NEURAL DYNAMICS OF LIGHT TEMPERATURE UNDER ATTENTIONAL LOAD

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By

Rabia Nur Kılıç

July 2024

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We certify that we have read this thesis and that in our opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Science.

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ABSTRACT

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This thesis investigates the neural dynamics of light temperature under varying levels of attentional load using EEG. The study involved twenty healthy adult participants (13 males, 7 females, mean age = 22.35) who performed rapid visual detection tasks under different correlated color temperatures (CCT) of light: 2000K, 6000K, and 10000K. The experimental design comprised 288 trials per participant, with tasks administered under low and high attentional loads. The results indicated significant variations in EEG time-frequency responses in the alpha (8-13 Hz) frequency band based on attentional load, CCT conditions, and hemisphere. The analysis revealed significant main effects of Load, CCT, and Hemisphere on mean ERSP values. Mean ERSP values were higher under low load conditions compared to high load conditions, indicating that increased attentional load enhances alpha suppression and heightens attention. Mean ERSP values were lower in the CCT conditions compared to the control condition, reflecting greater alpha suppression in the presence of distractor. Additionally, the right hemisphere exhibited significantly lower mean ERSP values compared to the left hemisphere and the midline, indicating lateralization of alpha band activity with greater alpha suppression in the right hemisphere. Behavioral data analysis showed significant differences in response times and accuracy across conditions. Participants demonstrated faster response times under cooler CCTs (6000K and 10000K) compared to the warm colors (2000K). These findings reveal the differential impacts of light temperature and attentional load on behavioral and neural activity, in which our cognitive systems respond to external stimuli.

Keywords: Correlated Color Temperature, Attentional Load Theory, Time-frequency analysis, EEG.

ÖZET

DİKKAT YÜKÜ ALTINDA IŞIK SICAKLIĞININ NÖRAL DİNAMİKLERİ

Rabia Nur Kılıç
Nörobilim, Yüksek Lisans
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Bu tez, dikkat yükünün farklı seviyelerinde ışık sıcaklığının nöral dinamiklerini EEG kullanarak incelemektedir. Çalışmaya, farklı ışık sıcaklıklarında (2000K, 6000K ve 10000K) hızlı görsel algılama görevlerini yerine getiren yirmi sağlıklı yetişkin katılımcı (13 erkek, 7 kadın, ortalama yaş = 22.35) dahil edilmiştir. Deneysel tasarım, her katılımcı için düşük ve yüksek dikkat yükü koşulları altında 288 deneme içermektedir. Sonuçlar, dikkat yükü, CCT koşulları ve hemisfere göre alfa (8-13 Hz) frekans bandında EEG zaman-frekans yanıtlarında önemli farklılıklar olduğunu göstermiştir. Analizler, ortalama ERSP değerleri üzerinde Dikkat Yükü, CCT ve Hemisferin önemli ana etkilerini ortaya koymuştur. Ortalama ERSP değerleri, düşük yük koşullarında yüksek yük koşullarına göre daha yüksek olup, artan dikkat yükünün alfa baskılanmasını artırdığını ve dikkati yükselttiğini göstermektedir. Ortalama ERSP değerleri, kontrol koşuluna kıyasla CCT koşullarında daha düşük olup, dikkat dağıtıcının varlığında daha büyük alfa baskılanmasını yansıtmaktadır. Ek olarak, sağ yarımküre, sol yarımküre ve orta hatta kıyasla önemli ölçüde daha düşük ortalama ERSP değerleri göstermiştir, bu da sağ yarımkürede daha büyük alfa baskılanması ile alfa bandı aktivitesinin lateralizasyonunu göstermektedir. Davranışsal veri analizi, koşullar arasında tepki sürelerinde ve doğruluk oranlarında önemli farklılıklar olduğunu ortaya koymuştur. Katılımcılar, soğuk CCT'ler (6000K ve 10000K) altında, sıcak renklere (2000K) kıyasla daha hızlı tepki süreleri göstermiştir. Bu bulgular, ışık sıcaklığı ve dikkat yükünün davranışsal ve nöral aktivite üzerindeki farklı etkilerini ortaya koyarak, bilişsel sistemlerimizin dış uyaranlara nasıl tepki verdiğini göstermektedir.

Anahtar sözcükler: İlişkili renk sıcaklığı, Dikkat Yükü Teorisi, Zaman-Frekans analizi, EEG.

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Chapter 1

Introduction

1.1 Physiology of Light and Color Perception

Light, a form of electromagnetic wave that stimulates vision, is a crucial environmental factor that significantly influences human physiology and behavior [57] [134] [34]. It plays an essential role in regulating the circadian rhythms by triggering the release of hormones such as cortisol, which helps manage stress responses, and serotonin, which is linked to mood regulation [27] [39]. It is a crucial component of daily living. Our mood, level of energy, and general well-being may therefore be impacted by these hormonal changes brought on by light [87] [97]. Furthermore, the significance of light in our surroundings is evident from the diverse functions it performs [136]. Whether it is the bright, fluorescent lights of a classroom, the warm glow of a bedside lamp, or the colorful lighting of a digital display, light shapes the perceptions of the spaces that people's inhabit. The illuminating properties of light significantly influence the ambiance of any environment, regardless of whether it is physical or virtual [135]. Different uses of light create distinct atmospheres and moods, evoking emotional responses and impacting cognitive processes [42] [78]. Understanding how different applications of light affect cognitive and behavioral mechanisms bears considerable implications for optimizing environments, enhancing productivity, and designing lighting interventions that foster improved cognitive performance. By investigating the complex relationship between color temperatures of illumination and attention, this thesis aims to contribute to the existing body of knowledge in the field. It seeks to investigate the nuanced effects of different light temperatures on attentional processes, examining both the potential advantages and disadvantages across a range of settings. By doing so, this thesis aims to investigates the neural dynamics of light temperature under varying levels of attentional load.

1.1.1 Structure and Function of the Human Eye

One of the brain's most intricate sensory systems, vision, is controlled by the human eye [105].It arranges and absorbs light, transforms it into electrical signals, and sends those signals to the brain for processing. As soon as light enters the eye through the cornea, sensory vision begins. Cornea is responsible for transmitting and focusing the incoming light [109]. After cornea, light reaches the pupil, a dark circular opening at the center of the iris [30]. The pupil is controlled by iris as adjusting its size depending on the amount of incoming light, preventing the retina to overwhelm from excessive amounts of light [5]. The lens, which is located behind the pupil, provides the essential function of refracting light and focusing it for the retina. This function results in acquiring distinct images of objects at different distances [4]. The retina is a light-sensitive layer in the back of the eye. The retina is composed of two different types of specialized photoreceptors named rods and cones [106]. Through a process called phototransduction, these specialized cells transform the light into electrical impulses and transmit those signals to the brain via the optic nerve [3]. Therefore, these specials cells are essential in visual processing. After the electrical signals have arrived to the brain, they are processed and interpreted in there. Electrical impulses are merged and evaluated by the brain's intricate neural networks to create visual representations that people see as their environment [145].

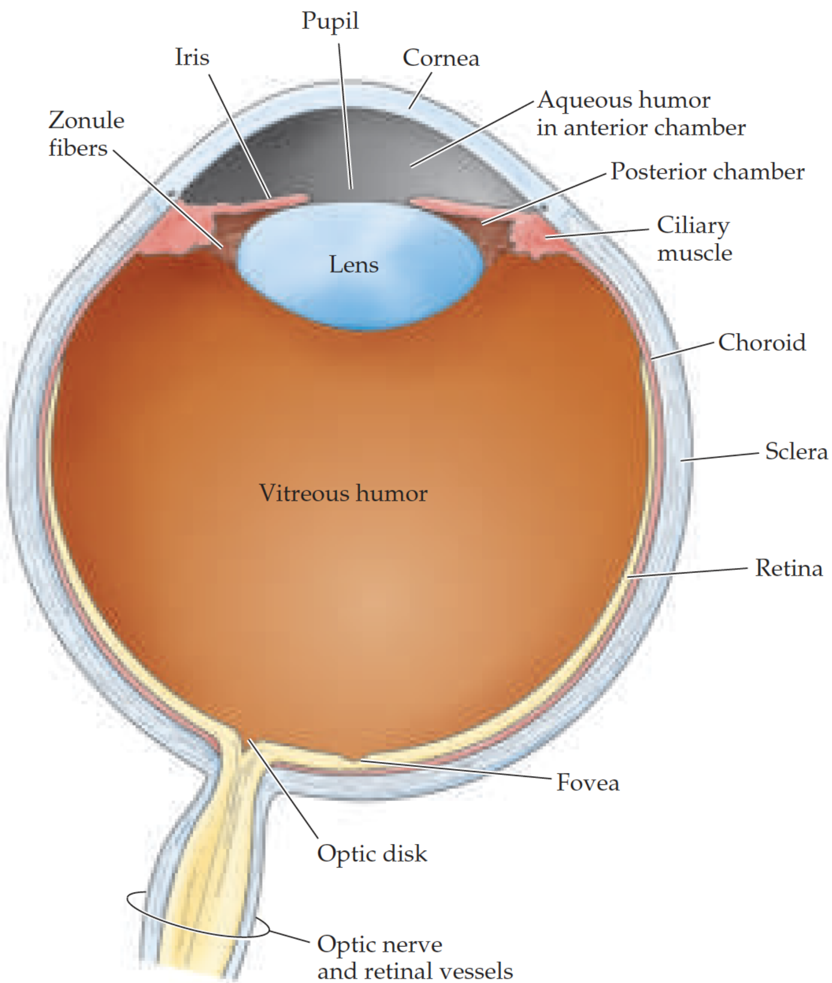

Figure 1.1: **Anatomy of the human eye.** This diagram shows the essential parts of the human eye that are necessary for the process of vision. Light first enters through the cornea, which focuses it as it travels to the lens. The lens further adjusts focus, directing light towards the retina at the back of the eye. The retina contains photoreceptors (rods and cones) that convert light into electrical signals, which are transmitted to the brain via the optic nerve, facilitating vision. Reused with permission from Agustine et. al., Neuroscience 3rd Edition; published by Sinauer Associates, 2004. [7].

1.1.2 Photoreceptors and Light Sensitivity

The main photoreceptor cells that mediate the physiological effects of light are cones and rods that reside in the retina of human eyes. The brain receives the electrical signals which these cells convert from light energy through the optic nerve [32]. However, not all light has the same effect on physiological processes; specific wavelengths of light or colors can also have a big impact. Cones are primarily responsible for color vision. They are concentrated in the fovea, which is the center of the retina and where high-acuity vision is produced [7]. Cones are sensitive to many light wavelengths, which enables us to distinguish a variety range of colors. The trichromacy principle, which states that there are three types of cones that respond to distinct light wavelengths—blue, green, and red, respectively—is the basis for color discrimination [100]. People are able to distinguish between various hues and see a wide range of colors because to the joint activation of these cones [7]. On the contrary, rods are more sensitive to low light levels and are principally in charge of vision in the dim or dark conditions. They are more evenly distributed in the retina's periphery and less concentrated in the fovea. Although rods lack color vision, they are very sensitive to low light levels, enabling us to perceive objects and navigate in dim lighting conditions such as night [100]. This explains why, for instance, when people are in a dark room, their peripheral vision frequently performs better than their center vision in identifying weak objects [82]. In summary, these specialized photoreceptors allow us to perceive a quality of visual experience in different environments and range of lighting conditions.

1.1.3 Neural Coding of Color

The perception of color involves several brain areas working together. The neural coding of color begins as electrical signals from the photoreceptors in the retina are transported and reach numerous visual processing regions in the brain. One of the area where the most of the color information encoded is the primary visual cortex (V1)[137]. Because, the V1 has specific neurons, simple and complex cells, that are selective to different visual features including color [144]. Within the visual cortex, there are also specialized higher regions called V2 and V4 that are particularly involved in color processing. Neurons in V4 exhibit more advanced color selectivity and a greater range of colors. They support to the perception of specific hues, color constancy, and the integration of color information with other visual features [129] [137].

The thalamus is also a structure that is located deep within the brain. It also plays a role in getting visual information from the eyes to the visual cortex. The lateral geniculate nucleus (LGN) is a structure located within the thalamus. The LGN is in charge of processing color information in the visual cortex before it is sent to the processes of color perception [140]. Additionally, other brain regions that affect color perception include the inferior temporal cortex (IT) and posterior parietal cortex (PPC) [26] [79]. These areas participate in higher-order processing, including the identification and classification of colors as well as other visual features including object and spatial awareness. Lastly, the color information is also processed in the other higher regions such as the prefrontal cortex. The executive functions are encoded here based on the contextual cues and top-down influences such as how people see color based on their environment [89] [151].

The neural coding of color is influenced by contextual factors and top-down processes. Factors such as lighting conditions, surrounding colors, and individual expectations can also modulate color perception and the neural responses to color stimuli. This demonstrates the complex nature of color processing in the brain and its interaction with other cognitive processes. In summary, these are the some of key regions that play a role in color perception. However, the neural networking of color is a complex process that requires interaction of multiple brain regions.

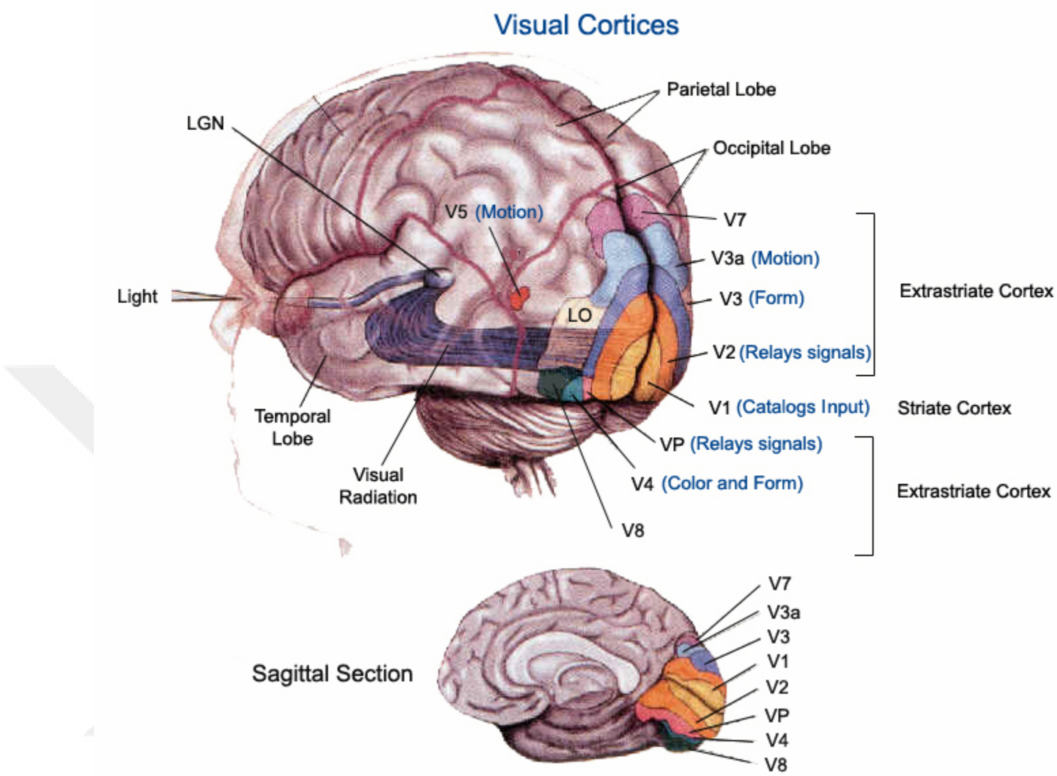

Figure 1.2: **Visual Cortices and Pathways in Color Perception.** This illustration represents the neural pathways and cortical areas involved in the perception of color. Light signals, processed by the retina, are transmitted through visual radiation to various cortical regions. Notable areas such as V1, V2, V4, and V5 are marked to show their roles in initial and advanced color processing. The diagram also highlights the lateral geniculate nucleus (LGN) within the thalamus and its function in this intricate network [102].

1.1.4 Neural coding of environments

fMRI Studies on Environmental Perception:

fMRI studies have been instrumental in identifying the brain regions specifically engaged in environmental perception. Key areas include the parahippocampal place area (PPA), retrosplenial complex (RSC), and the occipital place area

(OPA) [68]. These areas are pivotal in recognizing and spatially representing an environment's layout and features [38].

The PPA is known for processing scenes and environmental layouts, often activated by images of landscapes and interiors [111]. It plays a crucial role in recognizing the gist of an environment, helping the brain to categorize and store spatial layouts [41].

The RSC, located at the interface of the parietal and occipital lobes, integrates information about the environment with one's positional awareness within it, crucial for spatial navigation and memory. Its connectivity with both hippocampal and neocortical regions places it centrally in memory retrieval and contextual association processes [111] [142].

The OPA, in the occipital lobe's ventral pathway, handles the detailed visual processing of an environment's features, such as boundaries, edges, and colors [38].

This area complements the PPA by focusing more on the local features of a scene rather than its holistic view [68]. Together, these regions form a robust network for processing visual information, crucial for creating mental maps and interacting effectively within various spaces [68][2].

EEG Studies on Environmental Perception:

While fMRI provides insights into the 'where' of brain activities during environmental perception, EEG provides the 'when,' offering a dynamic view of how these processes unfold over time. EEG studies have shown that specific frequency bands are linked with different aspects of environmental processing.

- **Theta Waves in Navigation and Spatial Memory:**Theta waves, typically ranging from 4 to 8 Hz, are prominently observed in hippocampal and neocortical regions during navigation and spatial memory tasks [108]. These oscillations are particularly linked to movement and exploration in both real and virtual environments [67]. Research has shown that theta rhythms are not only a marker of navigation in space but also crucial for the encoding of new spatial information and the retrieval of spatial memories [22]. In virtual environments, where direct sensory feedback differs from real-world interactions, theta waves facilitate the integration of visual cues with spatial memory, supporting orientation and wayfinding [35].

For instance, a study by Ekstrom et al. (2005) demonstrated that theta activity increases in the hippocampus as individuals navigate through virtual environments, suggesting a direct role of theta rhythms in spatial navigation and memory formation [40]. This is supported by findings that disruptions in theta oscillation patterns can impair navigational abilities and spatial learning, underscoring their importance in environmental encoding [93].

- **Alpha Waves in Environmental Perception and Cognitive Regulation** Alpha waves, typically ranging from 8 to 13 Hz, are prominently involved in inhibitory control and attentional processes, particularly within the context of environmental perception [80] [76]. These waves are often associated with states of relaxation and calmness but play a crucial role during tasks requiring alertness and spatial awareness [76]. In environmental coding, alpha oscillations are thought to regulate the suppression of irrelevant sensory information, thereby enhancing the processing efficiency of pertinent environmental stimuli [77] [64].

  Studies have shown that alpha waves modulate attention by inhibiting distracting information, which allows individuals to concentrate on specific aspects of their environment more effectively [63][43] [75]. For example, when navigating complex environments or during tasks that require focused spatial attention, increased alpha activity can help to filter out non-essential sensory inputs, aiding in the more efficient processing of critical navigational cues [76] [71]. This mechanism is vital for effective interaction with environmental conditions.

  Furthermore, the role of alpha waves in cognitive load management during environmental interaction has been explored in various neuroimaging studies. These investigations reveal that fluctuations in alpha activity can reflect changes in cognitive demand as the environment alters, providing insights into the brain's adaptive strategies to maintain optimal levels of environmental engagement and awareness [152] [1]. This adaptability is particularly important in understanding how individuals navigate and remember spatial environments, whether they are natural settings or complex virtual simulations.

- **Beta Waves in Environmental Interaction** Beta waves, which range from 13 to 30 Hz, are associated with the brain's cognitive processes involving active thinking, problem-solving, and decision-making. In the context of environmental perception, beta activity is linked to the processing of visual and proprioceptive information necessary for anticipating and interacting with physical obstacles or changes in the environment. Beta oscillations facilitate the maintenance of the current motor and cognitive state, which is essential for interacting with complex environments.

  Research by Sipp et al. (2013) found increased beta activity in motor and prefrontal areas when participants navigated through spaces requiring frequent adjustments to avoid obstacles, indicating a role for beta waves in the anticipatory processes needed for successful navigation [117]. This suggests that beta waves may modulate attention and motor processes to adapt behaviors based on environmental demands.

- **Gamma Waves in Sensory Integration** Gamma oscillations, typically above 30 Hz, are critical in the processing and integration of multisensory information, which is crucial for forming a coherent perception of the environment [99]. These high-frequency waves are linked to the binding of sensory features across different modalities, such as visual, auditory, and tactile inputs, allowing for a unified experience of the environment [99] [17] [64].

  A study illustrated that gamma activity increases in sensory cortices when participants are exposed to congruent multisensory environmental stimuli, as opposed to incongruent stimuli, suggesting a role in sensory integration [125]. Gamma waves facilitate rapid information processing and cross-modal sensory binding, which are essential for navigating and understanding complex environments effectively.

These studies collectively enhance our understanding of how specific regions and the neural oscillations of the brain contribute to different aspects of environmental perception, from navigation and anticipation to sensory integration, each playing an important role in how people perceive and interact with surrounding environments.

1.2 Color Temperature of Illumination

By the definition, light is an electromagnetic radiation of linear wavelength [60]. It is one of the most important factors affecting people's daily life, and has a great role in the biological and physiological evolution of the human brain. The advent of artificial lighting transformed how humans interacted with their environment, replacing reliance on sunlight with a controlled, versatile illumination source [103]. With rapid urbanization and architectural advancements, light has become indispensable in everyday life, providing not only functionality but also shaping aesthetics and ambiance in modern environments [126] [34].

It is a complex phenomenon with several primary properties, including reflection, refraction, and the ability to travel in straight lines [14]. It can be measured using units such as the candela, lumen, lux, and candela per square meter [54]. Light can be described as a wave, a quantum particle, or a quantum field [53]. It also has a dualistic nature, exhibiting both wave and particle properties [123]. The propagation of light beams can be described using Maxwell's equations, and light can interact with matter in various ways [58]. As part of the electromagnetic spectrum, light is measured in terms of wavelength (frequency) [23].

Visible light, falling within the 400 to 700 nanometers (nm) wavelength range of the electromagnetic spectrum, is the portion that the human eye can perceive [29]. The wavelength of light, in particular, affects how colors appear to the human eye. Each wavelength within this range is associated with a distinct color, where shorter wavelengths denote higher energy and bluer hues, while longer wavelengths indicate lower energy and redder colors [8]. It is linked to the color of light emitted by a heated light source associated with a reference source, often referred to as correlated color temperature (CCT) [107].

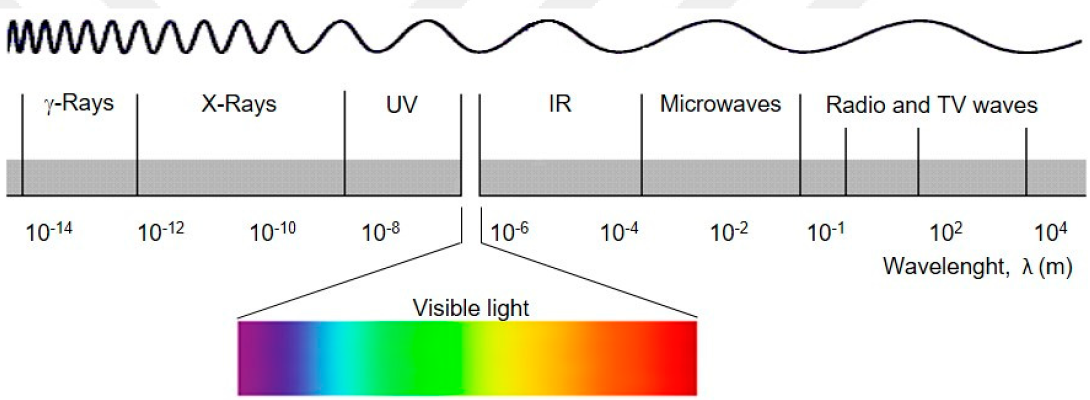

Figure 1.3: **The Electromagnetic Spectrum.** This figure illustrates the different types of electromagnetic radiation with respect to wavelength. The spectrum includes gamma rays, X rays, ultraviolet, visible light, infrared, microwaves, and radio waves. The visible light portion is highlighted and expanded to show the range of wavelengths detectable by the human eye [24].

Correlated color temperature (CCT), which is measured in Kelvin (K), is a metric that describes the color appearance of a light source and plays a critical role in shaping the atmosphere of illuminated spaces. It quantifies how "warm" or "cool" the light appears based on the comparison to a theoretical blackbody radiator. A lower CCT (less or equal to 3300 K) produces a warm, yellowish light akin to incandescent bulbs, while a higher CCT (above 5300 K) results in a cooler, bluish-white light often associated with daylight or fluorescent lamps [49]. The International Commission on Illumination's (CIE) color space from 1931, which established the first mathematically defined color spaces, and the CIE 1976 color space (see Figure 1.4), which improved perceptual uniformity, provide the foundational frameworks for understanding and quantifying these colorimetric properties [29] [31].

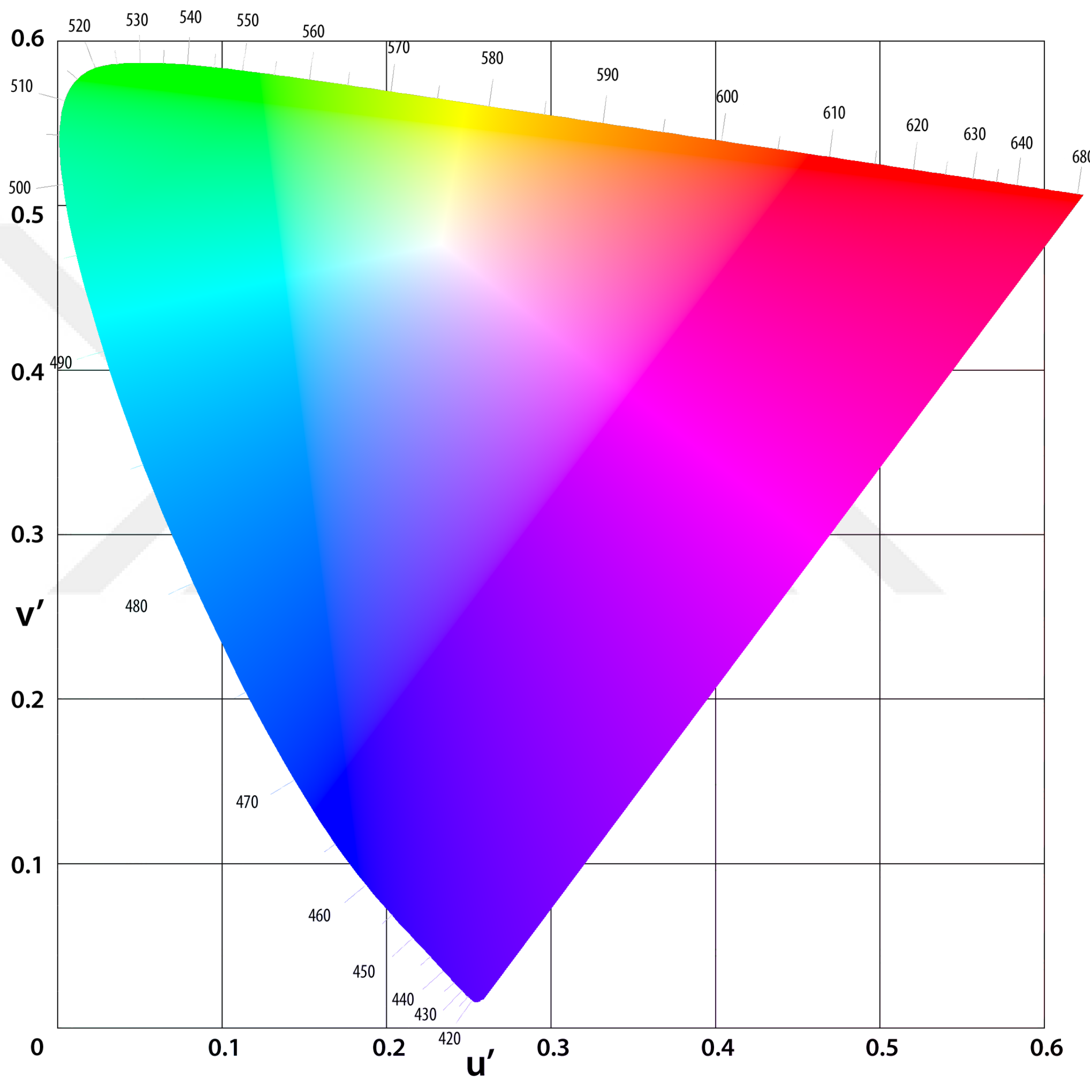

Figure 1.4: **CIE 1976 Uniform Chromaticity Scale (UCS) diagram.** This diagram shows the chromaticity coordinates (u', v') and the range of colors visible to the human eye. The boundary indicates different wavelengths of light, and the diagram is designed to be perceptually uniform, where distances correspond to perceived color differences [31].

Light sources within the warm temperature range (approximately 2000 K to

3300 K) emit a cozy, comforting glow akin to traditional incandescent bulbs or candlelight [12] [49]. Studies indicate that CCT around 2700K is particularly the most relaxing light for sleep, making warm light conducive to environments where comfort and relaxation are prioritized [147].

Neutral white light, falling in the CCT range of 3300 K and 5300 K, mirrors natural daylight and provides balanced illumination that is neither too warm nor too cool [49]. This light quality is especially advantageous in educational settings, such as classrooms, where a CCT of 3300-4300 K is often considered optimal [49]. It reduces glare while maintaining good visibility, which is essential for concentration and learning effectiveness [150].

At the higher end of the spectrum, cool light (approximately 5300 K and above) projects a bluish-white hue reminiscent of a clear midday sky [49]. This lighting type is rich in blue and green wavelengths, which are known to enhance focus and alertness, crucial in precision-required settings [101] [50]. For office lighting, it is recommended with a color temperature of 6500 K or 10000 K for work performance and visual perception [146]. Moreover, CCTs closer to 5700 K have been shown to suppress melatonin, thereby promoting alertness and improving task performance in environments where high cognitive function is required [6].

In summary, the relationship between wavelength and perceived color, coupled with the concept of correlated color temperature, offers valuable insights into how artificial light sources can be tailored to elicit specific emotional responses, enhance visual comfort, and optimize the overall lighting experience in different settings. By considering these dimensions in lighting design and engineering, professionals can create lighting solutions that align with human needs, foster well-being, and enhance the visual aesthetics of spaces.

1.2.1 Psychological Effects of Correlated Color Temperature

The influence of light on human physiology and psychology has been a topic of extensive research. Correlated color temperature (CCT) is a crucial characteristic of light that significantly impacts people's physiological and psychological responses. Hence, this chapter discusses the findings from current literature on the effects of different color temperatures of light.

The relationship between lighting and human behavior has been a subject of interest for researchers since Kruithof's pioneering work (1941) on general illumination [81]. In his studies, Kruithof investigated how the color temperature of light affects human visual comfort and perception. He observed that the color of light significantly influences the subjective feelings of individuals in a given environment. Specifically, Kruithof discovered that as the correlated color temperature (CCT) of light increases, there is a corresponding shift in visual comfort and preference [81].

At very low CCT values, such as candlelight, individuals may find the light visually comfortable due to its warm, reddish hue. On the other hand, at high CCT values, like daylight, people tend to prefer cooler, bluish light. Kruithof's pioneering research laid the foundation for subsequent studies on the psychological and physiological effects of different CCTs on human behavior, with specific attention to factors like attention, productivity, and mood [81]. The findings were encapsulated in what later became known as "Kruithof's curve", a graphical representation depicting the relationship between correlated color temperature and visual comfort (see Figure 1.5). This concept has been instrumental in guiding lighting design and research to create environments that promote well-being and optimal human performance.

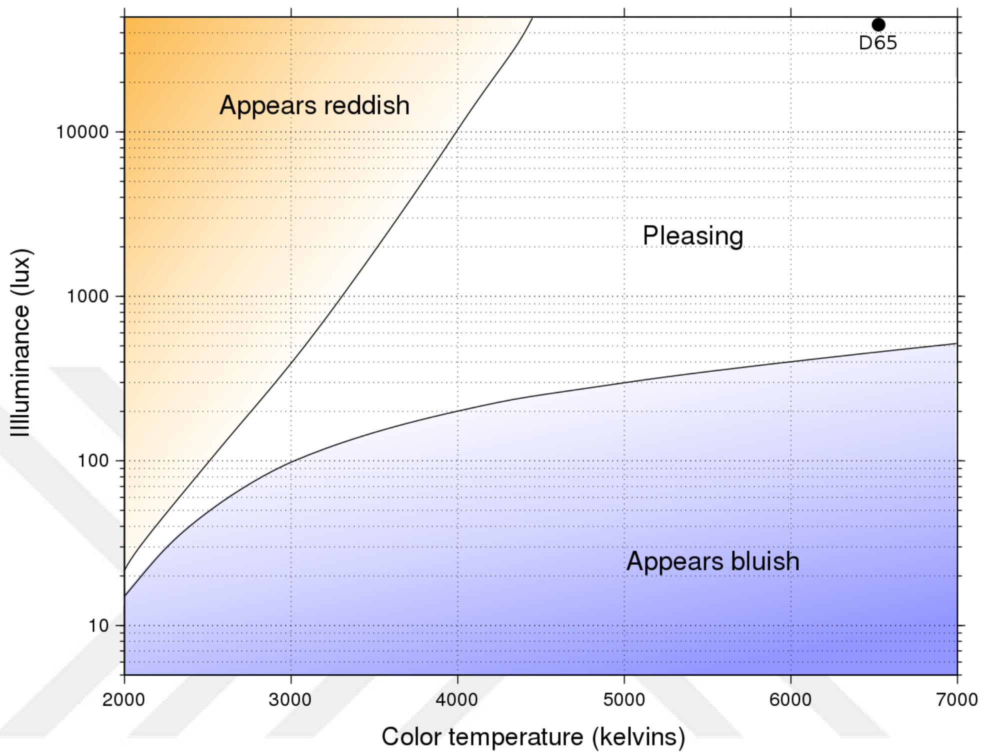

Figure 1.5: **The Kruithof's Curve.** It shows the relationship between the correlated color temperature (CCT) of a light source and the perceived pleasantness of its illumination. The graph divides the space into three regions: areas where the light appears reddish, areas where it appears bluish, and a central area where the light is perceived as pleasing. The point marked D65 represents the standard illuminant used for colorimetry, which corresponds to average daylight with a CCT of about 6500K [81].

Studies on CCT Effects on Comfort: Since then, a lot of factors have been the focus of recent studies on the topic of the effects of CCT. One of the most studied areas in these recent studies is the impact of CCT on comfort and relaxation. Research indicates that warm light color temperature (below 4000K) plays a pivotal role in promoting feelings of comfort and relaxation. Warm light mimics natural evening light, evoking a response similar to sunset. This warm glow may activate the body's relaxation mechanisms by decreasing cortisol (the stress hormone) production and potentially increasing melatonin (the sleep hormone) secretion [15]. Psychologically, studies have shown that warm light is associated with positive emotional states like calmness, security, and intimacy , which may be linked to evolutionary experiences where firelight provided warmth, safety, and social connection in the evening [153].

From a physiological standpoint, exposure to warm light can result in reduced heart rate and blood pressure, further promoting relaxation [138] . Warm light may also stimulate the parasympathetic nervous system, responsible for relaxation and digestion, countering the fight-or-flight effects of the sympathetic nervous system [149]. Design considerations, such as combining warm color temperature with lower light intensity (illuminance), can further enhance comfort and relaxation by creating a calming ambiance [44].

In contrast, recent studies have expanded the focus to the effects of correlated color temperature (CCT) on thermal perception and comfort. For instance, a recent study found that higher CCTs were linked to cooler thermal perceptions among undergraduates in different environments [88]. Another study challenged the traditional hue-heat hypothesis, showing that light at 5700K improved thermal comfort, cognitive performance, arousal, and alertness during mild cold exposure [92]. However, another study observed that people felt more thermally comfortable with a CCT of 4000K in an indoor workplace, countering the hue-heat hypothesis [10]. These findings highlight the intricate relationship between CCT and thermal perception, influenced by varying environmental conditions and exposure durations.

Studies on CCT Effects on Cognitive Performance: Studies investigating the effects of CCT on cognitive performance have also shown promising results. Studies suggest that specific lighting conditions can positively impact cognitive function. For instance, Keis et al. (2014) found that blue-enriched white light improved information processing speed and concentration in high school students [70]. Similarly, another study reported that a higher CCT illumination benefited reaction time in attention and executive function tasks, although the effects varied by gender[56]. Specifically, females showed improved task-switching, while males demonstrated faster response times on go/no-go tasks under such lighting conditions.

Beyond these specific tasks, a study in office environments demonstrated that modern shading systems that provide ample daylight and a view can enhance cognitive function, user satisfaction, and even reduce eyestrain [61]. These findings highlight the potential of CCT to influence various aspects of cognitive performance in different settings.

Conversely, warm light (below 4000K) might not be ideal for peak alertness but could offer benefits for other cognitive functions. While it may not be optimal for tasks requiring sustained focus, warm light could promote feelings of comfort and relaxation, potentially benefiting tasks requiring creativity or divergent thinking [153].

Adding another layer of complexity, individual sensitivities to CCT and its interaction with light intensity (lux) necessitate personalized lighting solutions in learning environments. Boyce et al. (2006) emphasize the importance of individual variations, highlighting that people might respond differently to varying light spectrums [19]. Their research further underscores this point, suggesting that higher illuminance with cool light might have a stronger effect on alertness compared to warm light at a lower intensity.

In conclusion, the physiological and psychological effects of different color temperatures of light are multifaceted and complex. Understanding the relationship between color temperature and human responses can help optimize lighting design in various settings for improved comfort, productivity, and satisfaction.

1.2.2 Impact of Correlated Color Temperature on Attention

Another topic of interest concerning the efficient use of correlated color temperature (CCT) is its impact on attention. Recent studies have been conducted to explore how CCT influences attention and how it can be optimized lighting environments in various settings, such as schools, workplaces, or multi-functional spaces.

Attention and LED Lighting: Research into the effects of LED lighting on attention underscores how spectral power distribution directly influences cognitive processes. In a crossover study, blue-enriched light enhanced attention in the morning for typically developing adolescents, while red-enriched light provided slight benefits for evening sleep [116]. These findings reveal that different wavelengths of light have distinct effects on attention and sleep during key developmental stages.

In another study, it is explored the relationship between various LED illuminance levels (ranging from 300 lx to 1000 lx) and their impact on attention and long-term memory in college students [25]. Attention performance peaked at 1000 lx, while long-term memory was highest at 400 lx. This study emphasizes the significance of understanding and applying different illuminance levels tailored to specific cognitive processes when designing effective lighting environments.

CCT and Focused Attention: Recent research has focused on examining how varying CCT conditions affect focused and sustained attention. In a study, the researchers analyzed three different CCT settings (2700 K, 4300 K, and 6500 K) under white LED desk lighting using the Chu Attention Test [59]. The results showed that participants exhibited significantly better focused and sustained attention under the 4300 K condition compared to the other two. These findings emphasize the importance of selecting appropriate CCTs to promote focused attention, particularly in educational and work environments.

Effects on Alertness and Cognitive Performance: Higher CCTs can influence alertness and cognitive performance. Chellappa et al. (2011) found that 6500 K fluorescent light improved cognitive performance, mood, and visual comfort, particularly in tasks requiring sustained attention [27]. This lighting also led to greater melatonin suppression, resulting in faster response times. In a related study, Shamsul et al. (2013) observed that artificial daylight (6500 K) resulted in increased subjective alertness and computer-based performance compared to warm white light (3000 K) [132]. Furthermore, Park (2013) noted that higher color temperatures increased alpha power, leading to more pleasant feelings in bright conditions, and improved relaxation in warm CCT environments

[110]. Together, these studies suggest that CCTs in the 5800 K to 6500 K range enhance alertness, cognitive performance, and mood.

Inconsistencies in Attention Effects: While research has shown that CCT and lighting intensity impact cognitive functions, some inconsistencies persist. Hartstein et al. (2018) found that light color temperature did not significantly affect sustained attention but positively impacted task-switching performance at higher temperatures (5000 K) [56]. In neuroscientific studies, it is observed that light color temperature (3000 K and 7100 K) had no significant effect on sustained attention but significantly affected ERP components and EEG alpha activity (P1 amplitudes and parietal alpha oscillations) [98]. Bao et al. (2021) found that P3b amplitudes were significantly affected by light color temperature [11].

Research on CCT and attention provides valuable insights into the relationships between lighting environments and cognitive processes. Although inconsistencies exist, the evidence highlights the significant role of appropriate CCT and illuminance levels in optimizing attention and cognitive functions across diverse settings. A more comprehensive understanding of the mechanisms involved will enable the design of effective lighting interventions to enhance attention and overall cognitive capabilities, leading to improved well-being and productivity. Further research is essential for building evidence-based lighting solutions that meet the specific cognitive needs of individuals in various settings.

1.3 Selective Attention and Attentional Load Theory

Attention, in the context of human perception, refers to the cognitive ability to focus on certain aspects of the overwhelming sensory information people encounter constantly. This information flow is so rapid and comprehensive that it encompasses all the colors, buildings, people, sounds, smells, or the feel of the air temperature that people encounter while walking on a street. Due to the limited capacity of attention, people's brains process only certain sensory experiences from this vast information flow [139]. These processed sensory inputs are the ones that direct our attention or suddenly capture our attention. Therefore, attention is a fundamental aspect of human perception and cognitive functioning, allowing us to prioritize and process information efficiently in our environment. While people shift their attention to these significant events, all the remaining information either quietly fades into the background or passes unnoticed. The selective attention is the phenomenon in which the brain ignores irrelevant stimuli in the environment and directs its attention to important stimuli [65].

In the literature, there are several models and theories that explain selective attention. Some of these theories are early-selection theory, late-selection theory, and perceptual load theory. Early-selection [20] and late-selection [37] theories have been the subject of significant debates and controversies in the past literature, with relatively opposing views [72] [66] [119] [133]. According to the early-selection theory, the selection occurs before the semantic processing of stimuli, while according to the late-selection theory, the selection occurs after the semantic processing of stimuli. Although both theories have made important contributions to the field, they have inherent limitations that they cannot explain in isolation. One of the problems that early selection cannot explain, also known as the cocktail party problem [28], is the phenomenon where attention does not completely ignore the surrounding stimuli when focused on one direction and can even switch its focus when there is a meaningful stimulus. The problem with late-selection theory is that our attention does not have the capacity to process all stimuli.

On the other hand, the perceptual load theory [85] presents a hybrid model that offers a new approach to both early and late-selection theories. According to this model, as supported by the early-selection theory, our perception has a capacity, and as supported by the late-selection theory, the stimuli outside our focus, i.e., distractors, are not completely ignored. However, the processing of this information depends on the load of perception at that moment. When the perceptual load is low, for example, when people are performing a simple action, the influence of distractors is high, and they are more likely to be processed. But when their perceptual load is high, for instance, when people are performing a complex task, the detection and modulation of these distractors become much more difficult. Therefore, perceptual load plays an important role in the selection process and determines whether early or late selection is observed.

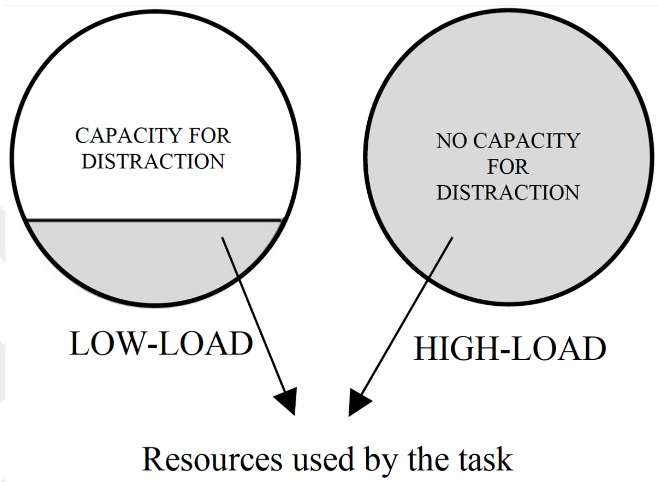

Figure 1.6: **The impact of attentional load on cognitive resources.** The diagram shows two circles representing cognitive resource allocation. In the low-load condition, only a portion of the resources are used, leaving capacity for distraction. In the high-load condition, all resources are utilized, leaving no capacity for distraction.

This theory has also been supported by numerous neurophysiological and neurobiological studies in recent years. For instance, in a recent cellular study, when they measured neural metabolism, it was observed that in conditions of high perceptual load, there was an increased demand for energy, and the brain used a balancing mechanism due to its limited capacity, resulting in a decrease in the energy spent on processing distractor stimuli [21]. Similarly, another study conducted a functional MRI study to investigate the perception of environmental stimuli based on the attention load [131] . They used different instructions to manipulate attention load while participants were asked to detect certain stimuli among different colored and oriented T shapes (upright or inverted). Through this manipulation, they observed that the primary visual cortex (V1) activation decreased in conditions with high-attention load. However, the exact timing of the decreased activation on V1 was not clear in this study, so it remained unknown whether the change affected early processing or feedback. In another study, it is used a similar set of stimuli and tasks, employing a high-density EEG device to monitor the effect of attention on early visual evoked potentials activation in real-time [121]. They found significant differences in the P1 and N1 amplitudes after the stimulus onset in response to different attention loads, aligning with previous findings.

1.3.1 EEG Studies in Attention and Attentional Load Theory

Selective attention and attentional load are critical areas of study within cognitive neuroscience, particularly using electroencephalography (EEG) to explore the underlying neural mechanisms [104]. EEG studies provide insights about the neural processes involved in filtering relevant from irrelevant information [122]. The perceptual load theory, proposed by Lavie, suggests that the efficiency of selective attention depends on the perceptual load of a task [86] [85]. High perceptual load consumes more attentional resources, thereby minimizing the processing of distractors. Schneider et al. (2021) discuss how alpha oscillations are crucial in both target enhancement and distractor suppression, modulating differently under varying task demands [130]. Their findings are supported by EEG studies that show decreased alpha power in regions processing distractors during high-load tasks [113].

Alpha suppression refers to the reduction in alpha power (typically in the 8-12 Hz frequency range) observed in EEG recordings when the brain is engaged in a task requiring focused attention [148] [75]. This suppression is believed to reflect the active inhibition of neural activity in regions processing irrelevant information, allowing for more efficient processing of task-relevant stimuli [45]. Schneider et al. (2021) highlighted that alpha power increases in regions processing distractors and decreases in regions processing targets, indicating distinct functional roles for alpha oscillations [130]. These findings align with studies demonstrating that alpha oscillations implement both target enhancement and distractor suppression [148] [75] [45].

Cognitive load, particularly working memory load, significantly impacts selective attention. Parks et al. (2009) demonstrated that visual perceptual load modulates auditory reflexes, indicating cross-modal influences of attentional load [114]. High working memory load impairs the brain's ability to filter out distractors, resulting in increased processing of irrelevant stimuli. EEG markers, such as changes in P300 amplitudes and alpha power, reflect the impact of cognitive load on attentional control [128]. Additionally, EEG studies have highlighted the role of early visual evoked potentials in attentional processes. It is also found that the significant differences in the P1 and N1 amplitudes in response to varying attentional loads [48]. These early components are sensitive to the allocation of attentional resources, with higher loads resulting in reduced amplitudes, reflecting diminished processing of irrelevant stimuli.

Recent EEG research focuses on the temporal dynamics of attentional load and selective attention using high-density EEG and time-frequency analysis. Alpha oscillations, specifically, have been identified as crucial for attentional processes [148] [75]. Lower alpha power is associated with enhanced target processing, while increased alpha power is linked to the suppression of distractors [75]. Studies such as those by Handy et al. (2001) have shown that perceptual load can modulate attentional selection early in visuocortical processing, as evidenced by reductions in the sensory-evoked P1 component for task-irrelevant stimuli when perceptual load is high [55].

The occipital region plays a pivotal role in visual attention, with significant alpha suppression observed in visual tasks requiring focused attention [131]. Rauss et al. (2009) highlighted how alpha suppression in the occipital cortex is more pronounced during high attentional load, underscoring its importance in managing visual attention [121]. EEG studies consistently show that alpha power in the occipital cortex decreases when attention is directed towards visual stimuli, supporting the link between alpha oscillations and attentional control [71]. Additionally, Rorden et al. (2008) found that increasing perceptual load leads to increased responses for target stimuli and decreased responses for irrelevant stimuli, as evidenced by event-related potentials [124]

Moreover, studies on intersubject correlations using EEG have shown that selective attention can be tracked through shared neural responses among individuals engaged in similar tasks. Rees et al. (1997) demonstrated that the degree of neural synchrony, measured by intersubject correlations, is higher for attended stimuli compared to ignored ones [122]. This indicates that selective attention not only modulates individual neural activity but also aligns neural responses across different individuals engaged in the same task.

1.4 Current Study

Building on the extensive research showing how light and color affect human cognition and physiology, this thesis aims to explore the detailed effects of light temperature on attention. The primary objective of this research is to systematically examine how different correlated color temperatures (CCTs) influence neural dynamics, with a specific focus on attentional load.

This study is motivated by the hypothesis that light temperature could significantly modulate cognitive functions through its impact on the mechanisms of visual attention. The CCTs selected for this investigation—2000K, 6000K, and 10000K—encompass a spectrum of light conditions that mimic both natural and artificial environments. This provides a comprehensive basis for analyzing the psychological and physiological responses to varied lighting scenarios.

To achieve these objectives, a rigorous experimental design is employed, assessing the effects of these CCTs and different attentional loads on cognitive and neurophysiological responses during rapid visual detection tasks [120] [131]. These tasks simulate typical visual challenges encountered in everyday life and professional settings, ensuring the ecological validity of the study. The choice of CCTs allows for a detailed examination of how warm versus cool light impacts cognitive load, potentially leading to significant insights into how attentional capacities are influenced by environmental lighting.

Understanding the interaction between light temperature and cognitive performance could lead to better lighting designs in environments as diverse as schools, offices, hospitals, and homes. For instance, educational settings could optimize light conditions to enhance students' concentration and learning capabilities, while office environments could adjust lighting to maximize productivity and reduce visual fatigue. However, this research specifically focuses on virtual coffeeshop environments, which, while not originally designed as study environments, have recently been used by many people for study and work purposes. Since there is no existing research on these newly multi-purpose environments, coffeeshop environments were chosen for this study.

In conclusion, this thesis investigates the impact of different correlated color temperatures (CCTs) on attention, with a particular focus on neural dynamics and attentional load. By examining the effects of 2000K, 6000K, and 10000K light temperatures, the study aims to provide a comprehensive understanding of how varying lighting conditions influence cognitive and physiological responses during visual detection tasks.

Chapter 2

Methods

2.1 Participants

Twenty healthy adult participants were recruited, aged between 18 and 29 years (mean age = 22.35, SD = 3.8). The sample consisted of 13 males and 7 females, from different departments in Bilkent university. All participants were selected through a rigorous screening process to ensure they had no history of neurological or psychiatric disorders, were not currently taking medications that could affect neural activity, and had normal or corrected-to-normal vision. All participants provided informed consent to take part in the study and were compensated for their time. The participants consist of Bilkent University undergraduate and graduate students, and they were randomly assigned to two groups for the experimental order (Low-High or High-Low order), by respecting the equal number for each group. To maintain anonymity and confidentiality, each participant was assigned a unique numerical code for data analysis. The necessary ethical approval for the study was received from İhsan Doğramacı Bilkent University Human Ethics Committee (2023/02/25/01). This research was conducted in compliance with the ethical guidelines of İhsan Doğramacı Bilkent University Human Ethics Committee, and all participants were treated in accordance with the Declaration of Helsinki.

2.2 Stimuli and Apparatus

2.2.1 Experimental Stimuli

The primary visual stimuli employed in this study encompass a total of 6 distinct "T" shapes, each having two different orientations; straight (upward orientation) and upside down (downward orientation). Additionally, each of these "T" shapes is presented in one of three different colors; red, yellow, or green for each orientation. This results in a total of six unique target stimuli.

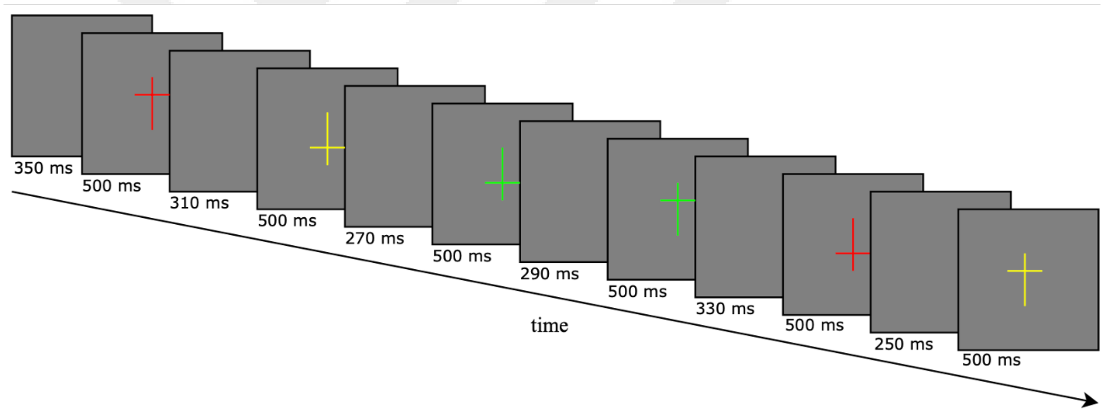

Figure 2.1: **Experimental Visual Stimuli and Setup.** A glimpse into an experimental trial showcasing the array of "T" shapes in varying orientations and colors, each presented for precise durations amidst randomized intervals. Adapted from established methodologies, these stimuli form the core of attentional load investigations.

The presentation of these stimuli occurs at the center of a computer screen and lasts for 500 milliseconds, followed by a series of interstimulus intervals, which vary between 250 milliseconds and 350 milliseconds with 20 milliseconds differences. The presentation of these foveal stimuli is randomized to create individual experimental trials. Figure 2.1 provides a representation of an example experimental trial. The creation of these experimental stimuli was accomplished using the Psychtoolbox library within the MATLAB software environment. These stimuli were adapted from prior studies focused on measuring attentional load in brain imaging [121] [131]. Although stimulus presentations remain consistent across different attentional load conditions (low load and high load) in the experiment, participants are provided with distinct task instructions for responding to the target stimuli.

2.2.2 Distracting Stimuli

To assess one of the independent variables in the experiment, the color temperature of light, virtual spaces featuring various light color levels utilized as distracting stimuli. These virtual spaces were created using Lumion 12 Pro 3D Rendering software. These virtual spaces replicate a café setting, with each environment sharing identical features, including furniture, layout, and decor. The distinguishing factor among these virtual spaces lies in the variation of light color temperature. Within the experiment, three distinct light colorations are implemented, each corresponding to a specific Kelvin value: 2000 K, 6000 K, and 10000 K. These Kelvin values represent a range of light color temperatures, from warm to cold hues, simulating different lighting conditions within the café environment.

The virtual café environments captured from various angles, to provide comprehensive coverage of the space. Each angle presents a unique perspective, allowing participants to experience the environment from different viewpoints. This variety enhances the ecological validity of the study, as it mirrors real-world scenarios where individuals encounter environments from multiple angles.

Participants exposed to images of the café illuminated with these different light color temperatures during the experiment. These images serve as distracting stimuli, intended to divert participants' attention away from the primary task at hand. The Figure 2.2.A.,B.,C., and D. provide visual representations of the virtual café environments from different angles.

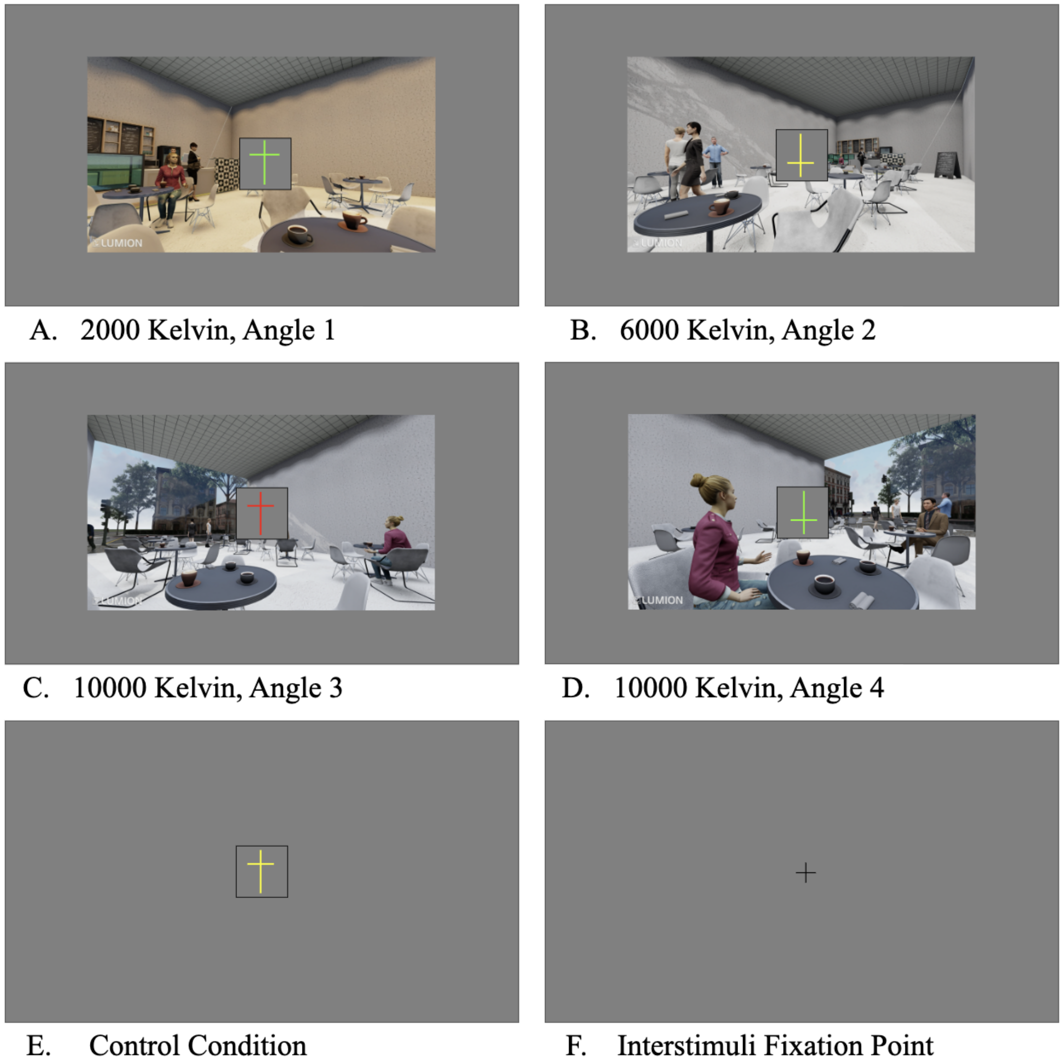

Figure 2.2: **Distracting stimuli and Control Condition.**Distracting stimuli and Control Condition. Panels A, B, C, and D show the virtual café environments illuminated with 2000 K, 6000 K, and 10000 K light color temperatures from different angles, respectively, created using Lumion 12 Pro 3D Rendering software. Panel E describes the control condition without any café environment. Panel F displays the interstimuli fixation point used between experimental trials to maintain participant engagement and focus.

Furthermore, a control condition is included to provide a baseline measure against which the effects of the different light color temperatures can be compared (see Figure 2.2.E.). In this control condition, a plain gray background is presented instead of the café environment, serving as a no-distracting condition for the task. This ensures that any observed effects can be attributed to the changes in light color temperature rather than other variables. The control condition helps to isolate the impact of the light color temperature on participants' performance and focus.

Between experimental trials, participants are presented with an interstimuli fixation point (see Figure 2.2.F). This neutral visual cue serves to maintain participant engagement and focus, minimizing distractions and ensuring consistent task performance throughout the experiment. It also served as a eye-blink reference point during the EEG experiment to avoid eye-related noise.

To prevent bias and maintain experimental difficulty constant, the order of both distracting and control conditions is randomized, as is the presentation of different angles within each environment. This randomization ensures that each distracting condition is encountered only once within a single experimental block, preventing potential confounds associated with image repetition.

2.3 Experimental Design

In this experiment, it is aimed to investigate the effects of two independent variables, namely, Attentional Load and Correlated Color Temperature of Light, on three dependent variables; response time, accuracy, and EEG activity. The experiment is implemented using Psychophysics Toolbox Version 3 (PTB-3) [74]. The detailed information regarding the session and variables is provided in below.

This experiment is an adaptation of previous studies on behavioral and brain imaging related to the modulation of attentional load [21] [131] [120]. The experiment requires participants to perform a Visual Detection Task within a Rapid Serial Visual Presentation (RSVP) flow of "T"-shaped stimuli while fixating on a central focal point. The experiment consists of a total of 288 experimental trials, distributed across 12 blocks. There are 6 blocks under low load conditions and 6 blocks under high load conditions, presented in a pseudorandom sequence (LHLH or HLHL). Figure 2.3 illustrates the task instructions at the beginning of each block. Throughout the experiment, the target stimuli for the low load condition were any red "T" shapes in any orientation. In the high load condition, the target stimuli were both straight yellow "T" shapes and upside-down green "T" shapes.

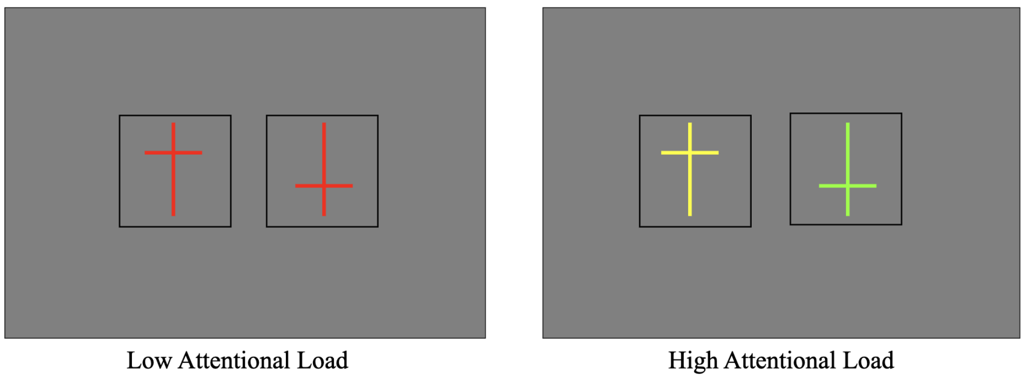

Figure 2.3: **Target stimuli for each cognitive load.** The figure shows the target stimuli for each attentional load condition. In low load condition, red stimuli are the targets from both orientation. In high load condition, participants should detect yellow upward and green downward conditions.

Each block contains 24 experimental trials, with half being control trials and half being attention-distracting trials. During each experimental trial, participants are shown a sequence of 12 "T"-shaped stimuli and must respond to 4 target "T" shapes.

There are a total of 144 experimental trials for each load condition, with 72 trials being control and 72 being attention-distracting. Additionally, the control condition contains only the main stimuli without any distracting elements, ensuring an equal number of trials with attention-distracting elements.

Lastly, the rest periods are included between each pair of blocks, allowing participants to proceed at their own pace by pressing a key to continue. Each block lasts 4.30 minutes, resulting in a total experiment duration of 52 minutes, excluding rest times and EEG setup time. The table 2.3 shows the overview of the experimental design elements in order.

Element	**Quantity**
Total Experimental Trials	288
Blocks	12
Low Load Blocks	6
High Load Blocks	6
Experimental Trials per Block	24
Control Experimental Trials per Block	12
Attention-Distracting Experimental Trials per Block	12
Low Load Experimental Trials	144 (72 control, 72 attention-distracting)
High Load Experimental Trials	144 (72 control, 72 attention-distracting)
Total Control Experimental Trials	144 (72 low load, 72 high load)
Total Attention-Distracting Experimental Trials	144 (72 low load, 72 high load)
Target Responses per Experimental Trial	4
Duration of Each Block	4.30 minutes
Total Duration (excluding rest and setup)	52 minutes
Rest Periods	Between each pair of blocks

Table 2.1: Overview of the experimental design elements. Each block contains 24 experimental trials, with half being control trials and half being attention-distracting trials. During each experimental trial, participants were shown a sequence of 12 "T"-shaped stimuli and must respond to 4 target "T" shapes. There are a total of 144 experimental trials for each load condition, with 72 trials being control and 72 being attention-distracting. Additionally, the control condition contains only the main stimuli without any distracting elements, ensuring an equal number of trials with attention-distracting elements. Rest periods are included between each pair of blocks, allowing participants to proceed at their own pace by pressing a key to continue. Each block lasts 4.30 minutes, resulting in a total experiment duration of 52 minutes, excluding rest times and EEG setup time.

2.3.1 Independent Variables

Attentional Load: In this experiment,the perceptual load theory, one of the most recognized attention theories, is employed in conjunction with the Visual Detection Task, which is commonly used in neuroimaging experiments [21] [131]

[120]. In the experiment, as the visual stimuli, a series of "T"-shaped images presented rapidly on a computer screen. These images are strategically positioned both above and below the center of the screen to ensure equal visual coverage. Each "T"-shaped image is presented in one of three distinct color combinations: yellow, red, or green. Importantly, these color combinations are not random; rather, they serve as task instructions, conveying specific directives to participants. The difficulty level of these task instructions varies, allowing for the manipulation of attentional load. Some combinations may be easier to detect or process, resulting in a low attentional load, while others may be more challenging, leading to a high attentional load. By systematically varying the complexity of these task instructions, participants' attentional engagement is modulated.

Correlated Color Temperature of Light (CCT): In this experiment, the manipulation of light color temperature, quantified in Kelvin (K), serves as a distractor to examine its effect on attentional load. Three distinct CCT conditions are employed: 2000K, 6000K, and 10000K. Each condition represents a different level of perceived warmth or coolness of light. The objective is to examine how these varying CCT conditions influence attentional processes and interact with different levels of attentional load. Specifically, it is aimed to discern whether participants' attentional engagement is modulated differently under varying CCT conditions and how this modulation may interact with the manipulation of attentional load. This investigation forms a central focus of EEG analysis, providing insights into the neural correlates of attentional processing under different lighting conditions.

2.3.2 Dependent Variables

Response Time and Accuracy: Throughout the experiment, participants' response times and the accuracy of their responses to each experimental trial are recorded. Response time refers to the duration between experimental stimulus presentation and participants' responses, while accuracy signifies the correctness of their responses. These data were collected to explore variations in response times and accuracy across different experimental conditions and attentional loads, providing the basis for behavioral analysis.

Electroencephalography (EEG) Activity: The dependent variables measured in the analysis of neural data include the P1, N1, and P300 Event-Related Potentials (ERPs), which are related to attention mechanisms [11] [90] [91] [95] [94] [118] [143]. These ERPs signify positive or negative peak changes in electrical potentials in the brain, occurring shortly after the onset of visual stimuli. P1 ERPs typically occur within the first 80-130ms after the appearance of visual stimuli, N1 ERPs within 150-200ms, and P300 ERPs occur both early (300-400ms) and late (380-440ms) in response to visual stimuli [95] [94] [118]. The times when the P1 and N1 components show the highest amplitudes are associated with selective attention mechanisms [141] [90] [91]. It is known that color temperatures influence P300 amplitudes [11]. Therefore, in this experiment, the impact of distracting stimuli on selective attention mechanisms is examined using these components.

Additionally, time-frequency analysis was conducted to examine the power of EEG signals across different frequency bands and time windows. Specifically, time-frequency representations were generated using wavelet transformations to capture changes in oscillatory activity across different conditions. This involved average event-related spectral perturbations (ERSP), facilitating the assessment of power changes in diverse frequency bands over time in response to stimuli or events. The analysis focused on a time window range of -500 to 3000ms, and frequency range of 4 to 30 Hz, encompassing the theta, alpha, beta bands, which play significant role in attention and executive functions [16] [69] **Smith_Kosslyn_2023**.

2.4 Data Collection and Acquisition

Prior to data collection, participants underwent a comprehensive procedure, which included consenting to participate and filling out a demographic questionnaire. Participants were also required to confirm having sufficient sleep the night before and refraining from consuming caffeine for at least 12 hours. To ensure optimal electrode contact and minimize noise, head measurements were taken to customize the EEG cap's fit, and conductive gel was meticulously applied under each electrode.

The data collection environment was carefully controlled to minimize external influences. Participants were comfortably seated in a distraction-free room, facing a computer screen. To mitigate potential artifacts, such as those induced by ambient light, the room lights were dimmed. Upon receiving task instructions, participants commenced the experiment independently, signaling the start of EEG recording.,

Throughout the recording session, data were continuously captured at a high sampling rate of 512 Hz, ensuring fidelity in capturing neural signals. During the neural data collection, participants were not only monitored for comfort and safety but also for their neural activity in real-time. While seated in the controlled environment, participants' brainwaves were simultaneously monitored on a separate computer screen located in an adjacent room, to ensure the quality of data acquisition and participants' engagement during the recording process. At the end of the experiment, all recorded data were securely stored for subsequent offline analysis.

2.5 Behavioral Data Analysis

2.5.1 Reaction Time

The behavioral data analyses focused on response time, measured as the duration between stimulus presentation and participants' responses. Repeated measures ANOVA was employed to examine the effects of attentional load and correlated color temperature of light (CCT) on response time. Specifically, the analysis assessed the main effects of attentional load and CCT, as well as their interaction, on participants' response times across experimental conditions. Post-hoc tests were conducted to further explore significant findings, considering statistical significance at $p < 0.05$. These analyses aimed to elucidate how variations in attentional load and CCT influence response times, providing insights into the cognitive mechanisms underlying task performance.

2.5.2 Accuracy

The analysis of accuracy focused on the percentage of response counts, specifically the total number of correct responses recorded across experimental conditions. This involved calculating the frequency of correct responses for each participant, then converting these frequencies into percentages. These percentages were subsequently compared across different levels of attentional load to discern any significant differences in performance.

2.6 Neural Data Preprocessing and Statistical Analyses

The neural data underwent comprehensive preprocessing to enhance signal quality and minimize artifacts using MATLAB and the EEGLAB toolbox [36].

Initially, data were filtered using a highpass filter (1 Hz) to remove low-frequency drifts and a lowpass filter (40 Hz) to attenuate high-frequency noise. Missing data points were reconstructed through interpolation, and a common average reference was computed for rereferencing. Independent Component Analysis (ICA) was applied to identify and remove artifacts, followed by the removal of persistently noisy channels. The data were then segmented into epochs, ranging from -100 to 499 ms for Event-Related Potential (ERP) analysis and from -500 to 3000 ms for Time-Frequency analysis.

Statistical Analysis of ERP Data: Following preprocessing, averaging across trials within each condition was performed to obtain grand average waveforms for ERP analysis, ensuring robust and reliable interpretation of the experimental effects on neural activity. The analysis of the event-related potentials comprised both parametric and non-parametric statistical tests for the ERP components.

To further investigate the effects of attentional load and correlated color temperature (CCT), cluster-based permutation tests were employed. This method enhanced the detection of significant effects by considering the spatial and temporal clustering of the data across multiple electrodes and time points [96] [52], which increased sensitivity and helped control for multiple comparisons, thereby reducing the likelihood of Type I errors[127] [115].

Statistical Analysis of Time-Frequency Data:

The EEG time-frequency analysis focused on investigating neural dynamics under varying light temperatures (CCT condition) and attentional load (Load condition) within the Alpha frequency band (8-13 Hz). The preprocessed neural data were transformed into the time-frequency domain using the newtimef function in EEGLAB [36], generating event-related spectral perturbations (ERSPs) for the Alpha band for each condition, channel, and subject. The analysis considered a frequency range of 8-13 Hz and a time range of 0 to 3000 ms post-stimulus. For each subject, ERSPs within the Alpha band were averaged across trials within each condition. The mean ERSPs were then computed for each region by averaging the ERSPs of the selected channels within that region. Channels were grouped into three regions: midline (POz, Oz), left hemisphere (PO7, PO3, O1), and right hemisphere (PO8, PO4, O2).

To examine the effects of load and Kelvin conditions, a three-way repeated measures ANOVA was conducted with the factors Load (low, high), CCT (control, 2000K, 6000K, 10000K), and Hemisphere (right, mid, left). The analysis aimed to identify significant main effects and interactions among these factors on the mean ERSP values. The repeated measures ANOVA, conducted using JASP [62], tested for main effects of Load, CCT, and Hemisphere on the mean ERSP values, as well as interaction effects between Load and CCT, Load and Hemisphere, and CCT and Hemisphere, and three-way interaction effects among Load, CCT, and Hemisphere. Post hoc comparisons were performed to further investigate significant main effects and interactions, providing detailed insights into how different levels of each factor (e.g., high vs. low load, different CCT levels, different hemispheres) influenced the mean ERSP values. Corrections for multiple comparisons were applied to ensure the robustness and reliability of the findings.

Chapter 3

Results

3.1 Behavioral Data and Statistical Results

3.1.1 Response Time

Main Effects and Interactions: The results from the Repeated Measures ANOVA indicate significant main effects for attentional load on response times, $F(1, 19) = 16.372, p < .001$. This indicates that varying levels of attentional load significantly affect the speed of participant responses. Post-hoc comparisons for attentional load, using the Bonferroni and Holm methods, showed that response times were significantly faster under low load compared to high load, $t(19) = 4.046, p < .001$. Contrary to attentional load theory, which suggests that higher loads slow down responses, our findings showed that participants responded faster under high load conditions.

Furthermore, a significant main effect of CCT (correlated color temperature) was observed, $F(3, 57) = 3.350, p = .025$, indicating that light temperature also impacts response times. In examining CCT levels, significant differences were found between the 2000K and 6000K conditions, $t(57) = -2.702, p = .054$, and the 2000K and Control conditions, $t(57) = -2.698, p = .054$, with Bonferroni-adjusted p-values suggesting marginal significance. These findings indicate that the lower CCT (2000K) may slow response times compared to slightly higher temperatures.

However, the interaction between attentional load and CCT was not significant, $F(3, 57) = 2.609, p = .060$, suggesting that the influence of CCT on response times does not differ significantly across different levels of attentional load.

Assumption Violations: Mauchly's test of sphericity indicated that the assumption of sphericity was violated for the interaction between attentional load and CCT, $\chi^2(5) = 13.493, p = .019$. This violation suggests that the variances of the differences between all combinations of related groups are not equal, which could affect the validity of the F-ratios. Therefore, Greenhouse-Geisser corrections were applied to adjust the degrees of freedom, resulting in an adjusted F-value of $F(1.984, 37.689) = 2.609, p = .087$.

For the main effect of CCT, the assumption of sphericity was not violated, $\chi^2(5) = 7.705, p = .174$.

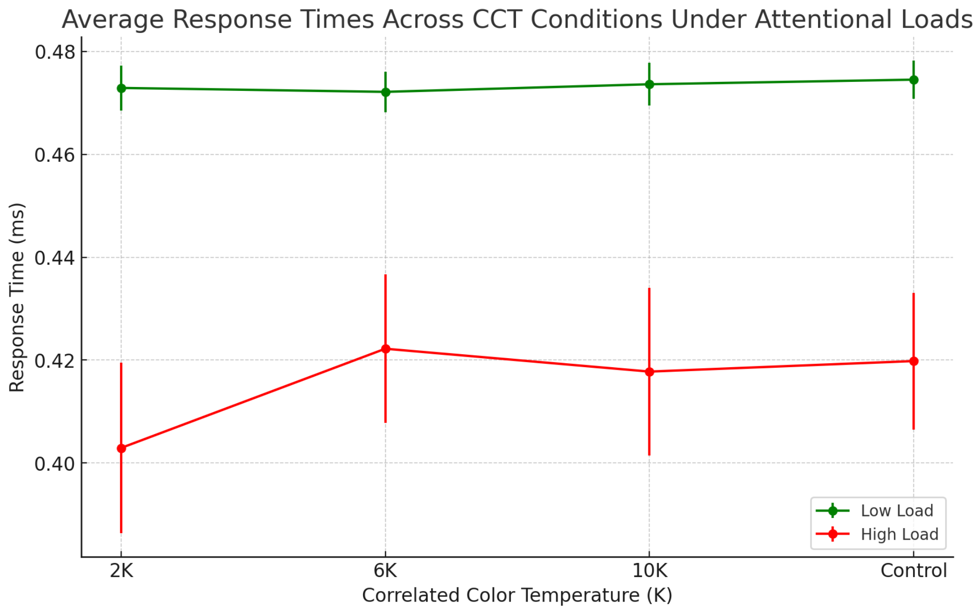

Figure 3.1: **Mean Reaction Time Across Different Correlated Color Temperature Conditions under Varying Attentional Loads.** The figure illustrates the mean reaction times (in milliseconds) for participants under different correlated color temperature (CCT) conditions: 2000K, 6000K, 10000K, and Control. The reaction times are plotted separately for low attentional load (represented by green circles) and high attentional load (represented by red circles). Error bars represent the standard error of the mean (SEM).

3.1.2 Accuracy

The results from the Repeated Measures ANOVA indicate significant main effects for attentional load on accuracy, $F(1, 19) = 436.289, p < .001$. This suggests that varying levels of attentional load significantly affect the accuracy of participant responses. Post-hoc comparisons for attentional load, using the Bonferroni and Holm methods, showed that accuracy was significantly higher under low load compared to high load, $t(19) = 20.888, p < .001$. These findings support attentional load theory, which suggests that higher loads decrease accuracy.

Furthermore, a significant main effect of CCT (correlated color temperature) was observed, $F(3, 57) = 586.477, p < .001$. However, the significant differences were found between several CCT levels and the control condition, particularly between the 2000K and control conditions, $t(57) = -34.176, p < .001$, the 6000K and control conditions, $t(57) = -34.035, p < .001$, and the 10000K and control conditions, $t(57) = -34.527, p < .001$. Therefore, there were no significant differences among the CCT levels themselves, suggesting no CCT effect.

Lastly, the interaction between attentional load and CCT was significant, $F(3, 57) = 334.849, p < .001$, however these differences were due to the attentional load and control factor.

Assumption Violations: Mauchly's test of sphericity indicated that the assumption of sphericity was violated for the main effect of CCT, $\chi^2(5) = 70.545, p < .001$, and for the interaction between attentional load and CCT, $\chi^2(5) = 63.763, p < .001$. This violation suggests that the variances of the differences between all combinations of related groups are not equal, which could affect the validity of the F-ratios. Therefore, Greenhouse-Geisser corrections were applied to adjust the degrees of freedom.

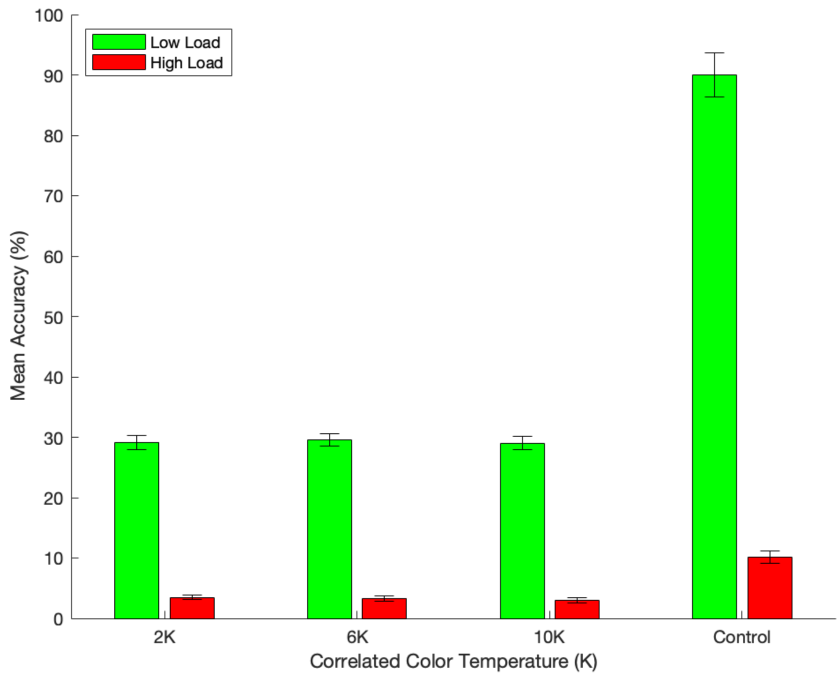

Figure 3.2: **Mean Accuracy in Percentages Across Different Correlated Color Temperature Conditions under Varying Attentional Loads.** The figure illustrates the mean accuracy (in percentage) for participants under different correlated color temperature (CCT) conditions: 2000K, 6000K, 10000K, and Control. The accuracies are plotted separately for low attentional load (represented by green bars) and high attentional load (represented by red bars). Error bars represent the standard error of the mean (SEM).

3.2 Neural Data and Statistical Results

3.2.1 Event-Related Potentials (ERP) Results

This analysis excluded the control condition, focusing on the 2000K, 6000K, and 10000K light temperatures with attentional load. A 2x3 repeated measures

ANOVA was conducted to examine these effects. This analysis involved 20 subjects, 64 channels, and 500 time points, resulting in 32000 comparisons. The False Discovery Rate (FDR) control procedure by Benjamini & Hochberg was applied [13].

- **Main Effect of Attentional Load:** No significant main effect of attentional load was found on ERP responses. The F-values and p-values across the analyzed time points and channels did not show significant differences between low and high load conditions.

  The ERP plots in 3.3 display neural responses to different attentional load conditions (low vs. high) across four selected channels. Frontal (F3,F4) and occipital (O1,O2) channels were chosen for their relevance to visual and attentional processing. Frontal Channels are important for executive functions and attentional control, often examined due to their sensitivity to attentional load [46] [73]. On the other hand, occipital channels are crucial for visual processing and capturing early visual ERP components (P1 and N1) influenced by attentional load [90] [91] [95].

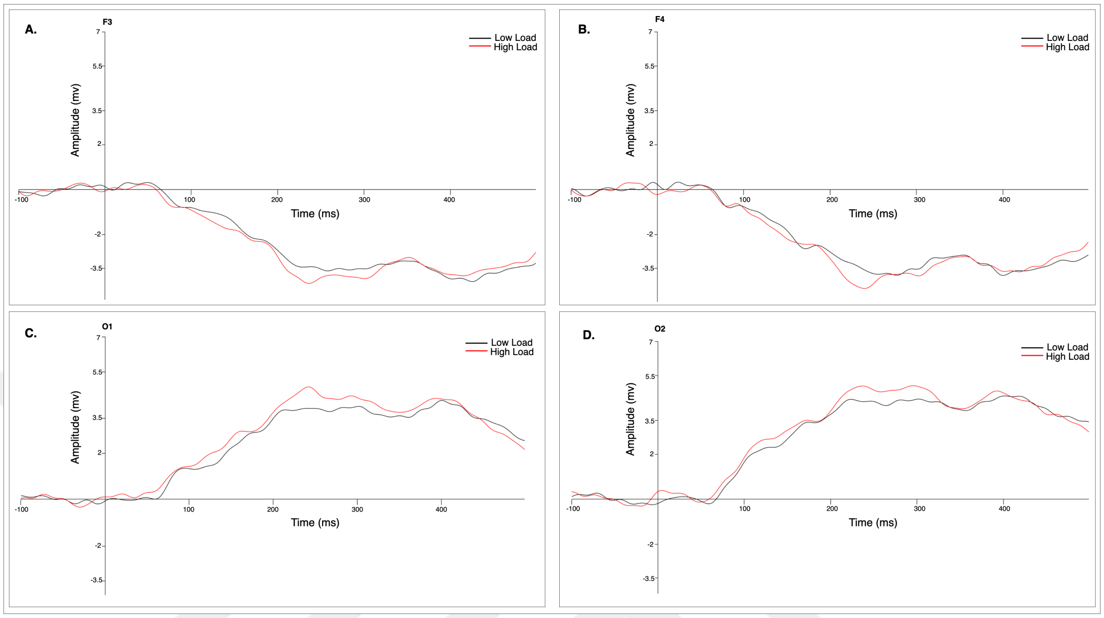

Figure 3.3: **ERP Responses for Different Attentional Load Conditions:** Panel A and B illustrate the frontal channels, F3 and F4, which are involved for executive functions and attentional control. Panel C and D present the occipital channels, O1 and O2, which are involved in visual processing. In each panel, the ERP waveforms for low load (black line) and high load (red line) conditions are displayed. These plots illustrate the lack of significant modulation of ERP responses by attentional load within the studied parameters.

The ERP waveforms indicate typical visual and attentional processing patterns without significant differences between low and high load conditions. This supports the statistical analysis, suggesting that variations in attentional load did not significantly modulate ERP responses within the study's parameters.

- **Main Effect of CCT:** The analysis did not reveal any significant effects of correlated color temperature (CCT) on ERP responses. The ERP responses did not differ significantly among the 2000K, 6000K, and 10000K conditions.

  The ERP results for different Kelvin conditions (2000K, 6000K, 10000K, and Control) are visualized in Figure 3.4, which illustrates the ERP responses across four selected channels. Occipital (O1, O2) and parieto-occipital (PO3, PO4) channels were chosen for their relevance to visual processing [90] [91] [95]. Occipital channels involves capturing early visual ERP components, such as P1 and N1, which are sensitive to light temperature effects [11]. Parieto-occipital channels are selected due to their involvement in higher-order visual processing and attention [9][47].

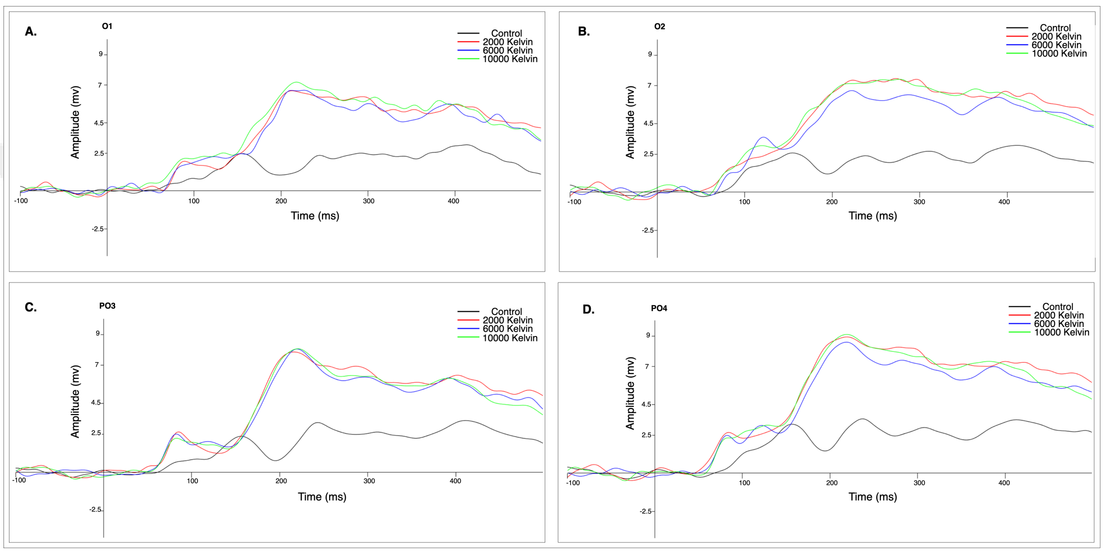

Figure 3.4: **ERP Responses for Different Kelvin Conditions.** Panel A and B illustrate the occipital channels, O1 and O2, which are involved in visual processing. Panel C and D present the parieto-occipital channels, PO3 and PO4, which are involved in higher-order visual processing and attention. In each panel, the ERP waveforms for the control condition (black line), 2000K (red line), 6000K (blue line), and 10000K (green line) are displayed. These plots illustrate the lack of significant modulation of ERP responses by light temperature within the studied parameters.

The ERP waveforms indicate typical visual processing patterns without significant differences among the different Kelvin conditions, supporting the statistical analysis that variations in light temperature did not significantly modulate ERP responses within the study's parameters.

- **Interaction Effect:** The interaction between attentional load and CCT conditions remained non-significant, suggesting that the combined effect of load and light temperature did not modulate ERP responses.

Cluster Analysis for Load and CCT Effects Cluster-based permutation tests were conducted across multiple electrodes and time points for both attentional load and CCT effects.

Load Effect: The cluster analysis revealed no significant clusters for the load effect. All p-values were $\geq$ 0.239400, indicating no significant differences across the clusters examined.

CCT Effect: Similarly, the cluster analysis for CCT showed no significant clusters. All p-values were $\geq$ 0.144600, indicating no significant effects of CCT on ERP responses.

These results further support the findings from the ANOVA analyses, indicating that neither light temperature nor attentional load had a substantial impact on the overall ERP patterns within the studied time windows and channels.

3.2.2 Time-Frequency Results

Descriptive statistics for the mean ERSP values under high and low load conditions across different CCTs and hemispheres are as follows:

For the low load condition (See Figure 3.5), the mean ERSP values for the 2K CCT were -4.564 (SD = 2.343) for the midline, -5.374 (SD = 2.603) for the right hemisphere, and -4.258 (SD = 2.617) for the left hemisphere. For the 6K CCT, the mean ERSP values were -4.744 (SD = 1.689) for the midline, -5.472 (SD = 2.060) for the right hemisphere, and -4.194 (SD = 2.223) for the left hemisphere. For the 10K CCT, the mean ERSP values were -4.061 (SD = 2.193) for the midline, -4.806 (SD = 2.284) for the right hemisphere, and -3.624 (SD = 2.604) for the left hemisphere. For the control CCT, the mean ERSP values were -3.612 (SD = 1.926) for the midline, -4.498 (SD = 2.118) for the right hemisphere, and -3.619 (SD = 2.341) for the left hemisphere.

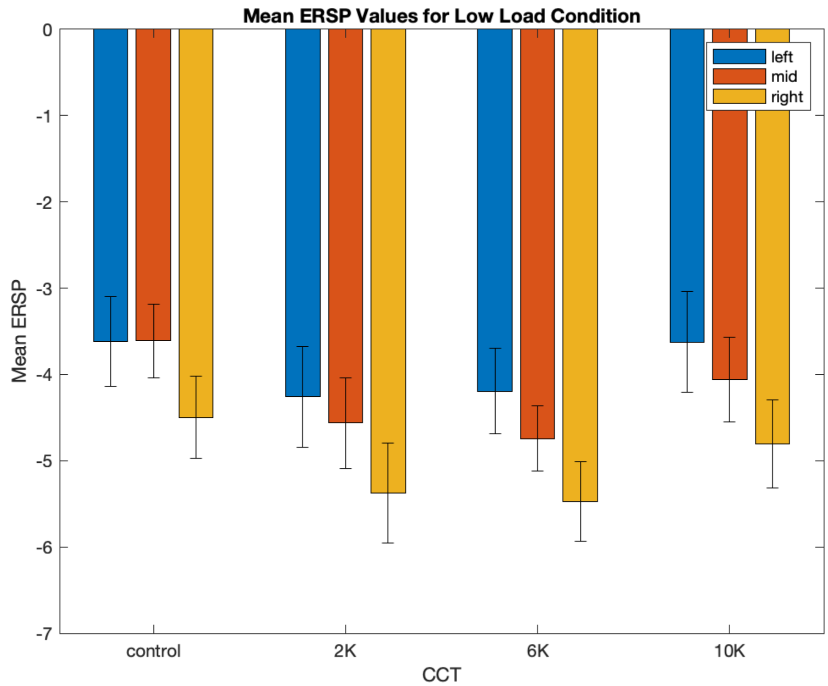

Figure 3.5: **Mean ERSP of CCT in different hemispheres under Low Load.** The x-axis represents the different Correlated Color Temperatures (Control, 2K, 6K, 10K). The y-axis represents the Mean Event-Related Spectral Perturbation (ERSP) values. The blue bars indicate Mean ERSP values for the left hemisphere, the orange bars for the midline, and the yellow bars for the right hemisphere. The error bars represent the standard error of the mean (SEM).

For the high load condition (See Figure 3.6), the mean ERSP values for the 2K CCT were -6.015 (SD = 2.243) for the right hemisphere, -5.042 (SD = 2.033) for the midline, and -4.882 (SD = 2.507) for the left hemisphere. For the 6K CCT, the mean ERSP values were -6.133 (SD = 2.680) for the right hemisphere, -4.797 (SD = 2.539) for the midline, and -4.609 (SD = 2.848) for the left hemisphere. For the 10K CCT, the mean ERSP values were -6.168 (SD = 2.375) for the right hemisphere, -5.102 (SD = 2.332) for the midline, and -5.043 (SD = 2.883) for the left hemisphere. For the control CCT, the mean ERSP values were -5.234 (SD = 2.073) for the right hemisphere, -4.114 (SD = 1.908) for the midline, and -4.106 (SD = 2.131) for the left hemisphere.

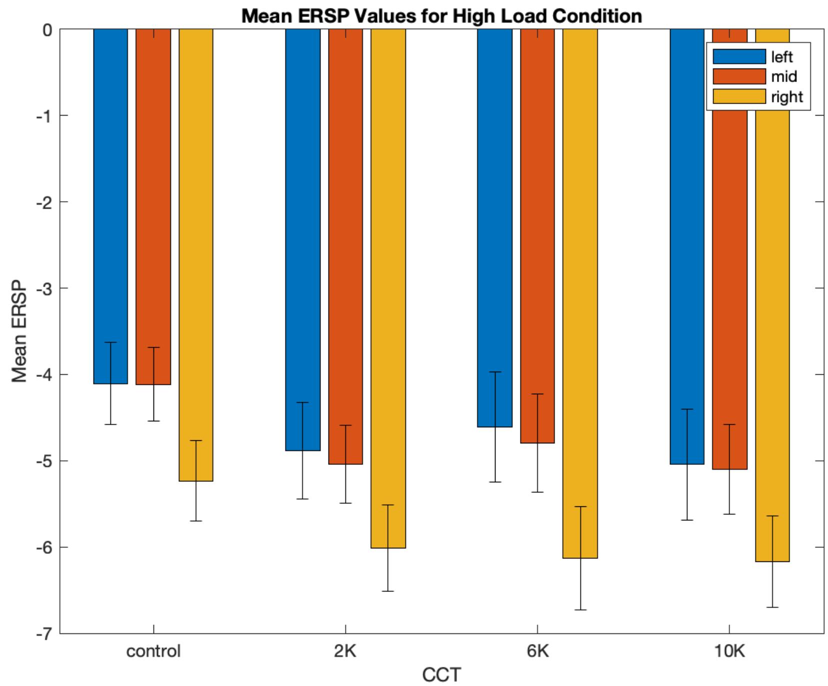

Figure 3.6: **Mean ERSP of CCT in different hemispheres under High Load.** The x-axis represents the different Correlated Color Temperatures (Control, 2K, 6K, 10K). The y-axis represents the Mean Event-Related Spectral Perturbation (ERSP) values. The blue bars indicate Mean ERSP values for the left hemisphere, the orange bars for the midline, and the yellow bars for the right hemisphere. The error bars represent the standard error of the mean (SEM).

The repeated measures ANOVA conducted on the mean ERSP values revealed significant main effects of Load, CCT, and Hemisphere. Specifically, there was a significant main effect of Load on the mean ERSP values, $F(1, 19) = 31.228, p < .001$. The main effect of CCT was also significant, $F(3, 57) = 6.698, p < .001$, with Mauchly's test indicating a violation of sphericity ($\chi^2(5) = 13.667, p = .018$). Greenhouse-Geisser correction was applied ($\epsilon = .707$). The main effect of Hemisphere was significant, $F(2, 38) = 18.161, p < .001$.

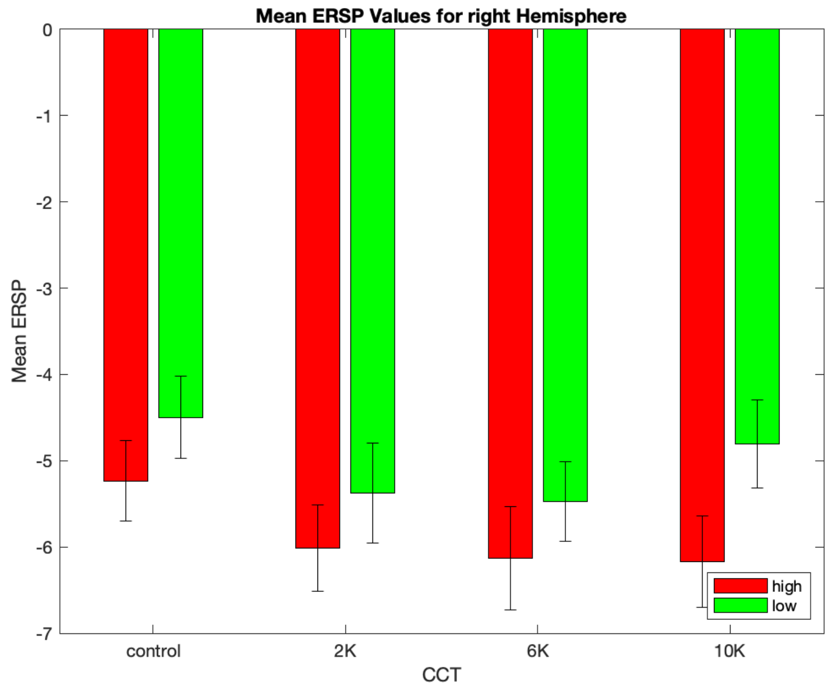

Figure 3.7: **Mean ERSP from Right Hemisphere of Occipital Channels.** The x-axis represents the different Correlated Color Temperatures (Control, 2K, 6K, 10K). The y-axis represents the Mean Event-Related Spectral Perturbation (ERSP) values. The red bars indicate Mean ERSP values under high attentional load, while the green bars indicate Mean ERSP values under low attentional load. The error bars represent the standard error of the mean (SEM).

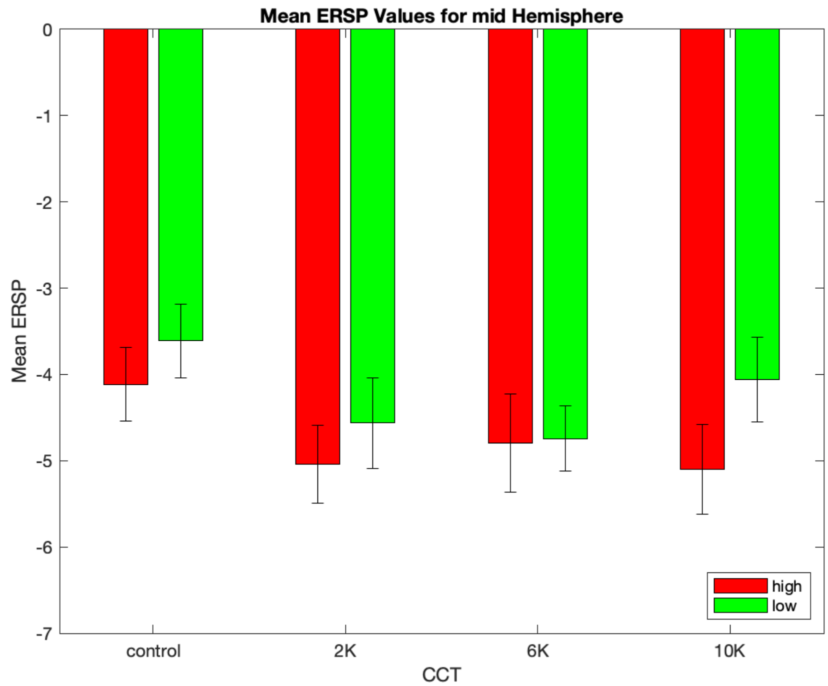

Figure 3.8: **Mean ERSP from Middle Hemisphere of Occipital Channels.** The x-axis represents the different Correlated Color Temperatures (Control, 2K, 6K, 10K). The y-axis represents the Mean Event-Related Spectral Perturbation (ERSP) values. The red bars indicate Mean ERSP values under high attentional load, while the green bars indicate Mean ERSP values under low attentional load. The error bars represent the standard error of the mean (SEM).

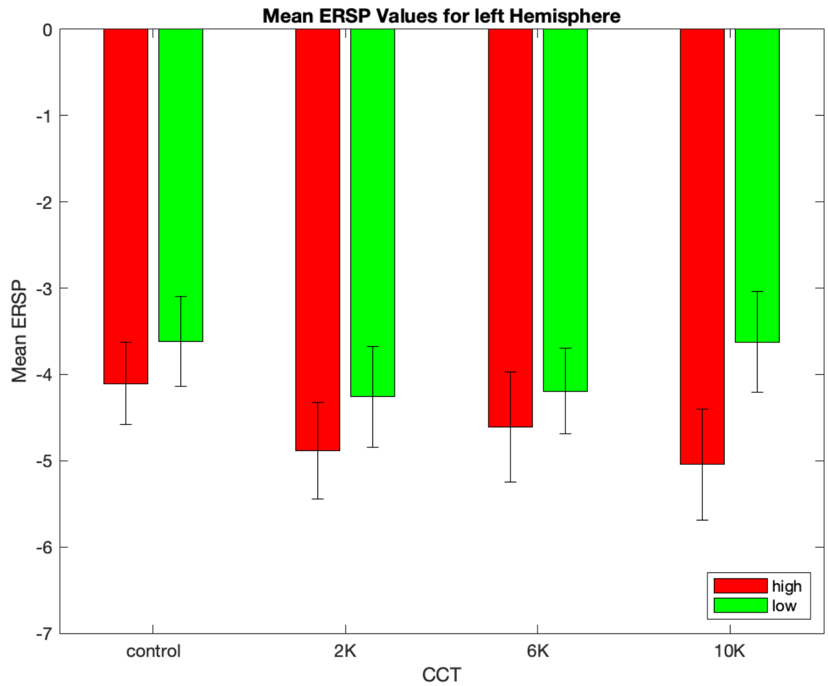

Figure 3.9: **Mean ERSP from Left Hemisphere of Occipital Channels.** The x-axis represents the different Correlated Color Temperatures (Control, 2K, 6K, 10K). The y-axis represents the Mean Event-Related Spectral Perturbation (ERSP) values. The red bars indicate Mean ERSP values under high attentional load, while the green bars indicate Mean ERSP values under low attentional load. The error bars represent the standard error of the mean (SEM).

Interaction effects were examined, revealing a non-significant Load × CCT interaction, $F(3, 57) = 2.146, p = .104$, with Mauchly's test indicating a violation of sphericity ($\chi^2(5) = 12.293, p = .031$). Greenhouse-Geisser correction was applied ($\epsilon = .724$). The Load × Hemisphere interaction was marginally significant, $F(2, 38) = 3.160, p = .054$, with Mauchly's test indicating a violation of sphericity ($\chi^2(2) = 7.274, p = .026$ (See Figure 3.10). Greenhouse-Geisser correction was applied ($\epsilon = .774$). The CCT × Hemisphere interaction was not significant, $F(6, 114) = 1.473, p = .194$, nor was the three-way interaction among Load, CCT, and Hemisphere, $F(6, 114) = 0.961, p = .455$.

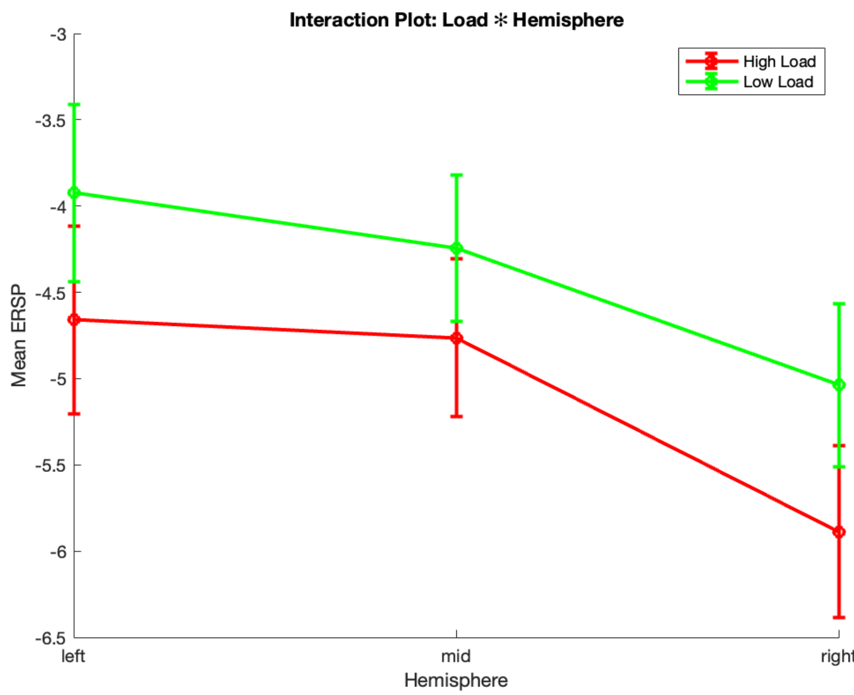

Figure 3.10: **Interaction Plot of Mean ERSP Values by Load and Hemisphere.** The figure presents an interaction plot examining the effects of attentional load (High Load vs. Low Load) and brain hemisphere (Left, Midline, Right) on Mean Event-Related Spectral Perturbation (ERSP) values. The green line represents the Low Load condition, while the red line represents the High Load condition. The y-axis denotes the Mean ERSP values, and the x-axis indicates the brain hemispheres.

Post hoc comparisons showed significant differences between high and low Load conditions. For the CCT condition, significant differences were found between the control and 2000K (mean difference = -0.825, SE = 0.209, p = .001), the control and 6000K (mean difference = -0.795, SE = 0.209, p = .002), and the control and 10000K (mean difference = -0.603, SE = 0.209, p = .034). For the Hemisphere condition, significant differences were found between the left and right hemispheres (mean difference = 1.171, SE = 0.207, $p < .001$) and between the mid and right hemispheres (mean difference = 0.958, SE = 0.207, $p < .001$).

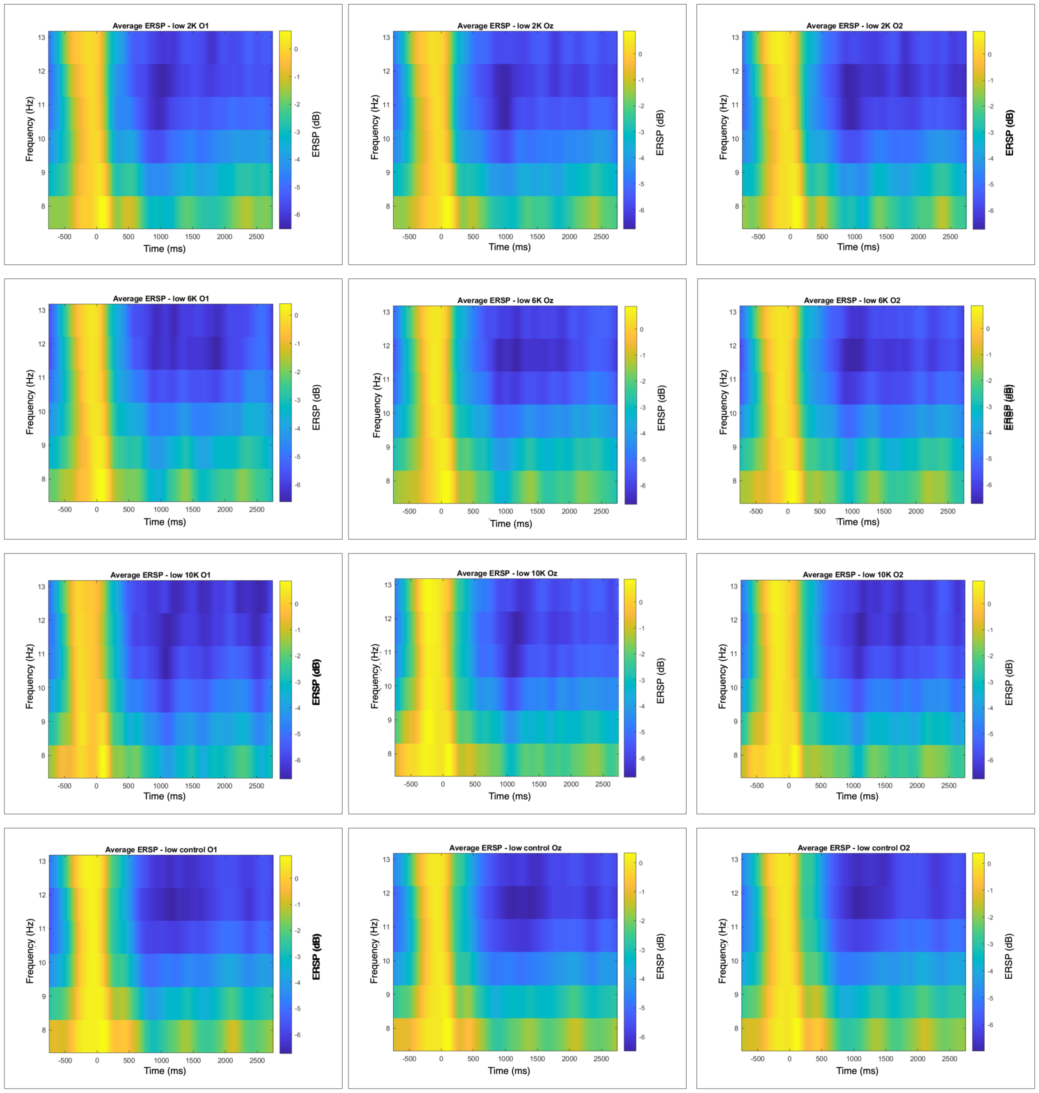

Figure 3.11: **Time Frequency Decomposition of CCT Conditions under Low Attentional Load.** The figure consists of 12 panels showing the average Event-Related Spectral Perturbations (ERSPs) under low attentional load. Each row represents a different Correlated Color Temperature (CCT) condition (2K, 6K, 10K, Control) and each column represents different occipital channels (O1, Oz, O2). The panels in each row represent the average ERSPs for the respective channels and CCT conditions. Each panel displays the time-frequency representation of the ERSP, with time (ms) on the x-axis and frequency (Hz) on the y-axis. The color scale indicates power changes (dB) relative to baseline, with warm colors (yellow) representing power increases and cool colors (blue) representing power decreases across frequencies (8-13 Hz) and time (-500 to 2500 ms).

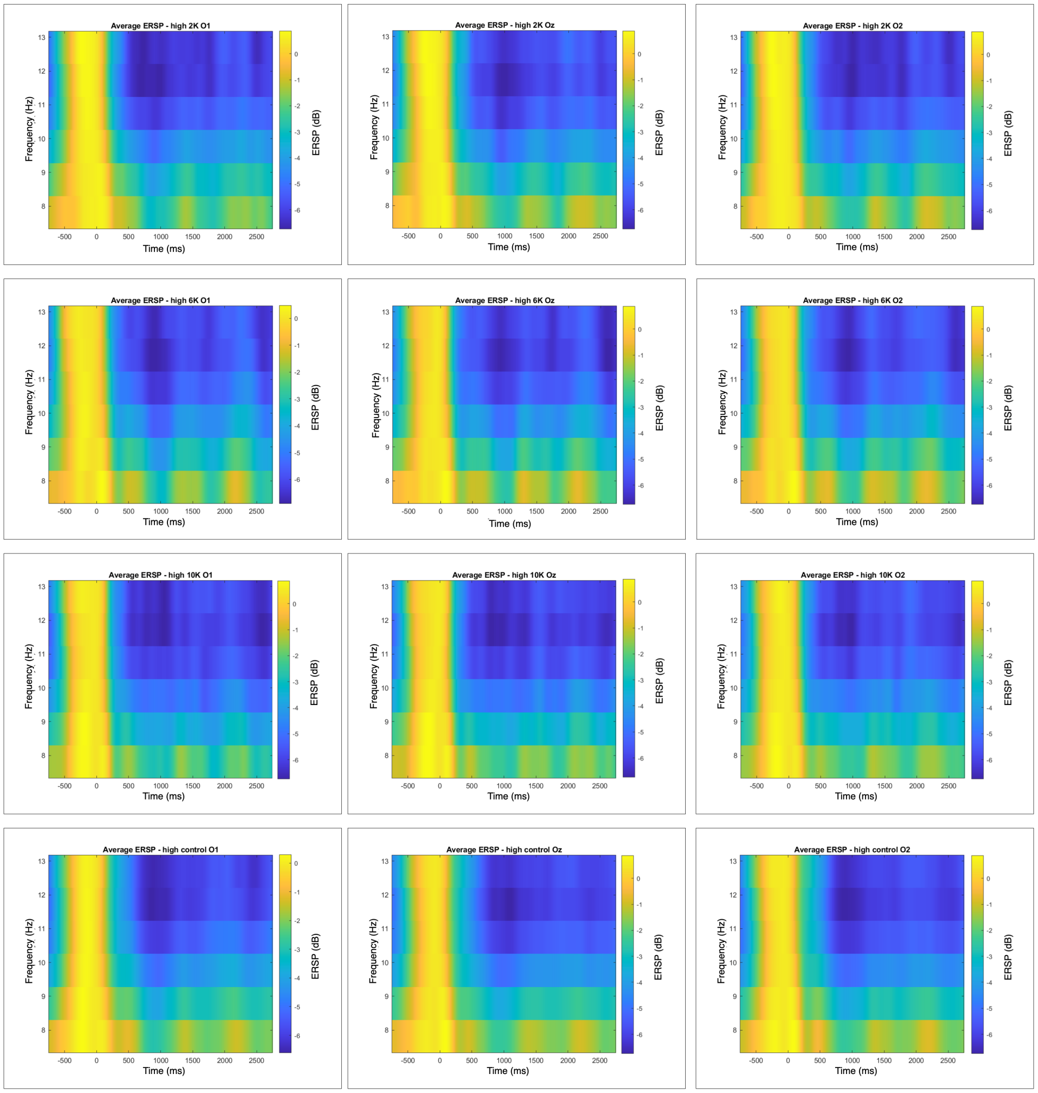

Figure 3.12: **Time Frequency Decomposition of CCT Conditions under High Attentional Load.** The figure consists of 12 panels showing the average Event-Related Spectral Perturbations (ERSPs) under high attentional load. Each row represents a different Correlated Color Temperature (CCT) condition (2K, 6K, 10K, Control) and each column represents different occipital channels (O1, Oz, O2). The panels in each row represent the average ERSPs for the respective channels and CCT conditions. Each panel displays the time-frequency representation of the ERSP, with time (ms) on the x-axis and frequency (Hz) on the y-axis. The color scale indicates power changes (dB) relative to baseline, with warm colors (yellow) representing power increases and cool colors (blue) representing power decreases across frequencies (8-13 Hz) and time (-500 to 2500 ms).

Chapter 4

Discussion

4.1 Summary and Interpretation of the Results

This study investigated the effects of different correlated color temperature (CCT) conditions (2000K, 6000K, and 10000K) and varying levels of attentional load (low and high) on both behavioral performance and neural activity. The findings are summarized in two main categories: behavioral data and neural data.

4.1.1 Behavioral Data

Response Times

The analysis of reaction times revealed some unexpected findings. Participants responded significantly faster under high load conditions compared to low load conditions. This result contradicts traditional theories of attentional load, which suggest that higher loads should slow down response times due to increased cognitive demands. One possible explanation is that under high load conditions, participants might have adopted a more focused or urgent response strategy, perhaps driven by the necessity to allocate cognitive resources more efficiently due to the increased task difficulty. This suggests that when faced with more challenging tasks, participants may engage in a more efficient processing mode, leading to faster responses. This finding aligns with the hypothesis that increased attentional load necessitates a more efficient allocation of cognitive resources, potentially leading to quicker reaction times as a compensatory mechanism [104].

Additionally, the study found a significant main effect of Correlated Color Temperature (CCT) on response times. Specifically, marginal effects were observed between the 2000K and 6000K conditions and between the 2000K and Control conditions, suggesting that lower CCT (2000K) tended to increase response times compared to higher temperatures. This might be due to the warmer light creating a more relaxed atmospher, but the effect is marginal. However, the interaction between attentional load and CCT was not significant, indicating that the effect of CCT on response times did not significantly vary with the level of attentional load. The impact of environmental conditions, such as CCT, on cognitive performance is well-documented in the literature, with studies indicating that environmental factors can influence cognitive and perceptual processes [78] [19].

Accuracy

The significant findings from the ANOVA reinforce the notion that attentional load has a substantial impact on task performance, particularly accuracy. As hypothesized, higher attentional load conditions led to a marked decrease in accuracy, aligning with traditional theories of attentional load and resource allocation. This outcome highlights the importance of managing cognitive demands in environments requiring sustained attention and precision. These results support Lavie's load theory, which posits that increased perceptual load depletes cognitive resources, thereby reducing the processing capacity for irrelevant stimuli and improving task performance [85] [84] [83].

There were significant differences only in the control condition in terms of CCT condition, which is not a CCT but a no-distraction condition. This can be explained by the fact that when there is no distraction, accuracy is higher. This finding underscores the impact of distraction on task performance and highlights the importance of minimizing distractions to maintain high levels of accuracy. The detrimental effects of environmental distractions on cognitive performance have been widely documented, suggesting that a distraction-free environment is crucial for optimal performance [104].

The significant interaction between attentional load and CCT can be primarily attributed to the presence of distraction in the CCT conditions compared to the control condition. This indicates that the interaction effect is due to the distraction rather than the CCT itself, adding another layer of attentional demand. The distraction introduced in the CCT conditions acts as an additional attentional load, further impacting accuracy. Thus, the interaction effect highlights the importance of considering both cognitive and environmental distractions when evaluating task performance. This interaction aligns with findings in the literature that emphasize the combined influence of perceptual load and environmental factors on cognitive processing efficiency [85] [84] [55].

4.1.2 Neural Data

Event-Related Potentials (ERP)

The ERP analysis focused on the effects of attentional load and Correlated Color Temperature (CCT) on neural responses. The results indicated that neither attentional load nor CCT had significant effects on ERP responses. Although the ERP results in this study did not reach statistical significance, several important implications can be drawn from existing literature.

Perceptual load theory suggests that as the attentional demands of a task increase, the processing of task-irrelevant stimuli decreases. Handy et al. (2001) demonstrated that higher perceptual loads lead to reduced sensory-evoked responses to parafoveal stimuli, supporting the idea that perceptual load affects initial sensory processing stages in the visual cortex. This finding aligns with the broader body of research suggesting that under high perceptual load, there is a trend towards reduced ERP amplitudes for task-irrelevant stimuli [55].

Rorden et al. (2008) further corroborate this by showing that increased perceptual load enhances the neural processing of relevant stimuli while diminishing the processing of irrelevant stimuli. This was evidenced by stronger N1 responses to relevant stimuli and weaker N1 responses to irrelevant stimuli under high load conditions. Although our study did not show significant changes, the trend of reduced ERP amplitudes under high load conditions suggests that similar mechanisms might be at play, where attentional resources are allocated more towards task-relevant processing, leaving less capacity for irrelevant stimuli [124].

Furthermore, Lavie's load theory postulates that under high perceptual load, the limited capacity of the visual system prioritizes the processing of relevant information, effectively reducing the processing of irrelevant inputs [86]. This model has been supported by various studies, including those utilizing fMRI and ERP methodologies. For instance, Rees et al. (1997) provided evidence that high load conditions at fixation led to decreased activity in visual areas responsive to task-irrelevant stimuli [122]. Although our ERP results were not significant, they align with the broader body of research suggesting that perceptual load modulates early visual processing [55] [124].

In this study, while the ERP results were not statistically significant, the amplitude differences observed in the ERP waveforms between low and high load conditions suggest a similar trend. Specifically, the ERP responses show that under high load conditions, the ERP amplitudes are slightly lower compared to low load conditions across various electrode sites (F3, F4, O1, O2) (See Figure 3.3). This trend is consistent with the hypothesis that increased attentional load results in reduced neural processing of task-irrelevant stimuli, reflecting a form of early attentional selection as proposed by the perceptual load theory [85] [124] [55].

Time-Frequency Analyses

The time-frequency analyses conducted in this study aimed to investigate the neural dynamics under varying light temperatures (CCT condition) and attentional load (Load condition) within the Alpha frequency band (8-13 Hz). The analysis considered the effects of these conditions across different hemispheres (left, midline, right) and how these factors interact to influence neural activity.

The results revealed significant main effects of Load, CCT, and Hemisphere on mean ERSP values. Specifically, mean ERSP values were higher under low load conditions compared to high load conditions. This suggests that increased attentional load is associated with a reduction in Alpha band activity, reflecting heightened cognitive processing demands [86] [85].

Differences in mean ERSP values were also found between the control condition (no distractor) and the CCT conditions. Post hoc comparisons indicated that mean ERSP values were lower in the 2000K, 6000K, and 10000K conditions compared to the control condition. This finding implies that the absence of distractors in the control condition allows for more efficient cognitive processing and higher alpha band activity. In contrast, the presence of distractors in the CCT conditions, regardless of light temperature, requires additional cognitive resources to manage distractor suppression, leading to decreased alpha activity. This underscores the theoretical significance of understanding how environmental and task-related factors influence neural dynamics and attentional control mechanisms. The observed suppression of alpha activity in the presence of distractors is consistent with findings from neurophysiological studies that indicate increased attentional load leads to enhanced filtering of irrelevant stimuli [55] [112].

Additionally, variations in mean ERSP values were observed among the midline, left, and right hemispheres. The right hemisphere exhibited significantly lower mean ERSP values compared to both the left hemisphere and the midline, suggesting lateralization of Alpha band activity, with the right hemisphere showing reduced neural activity in response to the experimental conditions. This lateralization effect supports previous research indicating that the right hemisphere is more involved in attentional control and the suppression of irrelevant stimuli [33].

Descriptive statistics supported these findings, showing distinct mean ERSP values for different combinations of Load, CCT, and Hemisphere conditions. Under high load conditions, the right hemisphere exhibited the lowest Alpha activity in the 2000K light temperature condition. Similarly, under low load conditions, the right hemisphere again showed reduced Alpha activity, particularly in the 10000K light temperature condition. These findings suggest that the right hemisphere may be particularly sensitive to variations in both attentional load and light temperature, influencing its role in attentional control and cognitive processing.

In summary, although no significant differences in EEG results were found among the different CCT conditions, the behavioral results revealed significant differences, indicating that light temperature may influence behavioral responses even if these effects are not detectable in neural measures. Attentional load showed significant effects in both EEG and behavioral measures. While the behavioral results for response time indicated an unexpected outcome—participants responded faster under high load conditions, contrary to the typical finding in the literature where response times are usually slower under high load—the EEG findings provided a clearer picture of the underlying neural mechanisms. The EEG results demonstrated alpha suppression, consistent with the increased cognitive effort and attentional demands under high load conditions. This discrepancy between behavioral and neural data highlights the complexity of attentional processes and suggests that EEG measures of alpha activity may offer more sensitive indicators of attentional load and attentional dynamics than behavioral performance alone.

4.2 Theoretical Implications

Enhanced Understanding of Attentional Load Theory: This study provides significant insights into attentional load theory by integrating behavioral and EEG results. The behavioral data revealed that response times and accuracy were significantly influenced by the attentional load, corroborating findings from previous studies on attentional load and cognitive processing efficiency. Notably, participants showed slower response times and higher accuracy under low load conditions, might be indicating more efficient cognitive processing when the attentional demands were lower.

The neural data further support these findings by demonstrating significant alpha suppression under high load conditions. Increased attentional load was associated with a reduction in alpha band activity (8-13 Hz), particularly in the right hemisphere, indicating enhanced neural engagement. This alpha suppression aligns with the mechanisms described in previous EEG studies, which have shown that alpha band activity is inversely related to increased attentional demands [45] [64] [75]. Our findings confirm this relationship, showing that higher attentional load results in greater alpha suppression, particularly in the right hemisphere, which is consistent with the lateralization of attentional processes.

The Intersection of Target Enhancement and Distractor Suppression: The time-frequency analysis of the CCT conditions revealed that while the 2000K, 6000K, and 10000K conditions did not show significant differences from each other, they were all significantly different from the control condition. This suggests that the presence of light temperature variations affects attentional mechanisms. However, the significant difference between the CCT conditions and the control condition raises the question: are these effects due to target enhancement or distractor suppression?

The article by Schneider et al. (2021) provides a valuable framework for understanding this phenomenon [130]. The authors discuss how alpha oscillations are involved in both target enhancement and distractor suppression, suggesting that these processes are functionally distinct. According to this phenomenon, decreases in alpha power are associated with target enhancement, while increases in alpha power are linked to distractor suppression [130]. This dual role of alpha oscillations indicates that both mechanisms could be at play in our study.

However, our study was not specifically designed to disentangle these two mechanisms. While we observed significant differences in alpha power between the experimental and control conditions, it is not possible to conclusively determine whether these differences are due to target enhancement or distractor suppression. Wöstmann et al. (2019) emphasize the importance of distinguishing between these two mechanisms using precise experimental designs that can separate the neural responses to targets, distractors, and neutral stimuli [148]. Future research should aim to incorporate such designs to clarify the specific contributions of target enhancement and distractor suppression in the context of light temperature and attentional load.

4.3 Practical Implications

The findings from this study offer important practical implications for designing environments that optimize cognitive performance and attentional focus, specifically through the manipulation of light temperature and management of distractions.

4.3.1 Educational and Office Environments

Educational and office environments can benefit from a strategic approach to managing attentional load to optimize student or worker engagement and learning outcomes. By implementing varied cognitive load activities and maintaining a balance between high and low load tasks, these environments can enhance overall productivity and learning efficacy. For instance, alternating between demanding and less intensive tasks can prevent cognitive fatigue and maintain sustained attention. Additionally, optimizing environmental factors such as lighting, noise levels, and ergonomic design can further support cognitive function.

4.3.2 Technology and User Interface Design

In the context of technology and user interface (UI) design, managing attentional load is essential for enhancing user experience and performance, especially in the gaming industry. Games are complex interactive systems that often require players to process a significant amount of information quickly and accurately. To minimize cognitive load and improve gameplay experience, game designers should focus on creating intuitive interfaces with clear, easily navigable menus and controls. Simplifying navigation and providing clear, immediate feedback can help players stay immersed in the game without feeling overwhelmed by the interface.

Multi-Functional Spaces: For multi-functional spaces like coffee shops, which are typically designed with dim lighting for a relaxed ambiance, the study's findings highlight the need to adapt these environments to better support the growing number of people who use them for work and study. Since distractions significantly impact accuracy, these spaces should be designed to minimize noise and visual clutter. Adjustable lighting that allows users to choose their preferred light temperature can help create a more conducive environment for various activities, supporting both comfort and productivity. For example, study desks could be placed near windows to take advantage of natural daylight (6000K), which enhances focus and cognitive performance according to previous literature [18] [61] [51] [103]. In contrast, chat tables could be positioned in the interior, dimly lit areas of the coffee shop to promote relaxation and social interaction. By offering a range of lighting options and thoughtfully designing the space, coffee shops can cater to the diverse needs of their patrons, enhancing overall user experience and satisfaction.

4.4 Limitations

While this study provides valuable insights into the effects of light temperature and attentional load on neural activity, several limitations should be acknowledged. The task design employed a rapid visual detection task to measure cognitive performance and neural activity. Although this task is effective for assessing certain aspects of attention, it primarily captures short-term attentional processes. Long-term attention and sustained cognitive engagement were not measured, which limits the ability to generalize findings to tasks requiring prolonged focus.

Additionally, this study focused exclusively on the Alpha frequency band (8-13 Hz) on occipital channels. While the Alpha band is crucial for understanding attentional processes, other frequency bands (such as Theta or Beta) might also be relevant and could provide additional insights into the neural dynamics of light temperature and attentional load.

Furthermore, the light manipulation in this study was achieved using a computer screen rather than ambient lighting from overhead sources. This method may not fully replicate the effects of room lighting on cognitive performance and neural activity. Additionally, the study was conducted in a dark, controlled laboratory environment, which may not fully replicate real-world conditions. Factors such as ambient noise, smell, natural light variations, and individual differences in light sensitivity could influence the results.

Finally, although not a primary focus of this study, any reliance on self-report measures to assess subjective experiences or preferences related to light temperature and attentional load could introduce bias. Objective measures, such as performance-based tasks and physiological indicators, should complement self-report data.

In summary, while this study provides important insights into the effects of light temperature and attentional load on neural activity, these limitations highlight the need for further validation and extension of the current findings to fully understand how environmental factors influence cognitive performance and neural dynamics.

4.5 Future Directions

Building on the findings and addressing the limitations of the current study, several future research directions are proposed. First, expanding the scope of tasks to include assessments of long-term attention and sustained cognitive engagement is another important direction. Future studies should incorporate tasks that measure these aspects to provide a more comprehensive understanding of attentional processes over extended periods. This approach would help determine whether the effects observed in short-term tasks persist during prolonged cognitive activities.

Also, including multiple frequency bands in future analyses could offer a more holistic view of neural dynamics. While the Alpha band provides valuable insights into attentional processes, other frequency bands such as Theta and Beta may also play significant roles. Examining these bands could reveal additional effects of light temperature and attentional load on cognitive performance.

Additionally, addressing individual differences in light sensitivity and other environmental factors is another important consideration. Future studies should account for variations in ambient noise, natural light exposure, and personal preferences to provide a more nuanced understanding of how these factors interact with light temperature and attentional load.

Moreover, future research should investigate the implications of this study's findings for the field of neuroarchitecture, particularly in designing environments that enhance attention and cognitive performance. Exploring the interaction between light temperature and other environmental factors, such as noise levels, the presence of other people, and varying attentional loads, is essential. These elements were not addressed in the current study but are critical in neuroarchitecture.

Finally, incorporating real room lighting conditions instead of relying on computer screens will better replicate real-world environments. Studies should explore the effects of ambient lighting from overhead sources to validate the findings under more naturalistic settings. This approach will help to better understand the practical implications of light temperature on cognitive performance and neural activity in everyday environments.

4.6 Conclusion

In conclusion, this study has provided valuable insights into the neural dynamics of light temperature under varying levels of attentional load. By employing a rapid visual detection task and analyzing neural data, we demonstrated that different attentional load modulate the cognitive dynamics in distinct ways.

The study revealed that participants exhibited faster response times when faced with high load conditions, suggesting increased urgency or prioritization under pressure [104]. On the other hand, accuracy was higher when the load was low, indicating that reduced cognitive demands allow for more precise performance as expected [86] [84]. Additionally, the presence of distractors had a significant negative impact on accuracy, highlighting the vulnerability of cognitive processes to interference from irrelevant stimuli [55] [112].

The neural data indicated significant effects of cognitive load, distractor presence, and hemispheric differences on mean ERSP (Event-Related Spectral Perturbation) values. Specifically, an increase in attentional load was associated with a decrease in Alpha band activity, suggesting that higher cognitive demands suppress neural oscillations typically linked to a relaxed and idle brain state [76] [64] [45]. Furthermore, the right hemisphere demonstrated greater Alpha suppression compared to the left hemisphere and midline, implying a more substantial role in processing attentional demands and managing cognitive load [33].

Altough there were no significant effect of CCT, the findings from both behavioral and neural data converge to suggest that increased cognitive load and the presence of distractors significantly impair performance. The neural correlates underscore the behavioral outcomes, showing that higher attentional demands reduce resources and modulate brain activity patterns, particularly in the Alpha band and within the right hemisphere. This integrated view enhances our understanding of how cognitive processes are managed under varying conditions of load and distraction, providing insights into the neural mechanisms underlying attention and performance.

Overall, this study contributes to the growing body of literature on neuroarchitecture and cognitive performance, emphasizing the significant impact of distractors on neural activity, response time, accuracy, and attentional processes. By using these insights, we can design environments that support optimal cognitive functioning and overall well-being, ultimately enhancing productivity, learning, and quality of life in various settings.

Bibliography

[1] F. M. Alessa, M. H. Alhaag, I. M. Al-harkan, et al. "A neurophysiological evaluation of cognitive load during augmented reality interactions in various industrial maintenance and assembly tasks". In: *Sensors* 23.18 (Sept. 2023), p. 7698. DOI: 10.3390/s23187698.

[2] A. S. Alexander, R. Place, M. J. Starrett, et al. "Rethinking retrosplenial cortex: Perspectives and predictions". In: *Neuron* (2022), S0896627322010273. ISSN: 08966273. DOI: 10.1016/j.neuron.2022.11.006.

[3] American Academy of Ophthalmology. *Optic Nerve and Visual Pathway.* Retrieved from https://www.aao.org/eye-health/anatomy/optic-nerve-101. Feb. 2021.

[4] American Academy of Ophthalmology. *What Is the Lens?* Retrieved from https://www.aao.org/eye-health/anatomy/what-is-lens. Oct. 2020.

[5] American Academy of Ophthalmology. *What Is the Pupil?* Retrieved from https://www.aao.org/eye-health/anatomy/pupil-101. July 2021.

[6] R. Arguelles-Prieto, J. A. Madrid, M. A. Rol, et al. "Correlated color temperature and light intensity: Complementary features in non-visual Light Field". In: *PLOS ONE* 16.7 (July 2021). DOI: 10.1371/journal.pone.0254171.

[7] G. Augustine, P. Williams, and D. Purves. *Neuroscience*. 3rd ed. Sinauer Associates, 2004. ISBN: 0-87893-725-0.

[8] E. Austin, R. Geisler, T. Nguyen, et al. "Visible light. part I: Properties and cutaneous effects of visible light". In: *Journal of the American Academy of Dermatology* 84.5 (May 2021), pp. 1219–1231. DOI: 10.1016/j.jaad.2021.02.048.

[9] B. R. Baltaretu, W. D. Stevens, E. Freud, et al. "Occipital and parietal cortex participate in a cortical network for transsaccadic discrimination of object shape and orientation". In: *Scientific Reports* 13.11628 (2023). DOI: 10.1038/s41598-023-38645-2.

[10] R. R. Baniya, E. Tetri, J. Virtanen, et al. "The effect of correlated colour temperature of lighting on thermal sensation and thermal comfort in a simulated indoor workplace". In: *Indoor and Built Environment* 27.3 (Oct. 2016). DOI: 10.1177/1420326X16673214.

[11] J. Bao, X. Song, Y. Li, et al. "Effect of lighting illuminance and colour temperature on mental workload in an office setting". In: *Scientific Reports* 11.1 (2021).

[12] D. Becker. "Color measurement". In: *Color Trends and Selection for Product Design* (2016), pp. 179–182. DOI: 10.1016/b978-0-323-39395-9.00037-2.

[13] Y. Benjamini and Y. Hochberg. "Controlling the false discovery rate: a practical and powerful approach to multiple testing". In: *Journal of the Royal Statistical Society, Series B* 57.1 (1995), pp. 289–300.

[14] G. Bhatnagar, S. Mehta, and S. Mitra. *An Interlude*. Elsevier, 2004, pp. 79–83. DOI: 10.1016/B978-012500453-4/50027-4.

[15] C. Blume, C. Garbazza, and M. Spitschan. "Effects of light on human circadian rhythms, sleep and mood". In: *Somnologie* 23 (2019), pp. 147–156.

[16] L. M. Bonacci, S. Bressler, J. A. Kwasa, et al. "Effects of visual scene complexity on neural signatures of spatial attention". In: *Frontiers in Human Neuroscience* 14 (2020). DOI: 10.3389/fnhum.2020.00091.

[17] M. Bonnefond and O. Jensen. "Gamma activity coupled to alpha phase as a mechanism for top-down controlled gating". In: *PLOS ONE* 10.6 (June 2015). DOI: 10.1371/journal.pone.0128667.

[18] M. Boubekri, J. Lee, P. MacNaughton, et al. "The Impact of Optimized Daylight and Views on the Sleep Duration and Cognitive Performance of Office Workers". In: *International Journal of Environmental Research and Public Health* 17.9 (2020), p. 3219. DOI: 10.3390/ijerph17093219.

[19] P. R. Boyce, J. A. Veitch, and C. M. Hunter. "Lighting quality and office work: two field simulation experiments". In: *Lighting Research & Technology* 38.3 (2006), pp. 191–223. DOI: 10.1191/1365782806lrt161oa.

[20] D. Broadbent. *Perception and Communication*. London: Pergamon Press, 1958.

[21] M. Bruckmaier, I. Tachtsidis, P. Phan, et al. "Attention and capacity limits in perception: A cellular metabolism account". In: *The Journal of Neuroscience* 40.35 (2020), pp. 6801–6811.

[22] G. Buzsáki. "Theta rhythm of navigation: Link between Path Integration and landmark navigation, episodic and semantic memory". In: *Hippocampus* 15.7 (Jan. 2005), pp. 827–840. DOI: 10.1002/hipo.20113.

[23] T. Caelli. *Light and Introductory Optics*. Elsevier, 1981, pp. 9–34.

[24] M. H. Casimiro, L. M. Ferreira, J. P. Leal, et al. "Ionizing Radiation for Preparation and Functionalization of Membranes and Their Biomedical and Environmental Applications". In: *Membranes* 9 (2019), p. 163. DOI: 10.3390/membranes9120163. URL: https://doi.org/10.3390/membranes9120163.

[25] N. Castilla, J. L. Higuera-Trujillo, and C. Llinares. "The effects of illuminance on students' memory. A neuroarchitecture study". In: *Building and Environment* 228 (Jan. 2023), p. 109833. DOI: 10.1016/j.buildenv.2022.109833.

[26] S. W. Cheadle and S. Zeki. "The role of parietal cortex in the formation of color and motion based concepts". In: *Frontiers in Human Neuroscience* 8 (2014). Published online 2014 Jul 28. PMCID: PMC4112936, PMID: 25120447, p. 535. DOI: 10.3389/fnhum.2014.00535.

[27] S. L. Chellappa, C. Cajochen, and P. Weber. "Can light make us bright? Effects of light on cognition and sleep". In: *Progress in Brain Research* 190 (2011), pp. 119–133. DOI: 10.1016/b978-0-444-53817-8.00007-4.

[28] E. C. Cherry. "Some experiments on the recognition of speech, with one and with two ears". In: *The Journal of the Acoustical Society of America* 25.5 (1953), pp. 975–979.

[29] CIE. *Commission internationale de l'Eclairage proceedings, 1931*. Cambridge: Cambridge University Press, 1932.

[30] Cleveland Clinic. *Anatomy of the Eye*. Retrieved from https://my.clevelandclinic.org/health/articles/8567-anatomy-of-the-eye. Feb. 2021.

[31] Commission Internationale de l'Eclairage. "CIE 1976 Colorimetry". In: *Bureau Central de la CIE* (1976).

[32] B. R. Conway and M. S. Livingstone. "Color vision, cones, and color-coding in the cortex". In: *The Neuroscientist* 15.3 (2009), pp. 274–290. DOI: 10.1177/1073858408331369.

[33] M. Corbetta and G. L. Shulman. "Control of goal-directed and stimulus-driven attention in the brain". In: *Nature Reviews Neuroscience* 3 (2002), pp. 201–215. DOI: 10.1038/nrn755.

[34] T. W. Cronin, S. Johnsen, N. J. Marshall, et al. *Visual Ecology*. Princeton University Press, 2014.

[35] R. Darken et al. "Spatial Orientation and Wayfinding in Large-Scale Virtual Spaces: An Introduction". In: *Presence: Teleoperators Virtual Environments* 7.2 (2002), pp. 101–107.

[36] A. Delorme and S. Makeig. “EEGLAB: an open source toolbox for analysis of single-trial EEG dynamics including independent component analysis”. In: *Journal of Neuroscience Methods* 134 (2004), pp. 9–21. DOI: 10.1016/j.jneumeth.2003.10.009.

[37] J. A. Deutsch and D. Deutsch. “Attention: Some theoretical considerations”. In: *Psychological Review* 70.1 (1963), pp. 80–90.

[38] D. D. Dilks, J. B. Julian, A. M. Paunov, et al. “The Occipital Place Area Is Causally and Selectively Involved in Scene Perception”. In: *The Journal of Neuroscience* 33.4 (Jan. 2013), pp. 1331–1336. ISSN: 0270-6474, 1529-2401. DOI: 10.1523/JNEUROSCI.4081-12.2013.

[39] J. F. Duffy and C. A. Czeisler. “Effect of light on human circadian physiology”. In: *Sleep Medicine Clinics* 4 (2009), pp. 165–177.

[40] A. D. Ekstrom, J. B. Caplan, E. Ho, et al. “Human hippocampal theta activity during virtual navigation”. In: *Hippocampus* 15.7 (Jan. 2005), pp. 881–889. DOI: 10.1002/hipo.20109.

[41] R. Epstein and N. Kanwisher. “A cortical representation of the local visual environment”. In: *Nature* 392.6676 (1998), pp. 598–601. ISSN: 0028-0836, 1476-4687. DOI: 10.1038/33402.

[42] H. Esteky and M. Rezaei. “Illuminating illumination: Understanding the influence of ambient lighting on prosocial behaviors”. In: *Journal of Environmental Psychology* 68 (2020), p. 101405. DOI: 10.1016/j.jenvp.2020.101405.

[43] T. Fernández, T. Harmony, M. Rodríguez, et al. “EEG activation patterns during the performance of tasks involving different components of mental calculation”. In: *Electroencephalography and Clinical Neurophysiology* 94.3 (Mar. 1995), pp. 175–182. DOI: 10.1016/0013-4694(94)00262-j.

[44] M. G. Figueiro et al. “Effect of Color Temperature and Illuminance on Psychology, Physiology, and Productivity: An Experimental Study”. In: *International Journal of Environmental Research and Public Health* 17.12 (2020), p. 4477.

[45] J. J. Foxe and A. C. Snyder. “The role of alpha-band brain oscillations as a sensory suppression mechanism during selective attention”. In: *Frontiers in Psychology* 2 (2011), p. 154. DOI: 10.3389/fpsyg.2011.00154.

[46] N. P. Friedman and T. W. Robbins. “The role of prefrontal cortex in cognitive control and executive function”. In: *Neuropsychopharmacology* 47 (2021), pp. 72–89.

[47] N. P. Friedman and T. W. Robbins. “The role of prefrontal cortex in cognitive control and executive function”. In: *Neuropsychopharmacology* 47 (2022), pp. 72–89.

[48] S. Fu, Y. Huang, Y. Luo, et al. “Perceptual load interacts with involuntary attention at early processing stages: Event-related potential studies”. In: *NeuroImage* 50.2 (2009), pp. 402–409. DOI: 10.1016/j.neuroimage.2009.12.031.

[49] X. Fu, D. Feng, X. Jiang, et al. “The effect of correlated color temperature and illumination level of LED lighting on visual comfort during sustained attention activities”. In: *Sustainability* 15.4 (Feb. 2023), p. 3826. DOI: 10.3390/su15043826.

[50] R. Golmohammadi, H. Yousefi, N. Safarpour Khotbesara, et al. “Effects of light on attention and reaction time: A systematic review”. In: *Journal of Research in Health Sciences* 21.4 (Oct. 2021). DOI: 10.34172/jrhs.2021.66.

[51] T. A. de Graaf, J. Gross, G. Paterson, et al. “Alpha-Band Rhythms in Visual Task Performance: Phase-Locking by Rhythmic Sensory Stimulation”. In: *PLOS ONE* (2013). DOI: 10.1371/journal.pone.0060035.

[52] D. M. Groppe, T. P. Urbach, and M. Kutas. “Mass univariate analysis of event-related brain potentials/fields I: A critical tutorial review”. In: *Psychophysiology* 48.12 (2011), pp. 1711–1725.

[53] R. F. Haglund. *The Properties of Light*. Springer Berlin Heidelberg, 2012, pp. 3–33.

[54] A. Haim and B. A. Portnov. *Artificial Light and its Physicochemical Properties*. Springer Netherlands, 2013, pp. 9–18.

[55] T. C. Handy, M. Soltani, and G. R. Mangun. “Perceptual Load and Visuocortical Processing: Event-Related Potentials Reveal Sensory-Level Selection”. In: *Psychological Science* 12.3 (2001), pp. 213–218. DOI: 10.1111/1467-9280.00339.

[56] L. E. Hartstein, M. K. LeBourgeois, and N. E. Berthier. “Light correlated color temperature and task switching performance in preschool-age children: Preliminary insights”. In: *PLOS ONE* 13.8 (2018).

[57] M. Hatori and S. Panda. “The emerging roles of melanopsin in behavioral adaptation to light”. In: *Trends in molecular medicine* 16 (Oct. 2010), pp. 435–46. DOI: 10.1016/j.molmed.2010.07.005.

[58] I. P. Herman. *The Properties of Light*. Elsevier, 1996, pp. 57–65.

[59] R.-H. Huang, L. Lee, Y. Chiu, et al. “Effects of Correlated Color Temperature on Focused and Sustained Attention under White LED Desk Lighting”. In: *Color Research Application* 40.3 (2014), pp. 285–293. DOI: 10.1002/col.21885.

[60] CIE (International Commission on Illumination). “A reference action spectrum for ultraviolet induced erythema in human skin”. In: *International Commission on Illumination Journal* 6 (1987), pp. 17–22.

[61] A. Jamrozik, N. Clements, S. S. Hasan, et al. “Access to daylight and view in an office improves cognitive performance and satisfaction and reduces eyestrain: A controlled crossover study”. In: *Building and Environment* 165 (2019), p. 106379. ISSN: 0360-1323. DOI: 10.1016/j.buildenv.2019.106379.

[62] JASP Team. *JASP (Version 0.18.3)[Computer software]*. 2024. URL: https://jasp-stats.org/.

[63] O. Jensen. “Distractor inhibition by alpha oscillations is controlled by an indirect mechanism governed by goal-relevant information”. In: *Communications Psychology* 2.1 (Apr. 2024). DOI: 10.1038/s44271-024-00081-w.

[64] O. Jensen and A. Mazaheri. “Shaping functional architecture by oscillatory alpha activity: Gating by inhibition”. In: *Frontiers in Human Neuroscience* 4 (2010). DOI: 10.3389/fnhum.2010.00186.

[65] W. A. Johnston and V. J. Dark. “Selective Attention”. In: *Annual Review of Psychology* 37 (1986), pp. 43–75.

[66] W. A. Johnston and S. P. Heinz. “Flexibility and capacity demands of attention”. In: *Journal of Experimental Psychology: General* 107 (1978), pp. 420–435.

[67] M. W. Jones and M. A. Wilson. “Theta Rhythms Coordinate Hippocampal–Prefrontal Interactions in a Spatial Memory Task”. In: *PLOS Biology* 3.11 (2005), e402. DOI: 10.1371/journal.pbio.0030402.

[68] F. S. Kamps, J. B. Julian, J. Kubilius, et al. “The occipital place area represents the local elements of scenes”. In: *NeuroImage* 132 (May 2016), pp. 417–424. DOI: 10.1016/j.neuroimage.2016.02.062.

[69] F. Karimi, Q. Almeida, and N. Jiang. “Large-scale frontoparietal theta, alpha, and beta phase synchronization: A set of EEG differential characteristics for freezing of gait in Parkinson’s disease?” In: *Frontiers in Aging Neuroscience* 14 (2022), p. 988037. DOI: 10.3389/fnagi.2022.988037.

[70] O. Keis, H. Helbig, J. Streb, et al. “Influence of blue-enriched classroom lighting on students’ cognitive performance”. In: *Trends in Neuroscience and Education* 3.3-4 (2014), pp. 86–92. ISSN: 2211-9493. DOI: 10.1016/j.tine.2014.09.001.

[71] S. P. Kelly, E. C. Lalor, R. B. Reilly, et al. “Increases in alpha oscillatory power reflect an active retinotopic mechanism for distracter suppression during sustained visuospatial attention”. In: *Journal of Neurophysiology* 95.6 (2006), pp. 3844–3851. DOI: 10.1152/jn.01234.2005.

[72] G. Keren. “Some consideration of two alleged kinds of selective attention”. In: *Journal of Experimental Psychology: General* 105 (1976), pp. 349–374.

[73] N. Y. Kim, E. Wittenberg, and C. S. Nam. “Behavioral and Neural Correlates of Executive Function: Interplay between Inhibition and Updating Processes”. In: *Frontiers in Neuroscience* 11 (2017), p. 378. DOI: 10.3389/fnins.2017.00378.

[74] M. Kleiner, D. Brainard, D. Pelli, et al. “What’s new in Psychtoolbox-3”. In: *Perception* 36.14 (2007), pp. 1–16.

[75] W. Klimesch. "Alpha-band oscillations, attention, and controlled access to stored information". In: *Trends in Cognitive Sciences* 16.12 (Dec. 2012), pp. 606–617. DOI: 10.1016/j.tics.2012.10.007.

[76] W. Klimesch. "Evoked alpha and early access to the knowledge system: The P1 inhibition timing hypothesis". In: *Brain Research* 1408 (Aug. 2011), pp. 52–71. DOI: 10.1016/j.brainres.2011.06.003.

[77] W. Klimesch, P. Sauseng, and S. Hanslmayr. "EEG alpha oscillations: The inhibition–timing hypothesis". In: *Brain Research Reviews* 53.1 (Jan. 2007), pp. 63–88. DOI: 10.1016/j.brainresrev.2006.06.003.

[78] I. Knez and I. Enmarker. "Effects of Indoor Lighting, Gender, and Age on Mood and Cognitive Performance". In: *Environment and Behavior* 32.6 (2000), pp. 817–831. DOI: 10.1177/0013916500326005.

[79] H. Komatsu, Y. Ideura, S. Kaji, et al. "Color selectivity of neurons in the inferior temporal cortex of the awake macaque monkey". In: *Journal of Neuroscience* 12.2 (1992), pp. 408–424. DOI: 10.1523/JNEUROSCI.12-02-00408.1992.

[80] J. D. Kropotov. "Alpha rhythms". In: *Quantitative EEG, Event-Related Potentials and Neurotherapy* (2009), pp. 29–58. DOI: 10.1016/b978-0-12-374512-5.00002-5.

[81] A. A. Kruithof. "Tubular luminescence lamps for general illumination". In: *Philips technical review* 6 (1941), pp. 65–96.

[82] T. D. Lamb. "Phototransduction, dark adaptation, and rhodopsin regeneration: The proctor lecture". In: *Investigative Ophthalmology Visual Science* 47.12 (2006), pp. 5137–5152. DOI: 10.1167/iovs.06-0532.

[83] N. Lavie. "Attention, Distraction, and Cognitive Control Under Load". In: *Current Directions in Psychological Science* 19.3 (2010), pp. 143–148. DOI: 10.1177/0963721410370295.

[84] N. Lavie. "Distracted and confused?: Selective attention under load". In: *Trends in Cognitive Sciences* 9.2 (2005), pp. 75–82. DOI: 10.1016/j.tics.2004.12.004.

[85] N. Lavie. “Perceptual load as a necessary condition for selective attention”. In: *Journal of Experimental Psychology: Human Perception and Performance* 21.3 (1995), pp. 451–468.

[86] N. Lavie and Y. Tsal. “Perceptual load as a major determinant of the locus of selection in visual attention”. In: *Journal of Experimental Psychology: Human Perception and Performance* 20.4 (1994), pp. 139–153. DOI: 10.3758/bf03213897.

[87] M. Lavoie, A. Cheng, and T. Julien. “Vigilance Levels During and After Bright Light Exposure in the First Half of the Night”. In: *Chronobiology International* 20.6 (2003), pp. 1019–1038. DOI: 10.1081/CBI-120025534.

[88] C. Liu, L. Sun, X. Jing, et al. “How correlated color temperature (CCT) affects undergraduates: A psychological and physiological evaluation”. In: *Journal of Building Engineering* 45 (2022), p. 103573. DOI: 10.1016/j.jobe.2021.103573.

[89] Z. Liu, W. Lu, and C. A. Seger. “Perceptual and categorical processing and representation in color categorization”. In: *Brain and Cognition* 136 (2019), p. 103617. DOI: 10.1016/j.bandc.2019.103617.

[90] S. J. Luck, S. A. Hillyard, M. Mouloua, et al. “Effects of spatial cuing on luminance detectability: Psychophysical and electrophysiological evidence for early selection”. In: *Journal of Experimental Psychology: Human Perception and Performance* 20 (1994), pp. 887–904.

[91] S. J. Luck, G. E. Woodman, and E. K. Vogel. “Event-related potential studies of attention”. In: *Trends in Cognitive Sciences* 4 (2000), pp. 432–440.

[92] W. Luo, R. Kramer, M. Kompier, et al. “Personal control of correlated color temperature of light: Effects on thermal comfort, visual comfort, and cognitive performance”. In: *Building and Environment* 238 (2023), p. 110380. ISSN: 0360-1323. DOI: 10.1016/j.buildenv.2023.110380.

[93] D. M. Maharjan, Y. Y. Dai, E. H. Glantz, et al. “Disruption of dorsal hippocampal–prefrontal interactions using chemogenetic inactivation impairs

spatial learning". In: *Neurobiology of Learning and Memory* 155 (Nov. 2018), pp. 351–360. DOI: 10.1016/j.nlm.2018.08.023.

[94] G. R. Mangun and S. A. Hillyard. "Modulations of sensory-evoked brain potentials indicate changes in perceptual processing during visual-spatial priming". In: *Journal of Experimental Psychology: Human Perception and Performance* 17.4 (1991), pp. 1057–1074.

[95] G. R. Mangun, J. B. Hopfinger, C. L. Kussmaul, et al. "Covariations in ERP and PET measures of spatial selective attention in human extrastriate visual cortex". In: *Human Brain Mapping* 5 (1997), pp. 273–279.

[96] E. Maris and R. Oostenveld. "Nonparametric statistical testing of EEG- and MEG-data". In: *Journal of Neuroscience Methods* 164.1 (2007), pp. 177–190.

[97] P. McCloughan, P. Graham, and J. Harrison. "The impact of lighting on mood". In: *Lighting Research and Technology* 31.3 (1999), pp. 81–88. DOI: 10.1177/096032719903100302.

[98] B.-K. Min, Y.-C. Jung, E. Kim, et al. "Bright illumination reduces parietal EEG alpha activity during a sustained attention task". In: *Brain Research* 1538 (2013), pp. 83–92. ISSN: 0006-8993. DOI: 10.1016/j.brainres.2013.09.031.

[99] J. Misselhorn, B. C. Schwab, T. R. Schneider, et al. "Synchronization of sensory gamma oscillations promotes multisensory communication". In: *eneuro* 6.5 (Sept. 2019). DOI: 10.1523/eneuro.0101-19.2019.

[100] J. D. Mollon. *The origins of modern color science*. 3rd ed. Elsevier Science Ltd., 2003. ISBN: 978-0-444-51251-2. DOI: 10.1016/B978-044451251-2/50002-7.

[101] B. L. Morrow and S. M. Kanakri. "The impact of fluorescent and LED lighting on students' attitudes and behavior in the classroom". In: *Advances in Pediatric Research* (2018). DOI: 10.24105/apr.2018.5.15.

[102] S. M. Muddamsetty. "Spatio-temporal saliency detection in dynamic scenes using color and texture features". Ph.D. Thesis. Dijon, France: Université de Bourgogne, July 2014.

[103] M. Münch, A. Wirz-Justice, S. A. Brown, et al. “The role of daylight for humans: Gaps in current knowledge”. In: *Clocks Sleep* 2.1 (2020), pp. 61–85. DOI: 10.3390/clockssleep2010008.

[104] G. Murphy, J. A. Groeger, and C. M. Greene. “Twenty years of load theory—Where are we now, and where should we go next?” In: *Psychonomic Bulletin Review* 23 (2016), pp. 1316–1340. DOI: 10.3758/s13423-015-0982-5.

[105] National Eye Institute. *How the Eyes Work*. Retrieved from https://www.nei.nih.gov/learn-about-eye-health/eye-conditions-and-diseases/how-eyes-work. n.d.

[106] National Eye Institute. *Retina*. Retrieved from https://www.nei.nih.gov/learn-about-eye-health/eye-conditions-and-diseases/retina. n.d.

[107] National Lighting Product Information Program (NLPIP). *Lighting Answers: Light Sources and Color*. Volume 8 Issue 1. Troy, NY: Lighting Research Center, Troy, Oct. 2004.

[108] A. Nuñez and W. Buño. “The Theta rhythm of the hippocampus: From neuronal and circuit mechanisms to behavior”. In: *Frontiers in Cellular Neuroscience* 15 (Mar. 2021). DOI: 10.3389/fncel.2021.649262.

[109] American Academy of Ophthalmology. *About Corneal Transplantation*. 2023. URL: https://www.aao.org/eye-health/treatments/about-corneal-transplantation.

[110] H. Park, V. Ryu, E. Kim, et al. “Effects of Color Temperature and Brightness on Electroencephalogram Alpha Activity in a Polychromatic Light-emitting Diode”. In: *Clinical Psychopharmacology and Neuroscience* 11 (Dec. 2013), pp. 126–31. DOI: 10.9758/cpn.2013.11.3.126.

[111] S. Park and M. M. Chun. “Different roles of the parahippocampal place area (PPA) and Retrosplenial Cortex (RSC) in panoramic scene perception”. In: *NeuroImage* 47.4 (Oct. 2009), pp. 1747–1756. DOI: 10.1016/j.neuroimage.2009.04.058.

[112] N. A. Parks, D. M. Beck, and A. F. Kramer. “Enhancement and suppression in the visual field under perceptual load”. In: *Journal of Cognitive Neuroscience* 25.8 (2013), pp. 1316–1329. DOI: 10.1162/jocn_a_00428.

[113] N. A. Parks, M. R. Hilimire, and P. M. Corballis. “Steady-state Signatures of Visual Perceptual Load, Multimodal Distractor Filtering, and Neural Competition”. In: *Journal of Cognitive Neuroscience* 23.5 (2011), pp. 1113–1124. DOI: 10.1162/jocn.2010.21504.

[114] N. A. Parks, M. R. Hilimire, and P. M. Corballis. “Visual perceptual load modulates an auditory microreflex”. In: *Psychophysiology* 48.9 (2009), pp. 1224–1231. DOI: 10.1111/j.1469-8986.2011.01188.x.

[115] C. R. Pernet, M. Latinus, T. E. Nichols, et al. “Cluster-based computational methods for mass univariate analyses of event-related brain potentials/fields: A simulation study”. In: *Journal of Neuroscience Methods* 250 (2015), pp. 85–93.

[116] J. Phipps-Nelson, J. R. Redman, D. J. Dijk, et al. “Daytime exposure to bright light, as compared to dim light, decreases sleepiness and improves psychomotor vigilance performance”. In: *Sleep* 26.6 (Sept. 2003), pp. 695–700. DOI: 10.1093/sleep/26.6.695.

[117] G. Piantoni, K. A. Kline, and D. M. Eagleman. “Beta oscillations correlate with the probability of perceiving rivalrous visual stimuli”. In: *Journal of Vision* 10.13 (Nov. 2010), pp. 18–18. DOI: 10.1167/10.13.18.

[118] J. Polich. “Overview of P3a and P3b”. In: *Detection of Change: Event-Related Potential and fMRI Findings*. Ed. by J. Polich. Boston: Kluwer Academic Press, 2003, pp. 83–98.

[119] M. I. Posner and C. R. R. Snyder. “Facilitation and inhibition in the processing of signals”. In: *Attention and performance V*. Ed. by P. M. A. Rabbitt and S. Dornic. New York: Academic Press, 1975.

[120] K. Rauss, G. Pourtois, P. Vuilleumier, et al. “Effects of attentional load on early visual processing depend on stimulus timing”. In: *Human Brain Mapping* 33.1 (Mar. 2011), pp. 63–74. DOI: 10.1002/hbm.21193.

[121] K. S. Rauss, G. Pourtois, P. Vuilleumier, et al. "Attentional load modifies early activity in human primary visual cortex". In: *Human Brain Mapping* 30.5 (2009), pp. 1723–1733.

[122] G. Rees, C. D. Frith, and N. Lavie. "Modulating Irrelevant Motion Perception by Varying Attentional Load in an Unrelated Task". In: *Science* 278.5343 (1997), pp. 1616–1619. DOI: 10.1126/science.278.5343.1616.

[123] J. W. Robinson. *A New Look at Light*. Springer US, 1964, pp. 219–230.

[124] C. Rorden, C. Guerrini, R. Swainson, et al. "Event related potentials reveal that increasing perceptual load leads to increased responses for target stimuli and decreased responses for irrelevant stimuli". In: *Frontiers in Human Neuroscience* 2 (2008), p. 4. DOI: 10.3389/neuro.09.004.2008.

[125] F. Roux, M. Wibral, H. M. Mohr, et al. "Gamma-band activity in human prefrontal cortex codes for the number of relevant items maintained in working memory". In: *The Journal of Neuroscience* 32.36 (Sept. 2012), pp. 12411–12420. DOI: 10.1523/jneurosci.0421-12.2012.

[126] D. Sanders, E. Frago, R. Kehoe, et al. "A meta-analysis of biological impacts of artificial light at night". In: *Nature Ecology Evolution* 5.1 (2020), pp. 74–81.

[127] J. Sassenhagen and D. Draschkow. "Cluster-based permutation tests of MEG/EEG data do not establish significance of interaction effects". In: *NeuroImage* 187 (2019), pp. 181–185.

[128] C. Scharinger, A. Soutschek, T. Schubert, et al. "Comparison of the Working Memory Load in N-Back and Working Memory Span Tasks by Means of EEG Frequency Band Power and P300 Amplitude". In: *Frontiers in Human Neuroscience* 11 (2017), p. 6. DOI: 10.3389/fnhum.2017.00006.

[129] M. C. Schmid, J. T. Schmiedt, A. J. Peters, et al. "Motion-sensitive responses in visual area V4 in the absence of primary visual cortex". In: *Journal of Neuroscience* 33.48 (Nov. 2013), pp. 18740–18745. DOI: 10.1523/JNEUROSCI.3923-13.2013.

[130] D. Schneider, S. K. Herbst, and M. Wöstmann. "Target enhancement or distractor suppression? Functionally distinct alpha oscillations form the basis of attention". In: *Journal of Neuroscience* 42.12 (2022), pp. 2385–2397. DOI: 10.1523/JNEUROSCI.0421-21.2022.

[131] S. Schwartz, P. Vuilleumier, C. Hutton, et al. "Attentional load and sensory competition in human vision: Modulation of fMRI responses by load at fixation during task irrelevant stimulation in the peripheral visual field". In: *Cerebral Cortex* 15.6 (2004), pp. 770–786.

[132] B. M. T. Shamsul, C. C. Sia, Y. G. Ng, et al. "Effects of light's colour temperatures on visual comfort level, task performances, and alertness among students". In: *American Journal of Public Health Research* 1.7 (July 2013), pp. 159–165. DOI: 10.12691/ajphr-1-7-3.

[133] R. M. Shiffrin and W. Schneider. "Controlled and automatic human information processing: II. Perceptual learning, automatic attending, and a general theory". In: *Psychological Review* 84 (1977), pp. 127–190.

[134] H. Shin, J. Park, and J. Lee. "The effect on emotions and brain activity by the direct/indirect lighting in the residential environment". In: *Neuroscience Letters* 584 (2015), pp. 28–32. DOI: 10.1016/j.neulet.2014.09.046.

[135] H. Song, S. Kim, and K. Lim. "Ambient Lights Influence Perception and Decision-Making". In: *Frontiers in Psychology* 9 (2019), p. 2685. DOI: 10.3389/fpsyg.2018.02685.

[136] P. Studer, J. M. Brucker, C. Haag, et al. "Effects of blue- and red-enriched light on attention and sleep in typically developing adolescents". In: *Physiology Behavior* 199 (2019), pp. 11–19. DOI: 10.1016/j.physbeh.2018.10.015.

[137] M. Sun, L. Hu, X. Xin, et al. "Neural Hierarchy of Color Categorization: From Prototype Encoding to Boundary Encoding". In: *Frontiers in Neuroscience* 15 (2021), p. 679627. DOI: 10.3389/fnins.2021.679627.

[138] M. Tsunoda, T. Endo, S. Hashimoto, et al. "Effects of light and sleep stages on heart rate variability in humans". In: *Psychiatry and Clinical Neurosciences* 55.3 (2001), pp. 285–286. DOI: 10.1046/j.1440-1819.2001.00862.x.

[139] A. Tversky and D. Kahneman. "Availability: A heuristic for judging frequency and probability". In: *Cognitive Psychology* 5.2 (1973), pp. 207–232.

[140] W. M. Usrey and H. J. Alitto. "Visual Functions of the Thalamus". In: *Annual Review of Vision Science* 1 (Nov. 2015), pp. 351–371. DOI: 10.1146/annurev-vision-082114-035920.

[141] S. Van Voorhis and S. A. Hillyard. "Visual evoked potentials and selective attention to points in space". In: *Perception Psychophysics* 22.1 (1977), pp. 54–62.

[142] S. D. Vann, J. P. Aggleton, and E. A. Maguire. "What does the retrosplenial cortex do?" In: *Nature Reviews Neuroscience* 10.11 (2009), pp. 792–802. ISSN: 1471-003X, 1471-0048. DOI: 10.1038/nrn2733.

[143] E. K. Vogel and S. J. Luck. "The visual N1 component as an index of a discrimination process". In: *Psychophysiology* 37 (2000), pp. 190–203.

[144] B. A. Wandell. *Foundations of vision*. Sinauer Associates, 1995.

[145] B. A. Wandell and A. R. Wade. "Functional imaging of the visual pathways". In: *Neurologic Clinics* 21.2 (2003). PMID: 12916486, pp. 417–443, vi. DOI: 10.1016/s0733-8619(03)00003-3.

[146] Z. Weng, L. Wei, J. Song, et al. "Effect of enclosed lighting environment on work performance and visual perception". In: *2020 17th China International Forum on Solid State Lighting 2020 International Forum on Wide Bandgap Semiconductors China (SSLChina: IFWS)* (Nov. 2020). DOI: 10.1109/sslchinaifws51786.2020.9308687.

[147] Z. Weng, L. Zhou, M. Wei, et al. "Psychological and physiological influences of CCTs on young people before sleep". In: *2017 14th China International Forum on Solid State Lighting: International Forum on Wide Bandgap Semiconductors China (SSLChina: IFWS)*. 2017, pp. 105–108. DOI: 10.1109/IFWS.2017.8245985.

[148] M. Wöstmann, M. Alavash, and J. Obleser. “Alpha Oscillations in the Human Brain Implement Distractor Suppression Independent of Target Selection”. In: *The Journal of Neuroscience* 39.49 (2019), pp. 9797–9805. DOI: 10.1523/JNEUROSCI.1053-19.2019.

[149] H. R. Wright and L. C. Lack. “Effect of light wavelength on suppression and phase delay of the melatonin rhythm”. In: *Chronobiology International* 18.5 (2001), pp. 801–808. DOI: 10.1081/cbi-100107515.

[150] W. Yang and J. Y. Jeon. “Effects of correlated colour temperature of LED light on visual sensation, perception, and cognitive performance in a classroom lighting environment”. In: *Sustainability* 12.10 (May 2020), p. 4051. DOI: 10.3390/su12104051.

[151] S. Zeki and L. Marini. “Three cortical stages of colour processing in the human brain”. In: *Brain* 121.Pt 9 (1998). PMID: 9762956, pp. 1669–1685. DOI: 10.1093/brain/121.9.1669.

[152] N. Zhozhikashvili, I. Zakharov, V. Ismatullina, et al. “Parietal alpha oscillations: Cognitive load and mental toughness”. In: *Brain Sciences* 12.9 (Aug. 2022), p. 1135. DOI: 10.3390/brainsci12091135.

[153] Y. Zhu, M. Yang, M. Yang, et al. “Effects of Illuminance and Correlated Color Temperature on Daytime Cognitive Performance, Subjective Mood, and Alertness in Healthy Adults”. In: *Environment and Behavior* 51.1 (2017), p. 001391651773807. DOI: 10.1177/0013916517738077.

Appendix A

Supporting Figures

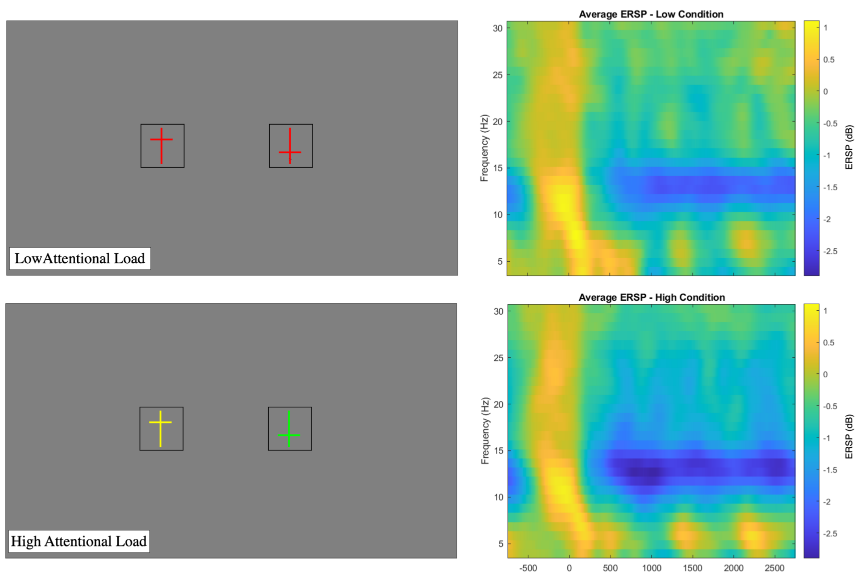

Figure A.1: **Time Frequency Decomposition of Attentional Load.** The right panels show the corresponding time-frequency representations (ERSPs) for attentional load conditions, with the top right panel representing the average ERSP for the low attentional load condition and the bottom right panel representing the average ERSP for the high attentional load condition. The color scale indicates power changes (in dB) relative to baseline, with warm colors (yellow) representing power increases and cool colors (blue) representing power decreases across frequencies (4-30 Hz) and time (-500 - 2500 ms).

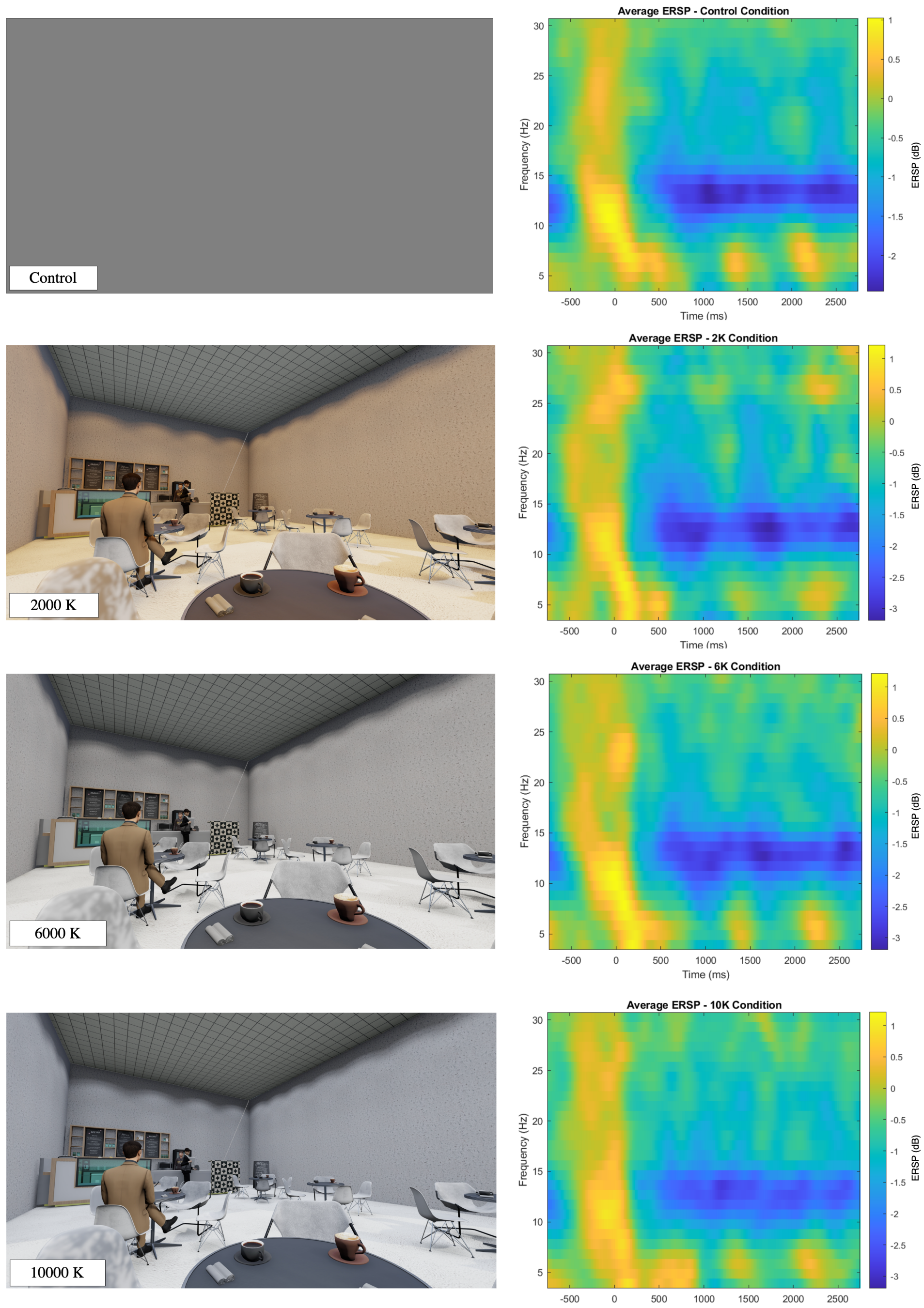

Figure A.2: **Time Frequency Decomposition of Color Temperatures on Low Attentional Load.** The right panels show the corresponding time-frequency representations (ERSPs) for CCT conditions. The color scale indicates power changes (in dB), with warm colors representing power increases and cool colors representing power decreases across frequencies (4-30 Hz) and time (-500 to 2500 ms).

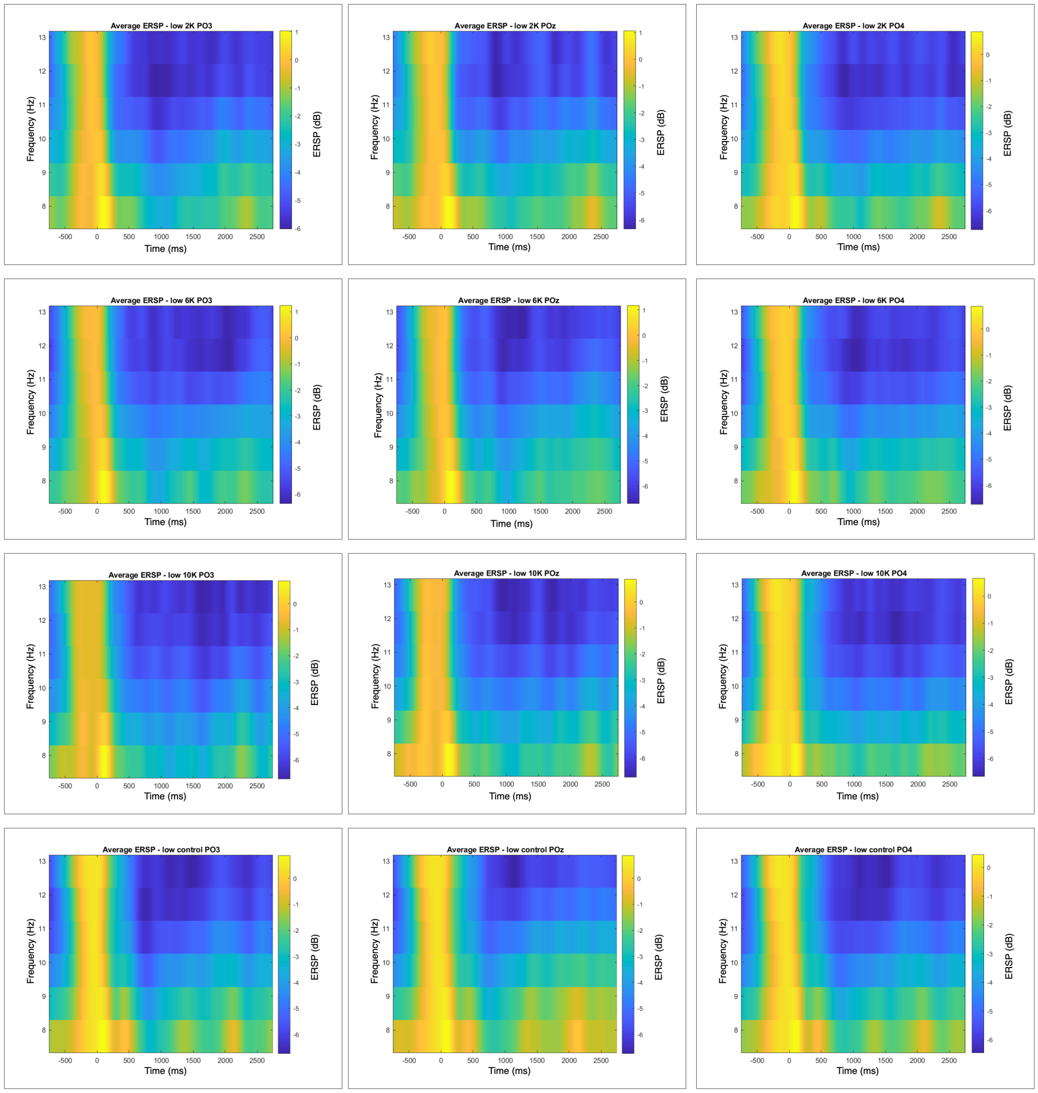

Figure A.3: **Time Frequency Decomposition of CCT Conditions under High Attentional Load.** The figure consists of 12 panels showing the average Event-Related Spectral Perturbations (ERSPs) under high attentional load. Each row represents a different Correlated Color Temperature (CCT) condition (2K, 6K, 10K, Control) and each column represents different occipital channels (Po3, Poz, Po4). The panels in each row represent the average ERSPs for the respective channels and CCT conditions. Each panel displays the time-frequency representation of the ERSP, with time (ms) on the x-axis and frequency (Hz) on the y-axis. The color scale indicates power changes (dB) relative to baseline, with warm colors (yellow) representing power increases and cool colors (blue) representing power decreases across frequencies (8-13 Hz) and time (-500 to 2500 ms).

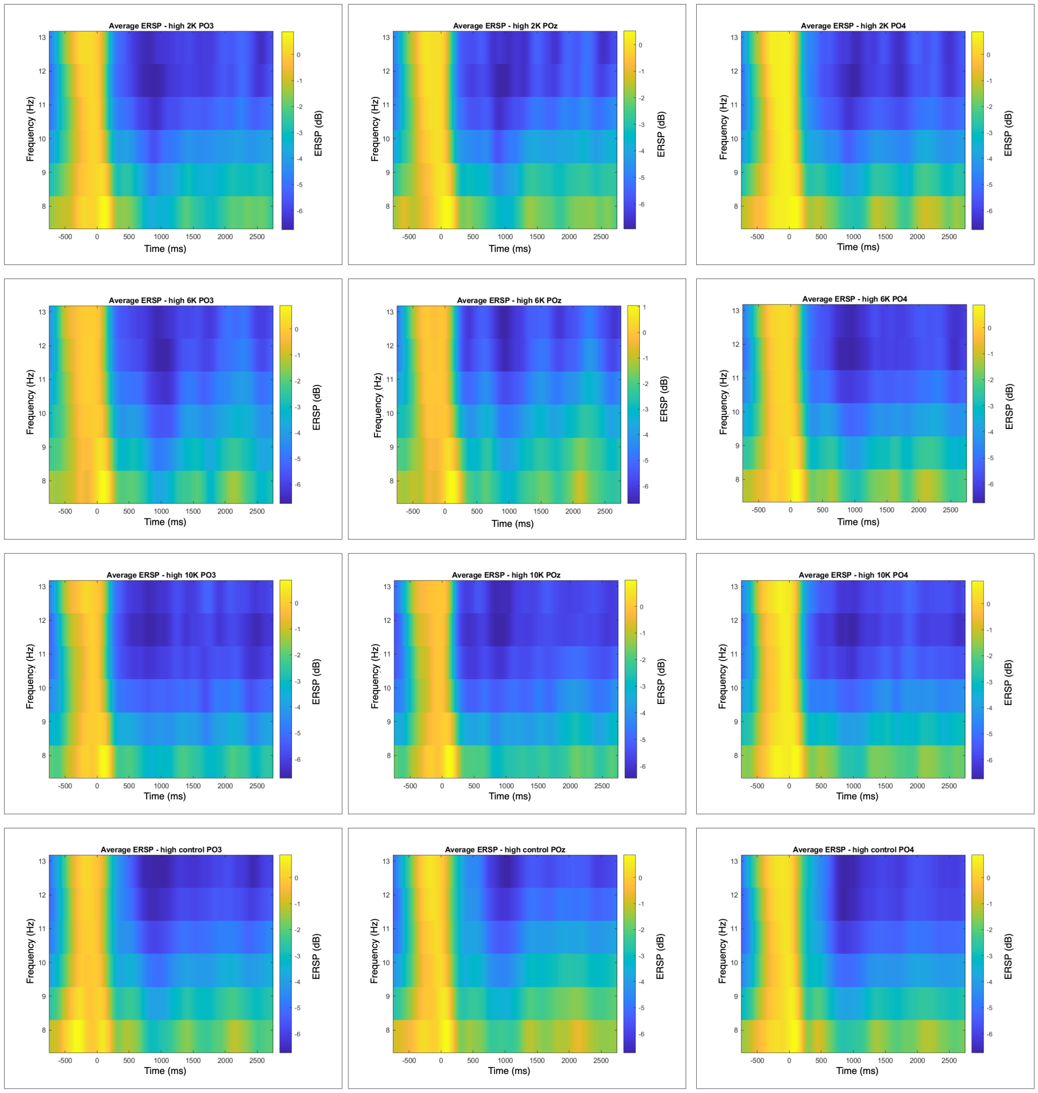

Figure A.4: **Time Frequency Decomposition of CCT Conditions under High Attentional Load.** The figure consists of 12 panels showing the average Event-Related Spectral Perturbations (ERSPs) under high attentional load. Each row represents a different Correlated Color Temperature (CCT) condition (2K, 6K, 10K, Control) and each column represents different occipital channels (Po3, Poz, Po4). The panels in each row represent the average ERSPs for the respective channels and CCT conditions. Each panel displays the time-frequency representation of the ERSP, with time (ms) on the x-axis and frequency (Hz) on the y-axis. The color scale indicates power changes (dB) relative to baseline, with warm colors (yellow) representing power increases and cool colors (blue) representing power decreases across frequencies (8-13 Hz) and time (-500 to 2500 ms).

Appendix B

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