of various wavelengths: 700 nm (red), 460 nm (blue), and 546 nm (green). During exposure to these stimuli, projected using spotlights positioned on the walls, the students performed a selective attention task (A1 test from NEPSY-II). The results were promising: exposure to blue and green light facilitated attention processes, whereas red light slowed attentional response times. This phase represents the first step in a project structured into four phases. The sequential progression of these phases aims to implement and replicate the experiment within classroom settings, providing a solution to the need for optimal learning conditions.

Keywords: envirnoment, cognitive functions, colors, blue, green

1. Introduction

The classroom environment, consisting of physical and structural elements such as seating arrangement, air conditioning, furniture, classroom size, and lighting, has a profound impact on students' learning. These factors not only enhance physical comfort but also support attention and concentration, helping to create conditions conducive to effective learning (Bozkurt et al., 2014). Among these, the colour and intensity of lighting play a crucial role, influencing cognitive activation, mood, and productivity (Ferlazzo et al., 2014).

Proper lighting is associated with greater accuracy and efficiency, while inadequate conditions can lead to visual fatigue and reduced performance (Duyan & Unver, 2022). Recent studies have expanded the focus from the visual properties of light to its psychological and biological aspects, demonstrating that lighting affects circadian rhythms, hormonal secretions, and cognitive functions (Küller et al., 2009). Attention and reaction time, which are closely linked, are particularly sensitive to the wavelengths of light: higher attention levels correspond to faster reaction times, but evidence regarding the specific effects of different wavelengths remains fragmented.

The integration of advanced technologies in schools offers the opportunity to design optimised educational spaces based on scientific evidence. Understanding how environmental factors influence cognitive functions and brain waves could personalise learning experiences, improving academic outcomes and student well-being (Cipollone, 2021).

The CROMA project (Colour Reaction on Memorization and Attention) fits into this context, aiming to explore the impact of light wavelengths on attention and memory. Through an experimental approach, the project seeks to identify optimal lighting conditions to enhance attention and memorisation. CROMA addresses a gap in the literature, offering new perspectives on the interactions between lighting and cognitive functions, and providing practical guidelines for designing school environments that foster learning and well-being. This approach highlights the importance of integrating physical and cognitive factors into educational design.

2. The Complex System of Visual Processing and Colour Perception

The processing of visual stimuli is the result of a complex system integrating physical, physiological, psychological, and neurological processes, enabling the perception of light stimuli derived from electromagnetic radiation at various wavelengths (Cipollone et al., 2024). Colour perception is based on the interaction between light and matter: for example, an object appears red because it absorbs shorter wavelengths and reflects longer ones, stimulating the retina's photoreceptors specific to red. The visible spectrum, ranging from 380 to 740 nanometres, represents the segment of the electromagnetic spectrum to which the human eye is sensitive. The higher level of sensitivity varies with lighting conditions: in bright environments, the sensitivity peak is at 555 nm, while in low-light conditions, it shifts to 507 nm. This adaptation is described by the luminous efficiency curve, which evaluates the effectiveness of light sources based on human perception (Chellappa et al., 2011).

The human eye functions as a biological camera: light enters through the cornea, which directs it towards the retina. Here, cones and rods, the main photoreceptors, convert the light signals into electrical impulse. Cones, responsible for colour vision, are sensitive to specific wavelengths: S cones respond to blue (higher sensitivity at 437 nm), M cones to green (higher sensitivity at 533 nm), and L cones to red (higher sensitivity at 564 nm), enabling trichromatic vision. Once generated, the signals are transmitted to the brain via the optic nerve, reaching the lateral geniculate body and finally the primary visual cortex, where they are processed to create the complete visual experience (Küller et al., 2009; Vandewalle et al., 2009).

3. Use of different Wavelengths in Learning environment in primary school children

Cognitive activities such as attention and reaction time are essential responses to visual stimuli and represent fundamental elements for understanding assigned tasks (Golmohammadi et al., 2021). Recent studies have expanded the focus from visual impairments to the non-visual effects of light, highlighting its impact on attention and cognitive performance (Mohebian et al., 2016). According to Cognitive Load Theory (Sweller et al., 2011), specific visual stimuli enhance attentional efficiency by reducing cognitive load. Similarly, Embodied Cognition emphasises the role of light and colour in sensory interaction with the environment.

Research by Alkotzei et al. (2017) and Mehta and Zhu (2009) demonstrates that specific colours improve concentration and complex processing, while blue light (460 nm) enhances sustained attention and working memory (Motamedzadeh et al., 2017; Souman et al., 2018). Theories such as Environmental Design (Evans, 2006) underline the potential of targeted school design that integrates neuroscience and pedagogy to optimise students' learning and well-being.

3.1 The influence of three types of wavelenghts on attentional processes

Light plays a fundamental role in regulating numerous circadian, neuroendocrine, and neurobehavioural functions, going beyond its simple impact on visual responses through the action of intrinsically photosensitive retinal ganglion cells (ipRGCs) (Bozkurt et al., 2014). These cells, recently identified within the class of retinal photoreceptors, work in conjunction with rods and cones to perceive light. They are particularly sensitive to short-wavelength blue light, around 460 nm. Their activation is crucial in regulating wakefulness and enhancing cognitive performance (Vandewalle et al., 2009).

Exposure to light not only directly influences vigilance and performance but also affects brain activity involved in higher cognitive processes, independently of the visual component. This complex network of interactions engages various brain regions, supporting a continuous flow of cognitive activity. Blue light, in particular, is a key resource for modulating cognitive and behavioural functions, offering new opportunities for interventions aimed at improving mental performance (Tonetti & Natale, 2019).

Numerous scientific studies indicate that exposure to blue light, with a wavelength of around 460 nm, has significant effects on cognitive processes, particularly attention and working memory (Motamedzadeh et al., 2017; Viola et al., 2008). Motamedzadeh et al. (2017) demonstrated that white light enriched with blue (17000 K) improves sustained attention and reduces cognitive errors compared to standard light (6500 K). Similarly, Baek and Min (2015) found that this light reduces alpha band activity, suggesting increased alertness. Studer et al. (2019) observed faster reaction times in attention tasks under blue light compared to red. Lee et al. (2021) confirmed that blue light enhances cognitive functions such as inhibitory control and cognitive load management. In educational settings, the use of blue light during tests and cognitive activities could improve concentration and reduce distractions (Alkozei et al., 2017). Additionally, for students with learning difficulties, this wavelength proves particularly effective in promoting rapid and precise responses (Tonetti & Natale, 2019). The ability of blue light to modulate vigilance through melatonin suppression underscores its critical role in the design of optimised educational environments (Chellappa et al., 2011).

Green light, known for its soothing effect on the human eye, is strongly associated with growth, balance, and harmony, making it particularly effective in creating environments that promote well-being and learning (Torrice & Logrippo, 1989). Engelbrecht (2003) highlighted that soft tones such as green reduce visual strain and enhance focus, making it ideal for classrooms. Unlike brighter colours, which can be overstimulating, green creates a balanced atmosphere, beneficial for both psychological well-being and cognitive learning. Furthermore, studies such as those by Gaines et al. (2011) indicate that green, through its calming effect, can enhance attention and reduce anxiety in students with special educational needs, such as those with autism spectrum disorders or ADHD.

Green is also closely associated with positive emotions, including joy and surprise, as demonstrated by Moller et al. (2009). This association may derive from daily interaction with nature and from the intrinsic wavelength characteristics of green, which promote a state of balance for the nervous system (Cipollone, 2022). This property makes it ideal not only for educational contexts but also for work and therapeutic settings, where the balance between calmness and activation improves well-being and productivity (Cipollone et al., 2024). Thus, integrating green into the design of educational spaces can optimise cognitive performance and foster a positive psychological state, highlighting its potential as a relevant variable in studies on well-being and learning.

Red light has distinct effects on attentional processes, influencing both alertness and the ability to concentrate. Studies such as Sall et al. (2014) have shown that flashing red lights capture attention but impair attentional control, increasing reaction times and diverting visual focus from critical signals. This effect reflects the dual nature of red light: alerting but potentially distracting. The impact may vary among individuals with typical and atypical development, such as those with neurodevelopmental disorders, where sensitivity to visual stimuli may amplify such effects.

Research by Studer et al. (2019) suggests that red light is less effective than blue light for tasks requiring sustained attention and rapid reactivity, being associated with lower cognitive performance. However, red light appears to support sleep regulation, reducing sleep onset latency and improving the stability of evening circadian rhythms (Sall et al., 2014). These circadian benefits limit its applicability in intensive educational contexts, where a high level of vigilance and concentration is crucial. Consequently, the use of red light in learning environments requires careful contextualisation to avoid interference with cognitive performance.

4. CROMA Research Project

CROMA is a research project aimed at identifying the optimal environmental chromatic conditions to enhance attentional and mnemonic processes in primary school students. The project is structured into four phases: (1) analysis of the influence of red, green, and blue on attentional processes; (2) analysis of the influence of red, green, and blue on mnemonic processes; (3) analysis of the combined influence of these stimuli with varying exposure times; and (4) replication of the experimental conditions in the natural classroom setting. Currently, we are conducting the first phase of the study.

The ultimate goal is to define the optimal lighting design for learning environments.

4.1. Research hypothesis

The research hypothesis states that the exposure to green stimuli enhances attentional processes, while red stimuli interfere with them in individuals with typical development.

4.2. Methods and Tools

The CROMA project adopts an experimental within-subject research design, where each participant is exposed to all the experimental conditions. This approach allows for controlling individual differences among participants, as each child serves as their own control.

The experiment was conducted at the primary school "Alessandra D'Angelo" in Testa di Lepre, in the province of Rome. Participation was voluntary, with parental informed consent obtained prior to the study, and included all classes within the school.

To evaluate attentional processes, two tests specialized in assessing visual and selective attention were employed: (1) the A1 test from the NEPSY-II battery; and (2) the Selective Visual Attention test from the BVN 5-11 battery.

The experiment took place in a specially prepared room at the school with strict control of environmental conditions. Stimuli were presented using eight adjustable LED spotlights, chosen for their ability to emit light at specific wavelengths, ensuring precise illumination control. The LED spotlights were programmed to emit blue light (460 nm) for the first experimental condition, green light (546 nm) for the second, and red light (700 nm) for the third. Saturation and brightness levels were kept constant (S:100, HSI:50%). The LED spotlights were positioned 200 cm from the floor, 80 cm apart from each other, and 150 cm away from the children.

Figure 1. Experimentation at the school

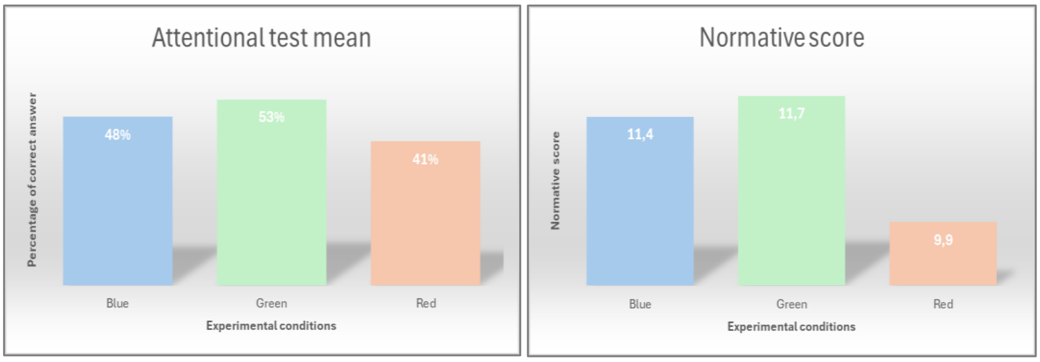
As shown in Figure 1, the test was conducted individually for each child. Each participant completed the tests under all three experimental conditions, performing the A1 test during the first and second experimental sessions, and the "Selective Visual Attention" test during the third session. To minimize the effects of test memorization, a three-month interval was maintained between each experimental condition.

4.3. Sample

The sample consisted of 92 children, including 48 boys and 44 girls. Among them, 82 children exhibited typical development, while 10 had atypical development, including 4 students with autism spectrum disorder, 2 with ADHD, and 4 with dys-lexia. The distribution by grade level included 19 children in the first grade (6 years old), 19 in the second grade (7 years old), 18 in the third grade (8 years old), 16 in the fourth grade (9 years old), and 20 in the fifth grade (10 years old).

4.4. Results

Here displayed below there are the results of the attentional test, divided between the three experimental conditions.



Graph 1-2. Results at attentional tests and normative scores for typical development

Graph 1 illustrates the results from the attentional tests, indicating that green and blue light significantly enhance attention in individuals with typical development. Graph 2 presents the normative scores, with a score of 10 representing the mean of the distribution. As shown in the graph, while the red color yields scores aligned with the average, green and blue contribute to better-than-expected performance for the age group.

4.5. Data Analysis

Here, displayed below there is the statistical analysis performed through Jamovi software (2.3.28).

Descriptives

	Groups	Stroop Test
N	Blue	92
	Red	92
	Green	92
Missing	Blue	0
	Green	0
	Red	0
Mean	Blue	48
	Green	53
	Red	41
Median	Blue	41
	Green	50
	Red	39
Standard Deviation	Blue	6,89
	Green	6,85
	Red	5,34
Minimum	Blue	23
	Green	27

	Red	11
Maximum	Blue	95
	Green	100
	Red	92

Table 1. Sample Descriptives

The results of the descriptive analysis of the three experimental conditions show differences in mean scores and response distributions. In the Blue group, participants achieved a mean score of 48 with a standard deviation of 6.89, indicating some variability in performance. In the green group, participants achieved a mean score of 53 with a standard deviation of 6.85. In the red group, participants achieved a mean score of 41 with a standard deviation of 5,34.

To compare the scores obtained in the attentional tests across the experimental conditions (blue, green, and red light stimuli), a repeated measures ANOVA was chosen. This approach was selected because each participant was exposed to all experimental conditions, allowing for the control of within-subject variability.

Before proceeding, the assumptions of normality were verified.

Normality of Distribution (Shapiro-Wilk)

	W	***p***
Blue	*0.939*	*0.014*
Green	*0.950*	*0.037*
Red	*0.886*	*>.001*

Note. A low p-value suggests a violation of the assumption of equal variances

Table 2. Shapiro Wilk Test

The Shapiro-Wilk tests revealed that the scores did not follow a normal distribution in any of the three conditions (p<0.05p < 0.05 for all). Although ANOVA is robust to minor violations of normality, this violation was considered when choosing to perform a non-parametric test as a confirmation.

Starting from this, two types of analyses were conducted such as repeated measures ANOVA and the Friedman test.

Repeated measures ***ANOVA***

	F	***Df1***	***Df2***	***p-value***
Results	*6.08*	*2*	*96*	*0.0033*

Table 3. Repeated measures **ANOVA**

Table 3 shows the repeated measures ANOVA results, suggesting the significativity of the difference between the experimental groups (F(2,96)=6,08, p= 0.0033).

Friedman's Test

	Chi-Square	*Df1*	*p-value*
Results	*10.24*	*2*	*0.006*

Table 4. Friedman's Test

The Friedman test also confirmed the presence of a significant difference between the conditions ($\chi 2(2)=10.24, p=0.006$).

5. Discussion

CROMA is a research project aligned within the field of learning environments, addressing the gap regarding the cognitive impact of light wavelengths. The literature has highlighted how exposure to light stimuli positively influences vigilance and performance, as well as impacts higher cognitive processes (Gaines & Curry, 2011; Tonetti & Natale, 2019; Golmohammadi et al., 2021).

Specifically, studies conducted in both experimental and non-environmental settings have shown that blue light, due to its calming properties in terms of cognitive load, enhances attention (Tonetti & Natale, 2019; Mehta & Zhu, 2009), green light promotes an optimal state of cognitive activation (Torrice & Logrippo, 1989; Duyan & Unver, 2022), and red light, due to its highly stimulating nature, is disruptive to attentional processes (Golmohammadi et al., 2021; Struder et al., 2019).

The central aim of this study was to analyse how controlled light stimulation, tailored to specific educational activities, affects the capacity for selective visual attention. The test results revealed differing scores for the three types of light stimulation, indicating that the colour of light may have influenced attentional performance. The combined use of repeated measures ANOVA and the Friedman test confirmed the presence of a significant effect, as the p-value was below 0.05 in both cases.

The data thus suggest that green and blue light enhance attentional performance compared to red light, with participants achieving scores nearly two points higher than expected. The research hypothesis is therefore confirmed by the significance of the differences in scores across the three experimental conditions.

Conclusion

In recent years, there has been a growing interest in studying learning environments and how to make them more effective. The calibration of chromatic stimuli within these environments is an important factor to consider, as colours and their wavelengths influence cognition and perception. CROMA, structured into four phases, aims to contribute to this field by defining the appropriate use of wavelengths to create optimal learning conditions.

The results of the first phase have been promising, confirming the hypothesis that green and blue light can enhance attentional processes, with a significance level of 0.003. It is now essential to further analyse these initial findings, examining how they are influenced by other factors such as gender and age, and identifying differences in participants with atypical development.

The research has certain limitations that may affect the interpretation and generalisability of the results. The violation of normality in attentional scores limits the applicability of parametric analyses, necessitating the use of non-parametric tests such as the Friedman Test. Additionally, the exposure duration to chromatic stimuli was not varied, reducing the possibility of exploring the optimal duration for maximising attentional processes.

Attribution

The contribution represents the result of a collaborative effort by the authors; specifically, Elèna Cipollone is the author of §§2, 4.1, 4.2, 4.3, 4.4, 4.5; Luna Lembo is the author of §§ 1,3.1, 3.2, 5 and conclusion; Franceco Peluso Cassese is Research Supervisor.

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