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Wavelengths of light and didactic times: exploratory investigation on the use of blue light to promote inhibitory control and processing speed

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Abstract: This study examines the impact of color wavelengths, particularly blue light (460 nm), on students' attentional capacities, focusing on inhibitory control, cognitive flexibility, and processing speed. Conducted with 218 art school students under controlled lighting conditions, the findings revealed that blue light significantly improved reaction times during the Stroop Test compared to neutral light ($p < 0.05$). These results highlight the potential of blue light to enhance executive functions, emphasizing the importance of integrating color as a key environmental factor in designing effective learning spaces.

Keywords: environment, executive functions, learning, didactic evaluation

1. Introduction

The influence of environmental factors on learning and cognitive performance has been the focus of numerous studies, with particular attention paid to the effects of light and colour on human behaviour. Recent research highlights that different wavelengths of light can affect key aspects of cognition, such as attention, reaction times, and memory (Motamedzadeh et al., 2017; Chellappa et al., 2011; Vandewalle et al., 2009; Cipollone et al. 2024). Among primary colours, blue is often associated with enhanced alertness and concentration (Keis et al., 2014; Mehta & Zhu, 2009). Specifically, exposure to blue light has been shown to reduce reaction times and enhance information processing efficiency (Küller et al., 2009; Ayoko & Ashkanasy, 2017).

In educational settings, optimising the learning environment is considered essential for maximising students' attentional capacities. Cognitive psychology and environmental ergonomics have recognised the importance of colour as a critical element in modulating arousal, mood, and sustained attention (Knez, 2001). According to Cognitive Load Theory (Sweller et al.,2011), visual stimuli such as colour can influence working memory and attentional efficiency by reducing cognitive load and facilitating student concentration. Moreover, the concept of Embodied Cognition (Barsalou, 2008) suggests that learning is a physical and perceptual process where environmental elements, such as light wavelengths, play a crucial role in supporting cognitive processing.

Numerous studies demonstrate that exposure to blue light can significantly enhance cognitive functions and reduce reaction times by increasing cortical activation and alertness (Souman et al., 2018; Knez, 2001; Chellappa et al., 2011). This effect is particularly relevant in educational contexts, where maintaining high levels of attention is fundamental for the acquisition and comprehension of information (Vandewalle et al., 2009). The strategic use of colors offers a valuable opportunity to enhance learning environments by improving students' cognitive efficiency and attentional control. This study investigates the impact of blue light (460 nm) on students' attentional capacities, using the Stroop Test as a measurement tool. The hypothesis suggests that blue light promotes superior cognitive performance compared to longer wavelengths, aligning with prior research associating blue with enhanced attention and memory (Motamedzadeh et al., 2017; Mehta & Zhu, 2009). This research seeks to provide further empirical support for an educational approach based on the intentional design of learning environments, while also leveraging the synergy between neuroscience and education to create optimal conditions for students to navigate the evaluative moments that shape their academic journeys.

2. Wavelengths and Attentional Capacities in Learning Environments

In the context of cognitive neuroscience and environmental psychology, colour and light wavelength have long been studied for their impact on individuals' cognitive and attentional abilities. Established theories, such as Cognitive Load Theory (Sweller et al.,2011), suggest that visual stimuli can directly influence information processing capabilities, either enhancing or hindering working memory and attentional efficiency (Cipollone, 2022). A well-designed visual environment, strategically utilising colour, can reduce cognitive load and facilitate student concentration during the learning process (Cipollone, 2021).

Another relevant perspective is offered by the concept of Embodied Cognition (Barsalou, 2008), learning involves not only cognitive processes but also physical and sensory interactions with the environment. Colors and wavelengths play a crucial role in this "embodied" learning approach, where visual stimuli directly influence cognitive processing and attention. Research has shown that color and wavelength can differentially affect cortical activation, vigilance, motivation, and cognitive performance. Researchers such as Mehta and Zhu (2009) have shown that exposure to certain colours can directly impact concentration and cognitive functions, enhancing the ability to process complex information. Specifically, blue wavelengths have been found to be associated with greater concentration and improved complex cognitive functions, such as sustained attention and working memory (Motamedzadeh et al., 2017; Barsalou, 2008; Bacca et al., 2014; Vandewalle et al., 2009).

In an educational context, integrating Environmental Design theory with modern pedagogical approaches, such as Constructivism (Piaget, 1970), has led to viewing the learning environment as a crucial element for optimising students' concentration and performance. Using color strategically in school environments can effectively enhance cognitive processing by improving the atmosphere and student attention. Research shows that exposure to blue light or similar wavelengths reduces reaction times, enhances visuo-spatial processing, and strengthens short-term memory capacity (Chellappa et al., 2011; Küller et al., 2009). Empirical evidence indicates that blue light significantly enhances cortical activation, improving attention and cognitive efficiency, particularly in educational contexts. This highlights the potential of strategically using wavelengths and colors to optimize learning environments. Integrating neuroscience, pedagogy, and environmental design can create school spaces that enhance students' cognitive and attentional capacities.

2.1 The Use of 460 nm Light to Improve Inhibitory Control and Cognitive Flexibility Skills During Competency Assessment

Inhibitory control is a fundamental component of the brain's executive functions, enabling individuals to suppress automatic, impulsive, or inappropriate responses to focus on more suitable behaviours based on the situation (Diamond, 2013). Inhibitory control is crucial for managing distractions and maintaining focus during assessments, playing a vital role in academic success, particularly in high-pressure situations like exams (Best & Miller, 2015; Kang et al., 2022). During assessments, students encounter numerous distractions, both external (e.g., noise) and internal (e.g., anxiety), that challenge their focus. Inhibitory control enables them to ignore irrelevant stimuli and critically evaluate task-relevant information, preventing impulsive responses and improving accuracy (Kang et al., 2022; Zelazo & Carlson, 2015).

Effective management of cognitive interference is essential for maintaining focus on relevant information during tasks requiring sustained attention, such as lengthy exams or fast-paced activities. Inhibitory control helps students stay concentrated, minimizing errors and enhancing performance (Lee et al., 2021).

In multiple-choice tasks, students must suppress impulsive responses and cognitive biases to focus on selecting the correct answer. This requires strong inhibitory control to overcome interference from misleading options that may appear familiar or superficially correct (McAuley & White, 2011).

Success in multiple-choice tasks relies on the ability to critically evaluate each option and inhibit selecting familiar but incorrect answers, which often require effort to overcome automatic associations with previously learned information (Kang et al., 2022).

In multiple-choice tasks, the challenge of inhibiting interference is heightened when incorrect options are semantically related to the correct answer, requiring students to resist choosing answers that seem logically related but are ultimately incorrect (Diamond, 2013). Inhibitory control is crucial for resisting cognitive interference and focusing on relevant information, enabling students to respond accurately and perform better in tasks.

2.2 The Use of 460 nm to Enhance Processing Speed During Skill Assessment

Processing speed is crucial in skill assessment activities, as it influences students' ability to respond quickly and accurately to demands (Motamedzadeh et al., 2017). Recent studies have shown that blue light at 460 nm enhances alertness, concentration, and processing speed while reducing errors and facilitating cognitive load management (Lee et al., 2021). This wavelength has proven particularly useful in educational settings, especially during assessments, by enhancing focus and response accuracy. Additionally, it can be beneficial for students with attention difficulties or learning disorders, supporting them in processing information quickly without compromising accuracy (Tonetti & Natale, 2019). The use of this light in educational environments could enhance cognitive performance and improve the overall educational process.

3. Research Project

3.1. Research hypothesis

The research hypothesis suggests that the specific 460 nm blue wavelength may enhance processing speed and inhibitory control in secondary school students compared to the wavelength of conventional white lights typically used in classrooms, indicating a direct effect of chromatic stimulation on executive functions.

3.2. Research Design

The research design employed in this study can be described as a cross-over design, as it allows the comparison of the effects of two treatment conditions (neutral light and blue light) on the same participants. This approach has the advantage of reducing between-subject variability and improving the precision of effect estimates for the experimental variable.

Specifically, each participant was exposed to both experimental conditions: the 460 nm blue wavelength and neutral light.

To minimise learning or fatigue effects, a 40-minute washout period was introduced between conditions, during which participants were not exposed to any specific light stimulus. This pause served to "reset" the effect of the initial exposure, making it less likely for the prior treatment to influence the subsequent one.

3.3. Methods and Tools

The study was conducted in the classrooms of the Artistic – Choreutic – Grafic High School Branciardi in Grosseto. The equipment used for the experiment consisted of 10 adjustable and programmable LED spotlights, chosen for their ability to emit light at specific wavelengths, ensuring precise control over illumination. The LED spotlights were programmed to emit blue light at a wavelength of 460 nm and neutral light, representing a short-wavelength spectrum and a control condition, respectively.

The light intensity was kept constant across both conditions to minimise confounding variables related to perceived brightness (S:100, HSI:50%). Natural external lighting was left unaltered to improve the study's replicability under typical classroom conditions. The classroom arrangement and spotlight placement were optimised to ensure uniform illumination throughout the room, so each participant was exposed to the same intensity and quality of light.

Participants were systematically exposed to the two chromatic conditions. Attentional capacities were measured using the Stroop Test, a widely employed cognitive assessment tool for evaluating attentional interference and selective response ability. The test, lasting eight minutes, was administered in a computerised format through specialised software installed on the participants' PCs, designed to monitor reaction times. The software automatically recorded the participants' response times for each test trial, ensuring high precision in the collected data.

Each participant completed two Stroop Test sessions: the first under neutral light exposure and the second under blue light exposure. Randomisation of stimuli presented by the Stroop Test minimised learning effects between test and retest sessions.

At the end of each session, the software provided participants with the following parameters:

- Reaction times for congruent stimuli
- Reaction times for incongruent stimuli
- Stroop effect

The Stroop effect is quantified by the difference in reaction times between congruent conditions (text color matches the word) and incongruent conditions (text color differs from the word). The Stroop effect is calculated by subtracting the reaction time in the congruent condition from the reaction time in the incongruent condition. A positive value indicates that participants took longer to respond in the incongruent condition, reflecting the cognitive cost of interference.

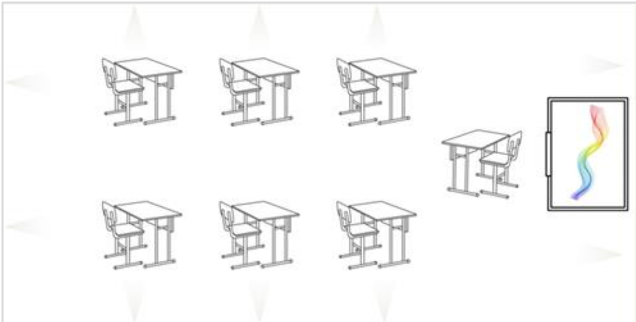


Figure 1. Neutral condition

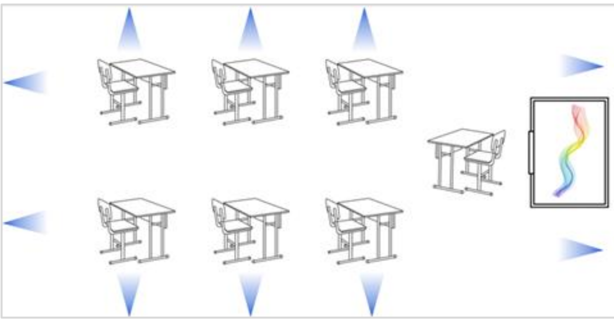


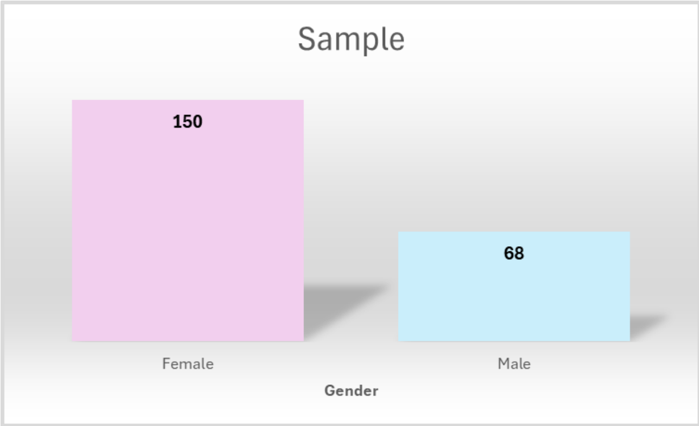
Figure 2. Blue condition

Figures 1 and 2 illustrate the two experimental conditions, showing the positioning of the lights in relation to the arrangement of the school desks.

The desk arrangement and the distance of the students from the computer screens were standardised throughout the experiment to ensure a consistent experimental setup, with the wavelength of the light being the only variable altered.

3.4. Sample Analysis

The sample for this study consisted of 218 students from the third and fourth years of the Artistic – Choreutic – Grafic High School Branciardi, comprising 150 females and 68 males, with a mean age of 17.5 years (± 0.5 years) (Graph 1).

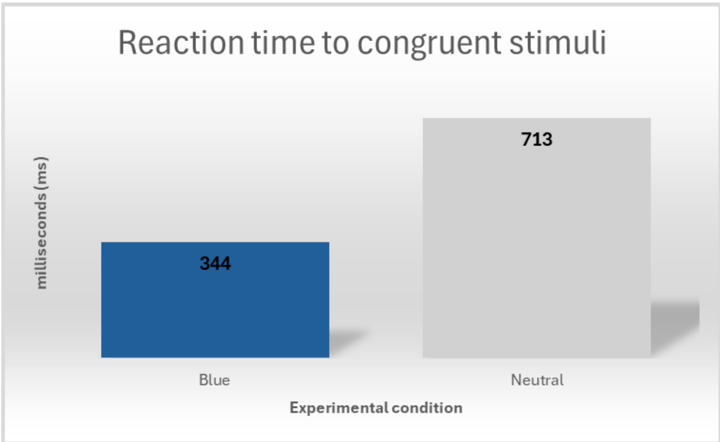


Graph 1. Sample distribution

This demographic composition ensures a degree of homogeneity in terms of age and reflects the typical structure of an art-focused secondary school.

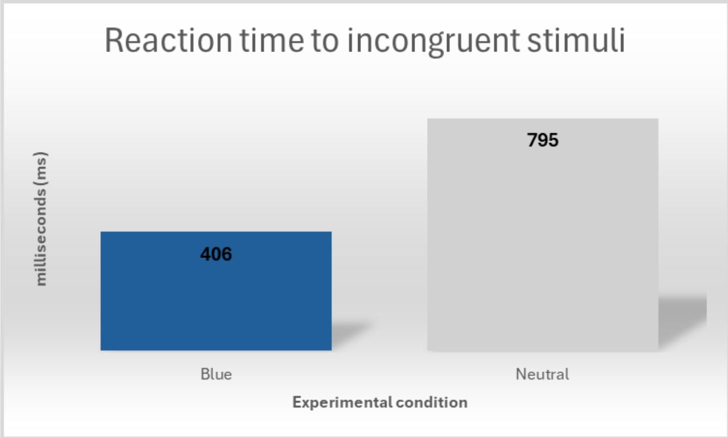
3.5. Results

Here displayed below there are the results of the Stroop test, comparising the mean results of the two experimental groups.



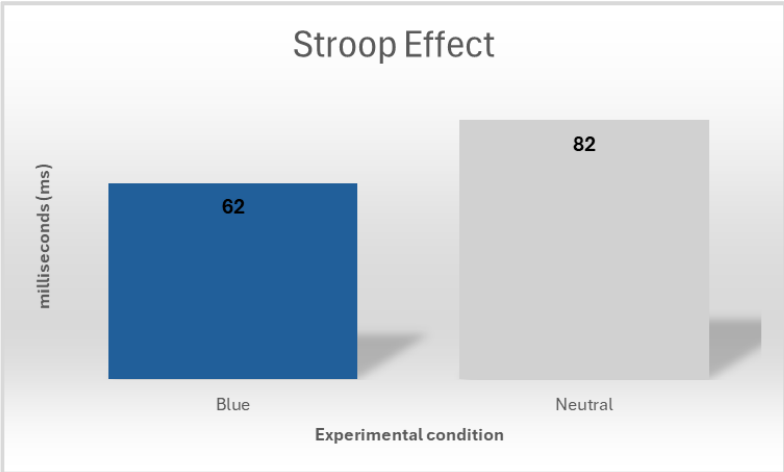
Graph 2. Reaction time to congruent stimuli

Graph 2 shows the mean reaction times to congruent stimuli for the two experimental groups. The data reveal a difference between the groups, indicating that the blue conditions enhanced students' inhibitory control and information processing speed.



Graph 3. Reaction time to incongruent stimuli

Graph 3, representing the mean reaction time to incongruent stimuli, reveals the same difference values, suggesting that blue helped student also with the incongruent stimuli processing.



Graph 4. Stroop Effect

Graph 4 shows the Stroop Effect, calculated from the differences between mean time of reaction of the previous situations. Also in this case, due to the blue exposition there is an enhancement of 32% between the two experimental conditions.

3.6. Data Analysis

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

Descriptives

	Groups	Stroop Test
N	Blue	218
	Neutral	218

Missing	Blue	0
	Neutral	0
Mean	Blue	62
	Neutral	82
Median	Blue	65,3
	Neutral	81,9
Standard Deviation	Blue	15,21
	Neutral	14,44
Minimum	Blue	29,54
	Neutral	35,23
Maximum	Blue	116,18
	Neutral	114,48

Table 1. Sample Descriptives

The results of the descriptive analysis of the Stroop test for the two experimental groups—one exposed to blue light (Blue) and the other to neutral light (Neutral)—show differences in mean scores and response distributions. In the Blue group, participants achieved a mean score of 62 with a standard deviation of 15.21, indicating some variability in performance.

In contrast, the Neutral group had a higher mean score of 82 with a standard deviation of 14.44, showing greater homogeneity compared to the Blue group.

Normality of Distribution (Shapiro-Wilk)

	W	***p***
Blue	*0.996*	*0.913*
Neutral	*0.993*	*0.522*

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

Table 2. Shapiro Wilk test

In terms of distribution, the results of the normality test (Shapiro-Wilk) for both groups indicate that the scores are normally distributed, with p-values of 0.913 for the Blue group and 0.522 for the Neutral group, both well above the significance threshold of 0.05 (Table 2).

Homogeneity of Variances Test (Levene's)

	F	***p***
Results	*0.463*	*0.496*

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

Table 3. Levene's test

Levene's test having the p-value (0.496) revealed that the variances between the groups are homogeneous, and the assumption of equal variances is not violated (Table 3).

The quantitative statistical analysis was conducted using the Jamovi data analysis software (version 2.3.28), applying a paired-sample t-test to compare two experimental conditions: exposure to the neutral light wavelength and exposure to the blue light wavelength during the Stroop Test. The paired-sample t-test was chosen because both measurements were taken from the same group of participants, making it a within-subject comparison, ideal for detecting differences in reaction times under the two different lighting conditions.

Paired sample T test

	Statistic	DoF	p value	Average difference	SD difference	Effect size Cohen's d
t di Student	7.95	434	< .001	-6,75	14.83	0,45

Note. H_a $\mu_{\text{Blue condition}} \neq \mu_{\text{Neutral condition}}$

Table 4. Paired Sample t test

The results of the paired-sample t-test between the Blue and Neutral conditions show a significant difference between the two groups, indicating that their means are not equal (Table 4). Specifically, the Student's t value is 7.95, with 434 degrees of freedom (DoF), confirming strong statistical evidence of a difference between the group means. The associated p-value is less than 0.001, meaning the probability that the observed differences between the two conditions are due to chance is less than 0.1%. This very low p-value provides a strong basis for rejecting the null hypothesis (H_0), which posits that the group means are equal, and supports the idea that the observed difference is statistically significant.

The mean difference between the two groups is -6.75, suggesting that participants in the Blue condition achieved lower average scores compared to those in the Neutral condition. This mean difference indicates an effect where the Blue condition appears to be associated with better performance compared to the Neutral condition.

The effect size, measured by Cohen's d, is 0.45, indicates a medium-sized effect. Overall, these results suggest that there is a real and significant difference between the Blue and Neutral conditions, but the observed effect size is moderate.

In conclusion, the analysis indicates that exposure to the blue wavelength leads to significantly faster reaction times compared to neutral light wavelengths, supporting the hypothesis that the colour blue enhances inhibitory control and cognitive processing speed.

4. Discussion

Statistical analysis of the Stroop Test revealed that exposure to blue light significantly improved students' reaction times compared to neutral light (Table 4). This suggests that blue wavelengths enhance attentional capacities, aligning with previous research highlighting blue light's ability to boost cognitive functions, reduce mental fatigue, and increase alertness (Blair & Raver, 2015; Chellappa et al., 2011; Vandewalle et al., 2009).

A paired-sample t-test confirmed a statistically significant difference between blue and neutral light conditions, demonstrating that these experimental settings have a measurable impact on students' inhibitory control and processing speed (Table 4). The findings align with studies showing that blue light enhances cognitive performance, particularly concentration and short-term memory (Mehta & Zhu, 2009).

The blue wavelength, in particular, was associated with shorter reaction times, suggesting greater efficiency in cognitive processing and attentional response Graph 3; Graph 2). These findings are consistent with research highlighting that exposure to blue light or similar wavelengths can enhance attention and reduce reaction times in cognitive tasks (Motamedzadeh et al., 2017; Küller et al., 2009; Mehta & Zhu, 2009). These data provide strong evidence supporting the research hypothesis that blue wavelengths enhance students' executive functions more effectively than neutral light, as demonstrated by the significant reduction in reaction times during exposure to blue light. Such evidence suggests that blue light could be a strategic choice to improve students' inhibitory control and processing speed in skill assessment situations or contexts requiring high levels of concentration. Initial research in this area has also shown that blue light stimulates higher cognitive and creative processes (Knez, 2001; Vandewalle et al., 2009), reinforcing the idea that it could positively impact students' cognitive performance (Beaven & Ekström, 2013). This study demonstrates the impact of light wavelengths on students' attentional capacities but notes limitations, including its art school setting, short exposure duration, and potential uncontrolled variables. Preliminary findings highlight the need for further research with diverse samples, varied contexts, and extended methodologies to confirm and expand the results.

Conclusion

Recent studies emphasize the role of learning environments as a "third educator," underscoring the importance of intentional space design. This research explores the impact of visual stimuli, particularly 460 nm light, on processing speed and inhibitory control, bridging neuroscience and education to enhance cognitive and emotional responses in academic settings. The statistical analysis revealed a significant difference in students’ reaction times during the Stroop Test, showing that exposure to the blue wavelength resulted in a lower average reaction time compared to neutral light. This difference in means clearly indicates a distinct influence of wavelengths on the aforementioned student capacities, with a marked advantage for blue light in terms of response time efficiency.

These findings not only support the research hypothesis but also have significant implications for educational environments. They suggest that the strategic use of blue light could serve as a simple and effective intervention to optimise student performance, particularly during skill assessment phases. The use of blue wavelengths could be targeted at specific times of the day or for cognitively demanding tasks requiring high levels of attention and precision, enhancing the effectiveness of educational activities and supporting a more productive study environment. However, the study's focus on an art-oriented school and brief blue light exposure highlights the need for further research. Future studies should explore prolonged exposure to various wavelengths in broader contexts, considering factors like age and learning styles. Replicating the research across diverse settings could confirm findings and inform the design of inclusive, adaptable educational spaces leveraging color as an effective teaching tool.

Attribution

The contribution represents the result of a collaborative effort by the authors; specifically, Luna Lembo is the author of §§ 3, 3.1, 3.2, 3.3, 3.4, 3.5, 3.6, 4; Elèna Cipollone is the author of §§ 1, 2, 2.1, 2,2 and conclusion; Stefania Morsanuto is Research Supervisor.

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