Impact of Bright Versus Dark Environments on Cognitive Functions in High School Students

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Abstract
The research investigates the relationship between environmental lighting and cognitive performance in Saudi Arabia, concentrating on the impact of extreme illumination levels on adolescent functioning. This study examines the differences in working memory and metalinguistic awareness among male high school students subjected to both bright light and complete darkness. This study enhances the underexplored field of environmental psychology in Middle Eastern educational settings, focusing specifically on the non-image-forming effects of light on high school populations. A within-subjects, crossover experimental analysis was performed with male secondary school students in Riyadh, comparing their performance across distinct lighting environments. Participants were selected according to strict criteria including normal vision, the absence of neurological disorders, and high language proficiency to ensure task validity. We employed two standardized cognitive tasks—the Backward Digit Recall task and the Grammatical Judgement Task—to assess the modulation of executive and analytical processes. The research utilized statistical comparisons of mean performance to determine substantial disparities in cognitive function between the two lighting conditions. The results demonstrate a task-dependent relationship, as bright light significantly improved working memory while complete darkness facilitated superior metalinguistic awareness. The difference between the enhancement of memory using bright light (M = 5.02) and the facilitation of linguistic reflection using dark light (M = 15.10) implies that different cognitive domains require different levels of arousal to achieve optimal performance. This study highlights the importance of adaptive lighting in the classroom environment and the reflective inhibition model in non-Western educational environments.
Keywords: Classroom Lighting, Working Memory, Metalinguistic Awareness, Adolescent Cognition, Task-Specific Optimization, Reflective Inhibition

Introduction

Playing a crucial role in academic achievement, environmental factors, especially lighting conditions, have a profound impact on cognitive functions such as attention, mood, and memory (Siraji et al., 2023). Research highlights that light significantly affects physiological arousal, neural activity, hormone production, and alertness (Ru et al., 2019; Siraji et al., 2023). These non-image-forming effects of light are not just abstract biological processes; they have tangible physiological and cognitive impacts (Siraji et al., 2023)

The recent changes in human-centric lighting (HCL) have sparked much debate among environmental psychologists and social scientists about the way classrooms should use artificial lighting to improve thinking. Central to this debate is a theoretical tension between reactive processing, characterized by alertness, rapid responding, and outward attentional orientation, and reflective processing, involving deep analytical thinking, internal focus, and cognitive control (Mostafavi et al., 2024; Mahoney & Schmidt, 2024). The use of bright lighting with blue light enhancements seems to improve alertness and attentional focus in classrooms (Studer et al., 2019; Wessolowski & Ostrowski, 2025). However, new research indicates that some higher cognitive functions, especially the ability to engage in deep internal reflection while avoiding distractions, may benefit from dim lighting or even darkness (Denis & Cairney, 2024; Wang et al., 2024; Payedar-Ardakani et al., 2024). This highlights a critical research gap in current the understanding of how lighting conditions influence students' cognitive performance.

Therefore, for students in complex educational environments, optimal lighting conditions go beyond mere comfort; they are rather critical facilitators of academic performance that must be matched to the specific cognitive demands of learning tasks. Studies conducted in various educational settings have consistently demonstrated that carefully considered lighting can have an effect on the level of students' performance and academic achievement (Siraji et al., 2022; Nolé, Higuera-Trujillo, & Llinares, 2021). Moreover, a recent simulated-classroom trial found no significant effects of illuminance level on working memory when melanopic efficacy was controlled, suggesting that the relationship between light intensity and cognition may be task-dependent and mechanistically complex (Mostafavi et al., 2024). The significance of the impact is demonstrated by the fact that chronic disruptions in the light/dark cycle can impair memory (Bonilla et al., 2024). These findings challenge the assumption that increasing brightness uniformly enhances cognitive performance.

To address these converging gaps, the current study aims to examine the differential effects of extreme lighting conditions—bright light versus complete darkness—on two distinct cognitive domains, working memory (a reactive, externally oriented executive function) and metalinguistic awareness (a reflective, internally oriented analytical skill), in male high school students in Saudi Arabia.

Statement of the Problem
The academic environment is often filled with activities that can disturb mental concentration, making the role of environmental factors like lighting even more critical for memory recall (García-Pérez et al., 2024). Although extensive research shows the positive impact of optimal lighting conditions on cognitive functions, including enhanced attention and memory task performance (Nolé, Higuera-Trujillo, & Llinares, 2021; Mostafavi et al., 2024), and brighter illumination influencing brain activity related to memory retention (Park et al., 2013), significant gaps persist in the existing literature. Specifically, most previous research concentrates on varying levels of illumination, overlooking the impact of environments characterized by complete darkness on cognitive functions in educational settings (Mostafavi et al., 2024). Although evidence suggests that different cognitive tasks may require varying illumination levels, the connection linking neurophysiological processes with various lighting conditions and their effects on memory remain largely unclear (Siraji et al., 2023).

Building on this limitation, the existing literature shows a methodological bias toward comparing differences within the normal range of illuminance levels found in classroom (e.g., comparing 300 lux versus 1000 lux, or LED versus fluorescent lighting) rather than focusing on extreme levels of contrast that would more clearly reveal differential effects on distinct cognitive systems (Mostafavi et al., 2024; Payedar-Ardakani et al., 2024). Although these comparisons are ecologically valid, they might also tend to neglect the underlying differences between bright versus dark conditions in terms of their ability to modulate arousal-dependent versus reflection-dependent cognitive processes. Recent findings suggest that darkness facilitates memory consolidation and that reduced illumination enhances performance on tasks requiring inhibition of external stimuli has not been systematically tested against bright-light conditions in adolescent populations performing educationally relevant cognitive tasks (Denis & Cairney, 2024; Wang et al., 2024; Payedar-Ardakani et al., 2024).

Beyond methodological limitations, the literature has largely neglected metalinguistic awareness, a critical higher-order cognitive skill involving conscious reflection on and manipulation of language structure, as an outcome measure in lighting research. Existing studies have largely focused on attention, working memory (measured using tasks such as N-back task), and reading comprehension (Mostafavi et al., 2024; Wessolowski & Ostrowski, 2025); however, metalinguistic awareness represents a qualitatively different cognitive demand. Unlike working memory tasks that necessitate rapid, externally paced responses, metalinguistic tasks demand sustained internal attention, analytical thinking about abstract linguistic patterns, and inhibition of automatic language processing (Dolas et al., 2022; Torregrossa et al., 2023). If, as emerging theory suggests, reflective cognitive processes are optimized under conditions of reduced external stimulation, then metalinguistic awareness may exhibit a pattern opposite to that of working memory, improving in darkness rather than bright light. This hypothesis has not been comprehensively tested.

In addition to these conceptual gaps, another notable limitation of existing literature is its focus on the impact of lighting conditions among university students (Siraji et al., 2022; Llinares et al., 2021; Cabriales-Orozco et al., 2023), thereby leaving the effect among younger populations, such as high school students, relatively underexplored (Jian, Zhou, & Liu, 2023). This demographic gap can be prominent in specific geographical settings. For example, studies on lighting in classrooms exist in Saudi Arabia, though these studies have mainly focused on particular scenarios such as daylight improvement (Sabbagh et al., 2022), classroom wall color (Bindaji et al., 2024), or general office productivity (Najjar et al., 2023), as opposed to the direct comparison of the effects of bright versus dark environments on memory functions among school students in the region. Regional (Abdulrahman & Al-Boloushi, 2023; Ferguson & Bornstein, 2012; Sangkakool & Jumani, 2024) and demographic factors (Nolé, Higuera-Trujillo, & Llinares, 2021; Jian, Zhou, & Liu, 2023) emphasize a critical gap in the understanding of how environmental conditions influence academic functioning (Grineski et al., 2020). As a result, the impact of environments defined by complete darkness in these functions in educational settings, especially in Saudi Arabia or in relation to high school adolescents, remains largely unexplored.

Collectively, these methodological, conceptual, demographic, and geographic limitations signal a clear need to examine the effect of extreme lighting conditions, particularly complete

darkness versus bright lighting, on various cognitive domains in educational settings for adolescents. The importance of addressing these gaps is to advance our theoretical understanding of how environmental arousal can influence cognitive processes and to improve the design of adaptive lighting systems for different educational contexts. As a result, a comparison between bright illumination and complete darkness across distinct cognitive domains in adolescent learners is required to clarify how environmental arousal differentially shapes high-order cognition.

Significance of the Study
This research problem is theoretically and methodologically consequential, with direct relevance to environmental psychology, educational neuroscience, and cross-cultural cognitive science.

At the theoretical level, this research gap is significant due to the unanswered question regarding the impact of environmental factors on cognitive functions. Previous studies have focused on the impact of different levels of illumination on cognitive functions, which, in turn, impacts many cognitive domains, including memory, mood, and attention (Siraji et al., 2023; Ru et al., 2019). However, one underexplored area of concern is the impact of environments defined by complete darkness on the memory performance of adolescents. Previous studies were centered on the exploration of different illuminance levels but has not directly compared the difference between bright and completely dark environments in educational settings (Mostafavi et al., 2024). This underexplored area remains crucial due to the fact that any slight variation in the level of illumination can profoundly impact cognitive functions (Mahoney & Schmidt, 2024).

By systematically contrasting bright and completely dark conditions across two cognitive systems with opposing processing demands—working memory and metalinguistic awareness—this study directly tests the hypothesis that distinct cognitive processes are optimized by different arousal states. If bright light enhances externally driven working memory performance but impairs reflective metalinguistic processing, while darkness produces the opposite pattern, such findings would challenge the prevailing "brighter is better" assumption underlying educational lighting design (Alkozei et al., 2017; Paterson et al., 2022; Siraji et al., 2022). More broadly, this would support a task-specific optimization model of environmental modulation, refining theoretical accounts of arousal, attention, and cognitive control (Cajochen et al., 2022).

Methodologically, this study addresses a major limitation in the lighting–cognition literature: its overwhelming reliance on Western, university-based samples. Existing research has largely overlooked the effects of lighting conditions on adolescent cognitive performance in Middle Eastern educational contexts. Conducting this research in a Saudi Arabian high school aims to extend the empirical scope of the study to a setting that is climatically, architecturally, and culturally distinct, with high levels of natural daylight and region-specific architectural features, as noted by Sabbagh et al. (2022). Without such cross-cultural examination, the generalizability of existing findings remains uncertain, as environmental factors may be moderated by adaptation, expectation, and cultural factors.

The focus on adolescents further amplifies the significance of this study. Adolescence is marked by ongoing maturation of the prefrontal executive systems responsible for reflective and metacognitive processing as well as heightened sensitivity of arousal-regulation systems to environmental cues (Tervo-Clemmens et al., 2023; Lau et al., 2024). Additionally, adolescents' circadian timing and their responsiveness to light can also make them highly responsive to environmental cues (Teicher et al., 2023). This neurodevelopmental suggests that any incongruence between the level of arousal that the environment elicits and the level that a task demands can have a greater cognitive impact on adolescents than on other groups (Bonilla et al., 2024).

From a practical perspective, educational lighting design has largely operated under uniform illumination standards that assume consistent cognitive benefits of increased brightness (Siraji et al., 2024). If lighting differentially enhances reactive versus reflective cognitive processes, then constant bright illumination may impair students' performance during tasks that require sustained internal focus and analytical reasoning (Siraji et al., 2024). Identifying such task-dependent effects could provide guidance for adaptive lighting systems that fit each learning activity (Liu et al., 2021).

As these issues are interconnected, this research is significant because it advances theoretical debates concerning arousal-dependent optimization of cognitive systems (de Gee et al., 2024), addresses methodological limitations related to extreme lighting contrasts and cross-cultural sampling, introduces metalinguistic awareness as a novel outcome variable in lighting research, and focuses on a developmentally sensitive population during a critical stage of cognitive maturation (Bonilla et al., 2024; Didikoglu et al., 2025). Together, these contributions position the study as both scientifically substantive and practically consequential.

This paper aims to address the following questions:

   a) How does cognitive performances, particularly in working memory and metalinguistic vary between students subjected to bright light and those in complete darkness?
   b) Which of the specified cognitive abilities—working memory and metalinguistic awareness—is more susceptible to enhancement or impairment under bright light compared to complete darkness?

By extending lighting–cognition research to adolescent learners within a Saudi Arabian educational context, this study aims to bridge the gap between existing research on light's impact on adults' cognitive abilities by applying it to students.

Literature Review
Introduction
Lighting is a crucial environmental factor that significantly affects human cognition, particularly among adolescents whose learning and behavioral regulation occur within artificially lit educational settings. Variations in illumination have been shown to influence alertness, attention, memory, and executive functions (Lee & Kim, 2020; Mostafavi et al., 2024). Although research has shown that lighting conditions significantly influence cognitive functions such as working memory, attention, metalinguistic awareness, and inhibitory

control (Wang et al., 2024; Münch et al., 2012; Velentza & Economou, 2020), these findings primarily emerge from laboratory or university-based samples outside the Middle Eastern region. This presents a notable gap, especially in countries such as Saudi Arabia, in which the educational environment and architectural lighting standards differ substantially from what Western-based research examined. Therefore, this review aims to synthesize the relevant literature to explore (a) how these cognitive abilities vary between students exposed to bright light and complete darkness, and (b) which cognitive domain is most prone to improvement or deterioration under such conditions.

Cognitive Performance Under Bright and Dark Environments
Studies suggests that a bright light condition, which ranges between 400-1100 lux and 4000-6500 K, facilitates better working memory performance by increasing cortical activation and alertness, as suggested by Kim et al. (2024) and Teicher et al. (2023). On the contrary, a dark or dim condition impairs recall accuracy and reaction time by decreasing arousal levels, according to a study by Smolders et al. (2018). Although a low-light condition might facilitate a relaxing state after learning, a bright condition is better for working memory performance.

The most responsive aspect is attention, for which bright light enriched in blue improves sustained and selective attention and reduces attention lapses, especially during the morning when the body's natural rhythms are heightened (Wessolowski & Ostrowski, 2025; Soltanzadeh, Chitsaz, & Kazemi, 2024; Sánchez-Lacambra et al., 2024). Dark environments impair vigilance and induce mental fatigue (Clarizio & Gill, 2022; Correa et al., 2016), thus confirming the dependency of attention on lighting levels.The empirical findings about metalinguistic awareness are inconsistent, with some suggesting that bright light facilitates reading fluency and visual comfort (Zhou & Pan, 2023), and others finding that the differences between bright light and dark environments are negligible in terms of language-based reasoning (Siraji et al., 2022; Liu et al. 2020). Because linguistic reflection is not heavily dependent on stimulation, light may facilitate this cognitive domain indirectly, not necessarily directly.

Inhibitory control, which includes aspects of impulse control and cognitive flexibility, is found to be moderately affected by light. Bright light has been shown to increase task-related inhibitions and conflict monitoring, as found by Payedar-Ardakani et al. (2024). Dark settings may sometimes be helpful for reflective inhibitions by reducing environmental distractions, as suggested by Correa et al. (2016).

Cognitive Domain Most Susceptible to Lighting Variation
Across studies, attention shows the highest sensitivity to changes in lighting. Brightness improves focus and alertness while darkness reduces performance (Bjerrum et al., 2024; Wessolowski & Rahim, 2025). Working memory comes next, showing significant improvement in bright light, but inhibitory control shows mixed results, and metalinguistic awareness shows the least sensitivity. The order of sensitivity is as follows:

Attention > Working Memory > Inhibitory Control > Metalinguistic Awareness.

Table 1
Effects of Lighting Environment on Cognitive Functions

Environment	Attention	Working Memory	Inhibitory Control	Metalinguistic Awareness
Bright Environment	Bright environments **significantly enhance** attention, improving sustained and selective focus, reducing lapses, and increasing alertness (Studer et al., 2019; Teicher et al., 2023; Wessolowski & Rahim, 2025). This leads to better performance in attention-based tasks and faster reaction times (Ru et al., 2019).	Bright illumination **enhances** working memory by increasing cortical activation and alertness, generally resulting in stronger outcomes. Short wavelength-enriched light specifically improves performance and reduces frontal theta power during retention (Grant et al., 2023; Park et al., 2013).	Bright illumination generally improves inhibitory control, enhancing task inhibition and conflict monitoring (Ru et al., 2019). Higher illuminance can boost reaction speed in inhibition tasks, although improvements under blue light are not always consistent (Kim, Park, & Lee, 2024).	Bright lighting **indirectly supports** metalinguistic awareness by improving visual comfort and reading fluency (Zhou & Pan, 2023). While it may not directly enhance linguistic reflection, high luminance has been linked to improved oral reading outcomes (Mott et al., 2012).
Dark Environment	Dark environments **negatively impact** attention by suppressing vigilance and increasing mental fatigue, leading to diminished performance. Lack of blue-enriched light or prolonged evening light exposure can hinder sleep, further reducing attentional capacity (Cyr et al., 2022).	Dark or dim settings **negatively affect** working memory by lowering arousal, reducing recall accuracy and response speed. Altered light–dark cycles and sleep deprivation associated with inadequate light also disrupt working memory performance (Alsameen et al., 2021; Behrens et al., 2019).	Dark environments show **mixed effects** on inhibitory control. They may promote reflective inhibition by reducing distractions, but overall effects depend on task complexity and arousal level Ru et al., 2019).	Dark environments show **negligible differences** in language-based reasoning compared to bright conditions. Linguistic reflection appears less susceptible to illumination changes, indicating limited direct enhancement or impairment (Zhou & Pan, 2023).

Methods of Research

This section focuses on the experimental design and the method of analysis employed to assess the effects of lighting conditions on the cognitive performances of adolescents in a high school setting. This study is theoretically founded on a framework that recognizes environmental lighting as a critical modulator of neurocognitive functioning, which influences cognitive processes, alertness, and academic performance (Liu et al., 2020; Mostafavi et al., 2024; Cabriales-Orozco et al., 2023). The modulatory role of environmental lighting on neurocognitive functioning is very important in real world settings, particularly in relation to adolescents who are very sensitive to their environment due to ongoing neurodevelopment (Bonilla et al., 2024; Soltanzadeh et al., 2024; Siraji et al., 2022; Liu et al., 2020). The is study aims to assess the impacts of classroom lighting conditions, which is a critical environmental factor in academic settings, on students' cognitive processes (Baloch et al., 2020; Siraji et al., 2022; Liu et al., 2020).

Research Design

This study will employ a within-subjects, crossover experimental design to assess the effects of bright and complete dark lighting conditions on the cognitive skills of high school students, which will directly address the gap in the literature regarding the lack of direct comparison between different lighting conditions and the assessment of different cognitive domains in educational settings. (Zoubi et al., 2024; Jian, Zhou, & Liu, 2023; Mostafavi et al., 2024; Studer et al., 2019). The focus of this study is to examine how different lighting conditions (independent variable) will impact the performance metrics (dependent variable) across tasks aimed to assess working memory and metalinguistic awareness (Grant et al., 2023; Alkozei et al., 2017; Paterson et al., 2022; Ru et al., 2019).

Participants

The participants of this study consist of high school students between the ages of 16 to 18 years. This age range is of utmost importance in the neurodevelopmental processes of cognitive functions (Tervo-Clemmens et al., 2023; Westbrook et al., 2020; Lau et al., 2024). The participants of the study will be selected from an international school; the consent of the participants, along with that of their parents, will be taken for the study (Luciana et al., 2023; Strode & Essack, 2022; Beauchamp & Childress, 2019). The selection of the participants will not be random. Therefore, specific criteria have to be fulfilled by each of the participants. Firstly, the participants of the study should be in their secondary education phase (Hong et al., 2020). Secondly, the participants should have normal or corrected-to-normal vision, which is of utmost importance in cognitive functions (Jian, Zhou, & Liu, 2023; Bernhardt et al., 2019). The participants of the study should not have a neurological or psychiatric disorder, which may impact cognitive functions (Luciana et al., 2023; Roberts et al., 2016; Tervo-Clemmens et al., 2023). Lastly, participants must be proficient in the language used during the experiment, to guarantee that participants are able to perform metalinguistic awareness tasks correctly (Friesen & Bialystok, 2012; Dolas et al., 2022; Spechtenhauser & Jessner, 2024). The detailed selection of participants helps to guarantee that any cognitive effects are more likely to be attributed to the stimulated lighting conditions.

Setting and Apparatus

The study will be conducted in a controlled classroom, which would be located in a high school, with specific conditions of lighting. The classroom would provide the appropriate conditions to produce two distinct conditions:

Bright Light Environment: It is an environment with high illuminance levels that are comparable to natural daylight. The color temperature is neutral to ensure maximum alertness and performance (Nolé, Higuera-Trujillo, & Llinares, 2021; Mostafavi et al., 2024).

Dark Environment: It is an environment that is deficient in light, simulating a state of total absence of light.

Other environmental factors, such as temperature, humidity, and noise levels, will be held constant across both conditions to prevent any unwanted effects. Cognitive tasks will be administered on a standardized computer with the use of a specialized software to ensure precise timing and data collection.

Cognitive Measurement Tools

The cognitive domains to be measured using these tools have been selected for their applicability to the adolescent population:

Working Memory

Working Memory, or the ability to hold and manipulate information for a short period of time, is to be measured using a Backward Digit Recall Task. This task involves the participant being presented with a series of numbers and being required to recall the numbers in reverse order. The difficulty of the task will gradually increase as the length of the sequence of numbers increases. The main outcome measure will be the length of the sequence recalled. The Backward Digit Recall task is a widely used and reliable test for the measurement of working memory (St Clair-Thompson & Allen, 2013).

Metalinguistic Awareness

Metalinguistic awareness, which shows the ability to reflect on and manipulate the structural features of language, will be evaluated with the Grammatical Judgement Tasks. Participants will be presented with sentences which some of them are grammatically correct while the others contain errors. They will be instructed to identify whether each sentence is correct or incorrect, and identify the error in case it is incorrect. The participants' performance will be measured by accuracy and response time.

Procedure

The research will be done over multiple sessions, and each participant will be required to undergo two sessions, one in a bright condition and one in a dark condition, separated by at least a 48-hour interval to avoid any unwanted effects. The participants will be asked to keep regular sleep-wake cycles for 24 hours before each session.

Results

Different lighting conditions can influence adolescents' cognitive performance (Llinares et al., 2021; Siraji et al., 2022). This section presents the link between lighting conditions and

cognitive abilities, such as working memory and metalinguistic awareness. The tasks that measure the mentioned cognitive domains include Backward Digit Recall (working memory) and Grammatical Judgement Task (metalinguistic awareness). This study uses the backward digit recall task to assess working memory and determine any relation between working memory performance and lighting conditions. This test requires participants to store the presented digit sequences and recall them in reverse order. Engaging both storage and executive processes, such as updating and reordering, makes the widely used in clinical batteries like the WAIS and WISC (Hilbert et al., 2015; Ikeda et al., 2023; Beck & Khanh, 2025).

This study uses the grammaticality judgement (GJ) task to assess metalinguistic awareness. Validating the correctness of a sentence's syntax is a key component of the grammaticality judgement (GJ) task. This test measures adolescents' level of analysis and control in identifying the best sentence structure; it disregards the semantics of a phrase which is the focal point of attention in daily language usage. Necessitating participants to ignore the semantic mistake requires a significant degree of self-control. Moreover, analysis demands finding the flaws while correcting the syntactic and semantic ones. Scholars prefer it for its correctness in analyzing linguistic knowledge (Prela et al., 2022; Torregrossa et al., 2023). The grammatical judgment task is a positive indicator of metalinguistic awareness for its ability to test the skill of disentangling words' meanings from their structural basis (Maayah et al., 2025).

Cognitive Abilities in Bright and Dark Environment
Table 4.1
The Difference Between Cognitive Abilities in Bright and Dark Environment

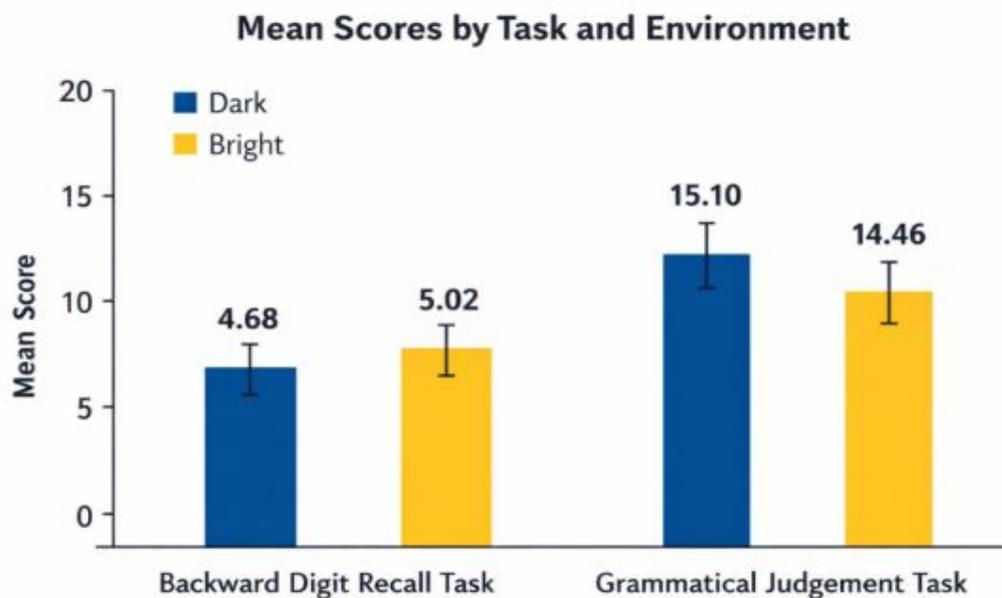| Task	Environment	N	Min	Max	Mean	SD
Backward Digit Recall	Dark	50	3	8	4.68	1.00
Backward Digit Recall	Bright	50	3	8	5.02	1.13
Grammatical Judgement	Dark	50	5	21	15.10	4.04
Grammatical Judgement	Bright	50	5	21	14.46	4.54
Valid N (listwise)		50				

Figure 4.1: The Difference Between Cognitive Abilities in Bright and Dark Environment

In the bright environment, the grammatical judgement task results range from a maximum of 21 to a minimum of 5, with a mean of 14.46 and a standard deviation of 4.54, as shown in (table 4.1). The standard deviation of 4.54 indicates that there was a moderate variability in grammatical processing abilities among the participants, suggesting differences in language proficiency and syntactic sensitivity. The mean score of 14.5 indicates that participants correctly identified about 69% of grammatical structures. On the other hand, the backward-digit recall task had a mean of 5.02 with results ranging from a maximum of 8 to minimum of 3. With a standard deviation of only 1.13, the results are quite close. According to research by Didikoglu et al. (2025), the observed mean of 5.02 aligns with the normative adolescent verbal working memory capacity. This suggests a connection between bright lighting condition and standard cognitive functioning.

In contrast, under the dark environment, the grammatical judgement task results also range from a maximum of 21 to a minimum of 5, but with a slightly higher mean of 15.10 and a lower standard deviation of 4.04. This indicates improved language performance in dim lighting. The backward-digit recall task results also range from a maximum of 8 to a minimum of 3, but with a slightly lower mean of 4.68 and a lower standard deviation of 1. Overall, the performance results for both cognitive domains under both lighting conditions revealed different levels, which highlighted meaningful individual differences. The backward digit recall showed a relatively compact distribution, whereas the grammatical judgement task showed substantial dispersion.

Discussion and Conclusion
Summary of Key Findings
The current study aims to investigate the differential impact of bright and dark lighting conditions on cognitive functions in high school students in Riyadh, Saudi Arabia. In this within-subjects study, 50 participants were selected and tested for the effect of two different cognitive tasks: working memory (tested using Backward Digit Recall tasks) and metalinguistic

awareness (tested using Grammatical Judgement tasks). The results of the current study revealed a complex and task-dependent relationship between lighting conditions and cognitive performance. In particular, bright lighting conditions were found to be associated with better working memory performance (M = 5.02) compared to dark lighting conditions (M = 4.68); however, dark lighting conditions were found to be associated with better performance in grammatical judgement tasks (M = 15.10) compared to bright lighting conditions (M = 14.46). These results indicate that the best lighting conditions may differ depending on the level of cognitive demands of the task being performed, contradicting the assumption that brighter conditions are always better for all cognitive functions.

Interpretation of Results
Bright Light Enhancement of Working Memory
The observed advantage of bright lighting on working memory performance is consistent established theoretical frameworks and empirical evidence. The Arousal Theory provides a foundational explanation for this effect of bright light, enriched with short wavelength blue components, which increases physiological arousal and alertness, leading to improved performance in attention demanding cognitive tasks (Gao et al., 2025; Keis et al., 2014). The underlying mechanism for this effect is mediated by non-image-forming (NIF) retinal pathways, specifically through intrinsically photosensitive retinal ganglion cells (ipRGCs) that express the melanopsin photopigment (a light-sensitive, blue-light-activated (~480 nm) photopigment found in a small subset of mammalian retinal ganglion cells (ipRGCs)) (Barkmann et al., 2012; Do & Yau, 2010). These specialized photoreceptors project to subcortical regions such as the suprachiasmatic nucleus (a tiny, paired structure in the anterior hypothalamus, located directly above the optic chiasm, which serves as the primary central pacemaker for circadian rhythms in mammals) and other regions of the brain involved in the regulation of arousal, thereby modulating thalamocortical (reciprocal neuronal connections linking the thalamus and the cerebral cortex) connectivity and frontal cortical activity during cognitive tasks (Alkozei et al., 2017).

In the context of the current study, the Backward Digit Recall task requires participants to maintain and manipulate numerical information in working memory while simultaneously reversing the sequence—a process that demands sustained attention, executive control, and active maintenance of information. The heightened arousal state induced by bright lighting appears to optimize the neural networks supporting these cognitive operations (Payedar-Ardakani et al., 2024). Previous research with adolescent populations has demonstrated that bright, blue-enriched classroom lighting increases cognitive performance measures in high school students (Keis et al., 2014), and that morning bright-light exposure enhances frontal beta power—a neural marker of alertness—alongside improvements in attention and mathematical performance (Gao et al., 2025). Even brief periods of brighter light exposure have been shown to produce measurable improvements in response speed and accuracy on cognitive control tasks among adolescents aged 16–18 years (Siraji et al., 2022).

The magnitude of the working memory advantage observed in the study (approximately 7% improvement under bright conditions) is consistent with the modest but reliable effects reported in the adolescent lighting literature. This finding holds relevance for educational settings in Saudi Arabia, where classroom lighting design may significantly influence students'

capacity to engage with cognitively demanding academic tasks that rely heavily on working memory and executive functions.

Dark Light Facilitation of Metalinguistic Awareness
The finding that dark lighting conditions improved performance on the Grammatical Judgement task is more surprising and interesting from a theoretical point of view. Metalinguistic awareness, the ability to consciously reflect on and manipulate the structural properties of language, is a very different cognitive process from working memory. Working memory tasks are facilitated by high arousal and fast information processing, whereas metalinguistic judgment is a deliberate and reflective process of linguistic structure analysis, which may involve the inhibition of automatic language processing in favor of rule-based processing.

The study proposes that the performance advantage under dark lighting conditions may be explained through a mechanism we term "reflective inhibition." Under low arousal levels, as would be expected in dim lighting conditions and hence lower activation of NIF pathways, the cognitive system may shift from a processing mode that is well-suited to fast and attention-intensive processing to a mode of processing that is better suited to slow and analytical processing. This explanation has conceptual roots in dual-process theories of cognition, which assume the existence of two different modes of processing: fast and automatic processing (System 1) and slow and controlled processing (System 2) (Kahneman, 2011; Stanovich & West, 2000). The lowered arousal level in dim lighting could suppress the dominance of automatic linguistic processing, making way for the reflective analysis required in grammatical judgment tasks.

However, it is important to note that this interpretation goes beyond the direct empirical support that is currently available in the literature. The results that have been gathered from the current literature available do not provide direct empirical evidence that dim or dark lighting conditions are specifically conducive to metalinguistic or language-reflective tasks. While one study in a classroom environment found that intermediate cognitive test scores were achieved in darkened conditions compared to natural and fluorescent lighting (Aghabi & Teeling, 2023), this did not specifically isolate metalinguistic outcomes. The theoretical construct of reflective inhibition, although theoretically well-founded, remains purely speculative without direct empirical analysis. Future research using neuroimaging or process tracing methods would be useful in evaluating whether reduced arousal in conditions of dim lighting does indeed facilitate reflective cognitive processes by regulating the balance between automatic and controlled language processing.

Task-Specific Lighting Optimization
Taken together, these results indicate that the relationship between ambient lighting and cognitive performance is not linear and instead depends very sensitively on the type of cognitive task being performed. Working memory tasks, which require high levels of sustained attention, rapid information processing, and active maintenance of information in memory, seem to be facilitated by the arousal-inducing effects of bright lighting via NIF pathways and ipRGC activation (Barkmann et al., 2012; Do & Yau, 2010). Metalinguistic tasks, which involve deliberate reflection and conscious analysis of linguistic structures, may instead be facilitated by the reduced arousal state induced by darker lighting conditions.

This task-dependent pattern has important implications for understanding the mechanisms by which environmental lighting affects cognition. Rather than thinking about lighting effects as being generally beneficial or harmful, this study's findings are consistent with a more nuanced model in which the optimal lighting conditions depend on the specific demands of the task. This is consistent with general principles of cognitive ergonomics, in which environmental conditions are matched to task requirements (Li et al., 2020; Payedar-Ardakani et al., 2024).

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