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RETAIL LIGHTING EFFECT ON CONSUMER EMOTION THROUGH HEART RATE VARIABILITY: A SYSTEMATIC LITERATURE REVIEW

Nesya Nandita Irwan[1], Etika Vidyarini[2]
[1,2]Faculty of Arts and Design, Institut Teknologi Bandung, Indonesia
E-mail: nesyanandita@gmail.com, etika.vidyarini@itb.ac.id

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Abstract: *The rapidly evolving retail industry demands a deep understanding of environmental stimuli that can regulate visitors' emotional states. Although lighting has been shown to be a crucial interior element of store ambiance, its impact on human psychophysiology, which shapes consumer behavior, still requires further exploration. This article aims to analyze the literature on how lighting influences visitors' emotional states, using Heart Rate Variability as an objective psychophysiological indicator. This review was conducted following PRISMA guidelines by searching through academic databases from 2015 to 2025. The data synthesis results indicate a strong correlation between lighting parameters, such as color temperature and illumination, and the autonomic nervous system. The findings highlight that certain lighting manipulations significantly affect fluctuations in HRV metrics, which reflect visitors' arousal and cognitive load. This internal state implicitly mediates the formation of positive emotions that ultimately influence purchase intentions. This review provides a data-driven framework for interior designers and retail owners to implement lighting strategies to optimize visitors' emotional experiences. Furthermore, this article identifies gaps in neuromarketing research and provides directions for future research on the use of neuroscience technology in retail marketing.*
Keyword: *Retail Lighting, Heart Rate Variability (HRV), Neuromarketing*

Abstrak: Industri ritel yang berkembang pesat menuntut pemahaman mendalam tentang stimulus lingkungan yang dapat mengatur keadaan emosional pengunjung. Meskipun pencahayaan telah terbukti sebagai elemen interior penting dari suasana toko, dampaknya pada psikofisiologi manusia, yang membentuk perilaku konsumen, masih memerlukan eksplorasi lebih lanjut. Artikel ini bertujuan untuk menganalisis literatur tentang bagaimana pencahayaan memengaruhi keadaan emosional pengunjung, menggunakan *Heart Rate Variability* (HRV) sebagai indikator psikofisiologis objektif. Tinjauan ini dilakukan mengikuti pedoman PRISMA dengan menelusuri basis data akademis dari tahun 2015 hingga 2025. Hasil sintesis data menunjukkan korelasi yang kuat antara parameter pencahayaan, seperti suhu warna dan iluminasi, dan sistem saraf otonom. Temuan tersebut menyoroti bahwa manipulasi pencahayaan tertentu secara signifikan memengaruhi fluktuasi metrik HRV, yang mencerminkan *arousal* dan beban kognitif pengunjung. Keadaan internal ini secara implisit memediasi pembentukan emosi positif yang pada akhirnya memengaruhi niat pembelian. Tinjauan ini menyediakan kerangka kerja berbasis data bagi perancang interior dan pemilik ritel untuk menerapkan strategi pencahayaan guna mengoptimalkan pengalaman emosional pengunjung. Lebih lanjut, artikel ini mengidentifikasi kesenjangan dalam penelitian neuromarketing dan memberikan arahan untuk penelitian masa depan tentang penggunaan teknologi ilmu saraf dalam pemasaran ritel.
Kata Kunci: Pencahayaan Ritel, *Heart Rate Variability* (HRV), *Neuromarketing*

INTRODUCTION

The rapid growth of retail business in Indonesia has intensified the competition here. Large retail stores have expanded globally through their distribution networks, acting as both wholesalers and retailers in all developing countries, including Indonesia (Rani and Purnami, 2019). One of the deciding factors of this rapid growth is the ever-changing lifestyles, such as people now prefer to shop in modern shopping malls over traditional markets. Marketing serves as the conduct between a product and customers, influencing the final sale (Khondakar et al., 2024). In a large and competitive market like retail, introducing products requires more effective marketing strategies. Traditional marketing techniques such as self-reports or interviews mainly allow the measurement of conscious reactions to marketing-related stimuli (e.g., advertisements, brands) (Alvino et al., 2020). Consumer don't always convey their true thoughts and often follow what others say, that's why using only traditional marketing won't always work. Marketers and academics look for

supplementary or alternative methods to address the limitations of traditional marketing strategies. One such option is to use Neuromarketing, which analyzes customers' spontaneous reactions to certain advertising campaigns, packaging, designs, etc., and explores how customers react to marketing stimuli (Khondakar et al., 2024). Neuromarketing practices involve measuring biometric variables that detect changes in physiological parameters such as respiratory rhythm, skin conductance, pupil dilation, heartbeat, sweating, eye fixation point displacement, and facial expression (Pluta-Olearnik & Szulga, 2022).

In this competitive market, capturing consumer attention while also encouraging quick purchasing decisions is very important. One of the interior elements crucial for creating the store atmosphere is lighting. Lighting not only serves as a visual aid to highlight products but also as an external stimulus that can manipulate consumers' emotional states and influence their purchase intentions. It showed that light is a Cognitive Map able to guide and direct the individual in the exploration and discovery of the surrounding environment, providing the interpretative keys of an increasingly complex reality (Tomassoni et al., 2015). Lighting is an important issue in retail spaces since it either emphasises or understates the product, its quality and its environment. The factors that have been largely studied with reference to the perception of interiors and associated behavioural connotations include illumination level, the colour of light and type of illumination (Ozkul et al., 2020). Both high and low illumination levels affect hue and saturation qualities of colour, and these factors affect task performance as well (Peretti, 1977, cited in Ozkul et al., 2020). In retail stores, where purchasing decisions depend on accurate product color visualization, Correlated Color Temperature (CCT) is an important factor. CCT describes the hue or visual warmth of a light source. The ability to perceive color accurately can increase consumer satisfaction and reduce perceived purchase risk, which can indirectly influence arousal and encourage consumer behavior such as impulsive buying. Therefore, manipulating lighting parameters is an important strategy in retail design to influence consumer behavior.

Psychophysiological responses are also used as a tool to determine how lighting relates to consumers' emotional states. Psychophysiology, according to O'Donnell et al. (2023), is the study of physiological signals recorded from the body or brain, and their relationships with psychological processes and disorders. Psychophysiological responses, as measured by Heart Rate Variability (HRV), provide an objective indicator of the level of arousal and cognitive load experienced by consumers when exposed to a stimulus. HRV is the fluctuation in the time intervals between adjacent heartbeats. HRV indexes neurocardiac function and is generated by heart-brain interactions and dynamic non-linear autonomic nervous system (ANS) processes (Shaffer & Ginsberg, 2017). Test results obtained from ECG (Electrocardiogram) are often used by neuromarketing experts to better understand how subjects' emotional states change during a test — the heartbeat is actually related to an individual's level of concentration: the lower it is, the more it indicates that the subject is in a mental state of attention and concentration (Chmielewska, 2013, in Pluta-Olearnik & Szulga, 2022). According to Spielman et al. (2020), emotions are produced under the combined influence of one's own experience, expression, cognitive evaluation and physiological response. Among many theories, "The Schachter-Singer two-factor theory of emotion" is a widely accepted theory. The theory claims that physiology and cognition work together to produce emotions. It believes that the process of emotional production is divided into three steps: receiving external stimuli, producing both physiological and cognitive responses, and generating emotions (Huang, 2024). Although the use of psychophysiological responses such as HRV began to be adopted in various research studies, the literature regarding retail lighting and autonomic nervous system activity remains very limited and fragmented. No systematic review has been found that specifically addresses how lighting affects consumers' emotions, validated through neuroscience biometric metrics. Therefore, this article aims to conduct a systematic literature review of studies that use psychophysiological indicators in the context of retail lighting. It will provide a comprehensive understanding of the scope and techniques of current research in neuromarketing, psychophysiology, and retail design. Following this brief introduction, the methodology for this systematic review will be presented, followed by key findings relevant to the questions and a discussion of significant results.

METHODOLOGY

This study uses a Systematic Literature Review (SLR) method. It systematically maps, assesses, and synthesizes scientific literature on relationships between variables. The primary focus is on studies that integrate retail lighting parameters, psychophysiological responses (especially HRV), and consumers' emotional states. The literature search covered academic databases: Scopus, ScienceDirect, Frontiers, Wiley, Taylor & Francis & PubMed. It included publications ranging from 2015 to 2025 to ensure relevance to the latest physiological biotechnology. The search used Boolean keywords: ("retail lighting" OR "lighting" OR "store atmosphere") AND ("Heart Rate Variability" OR "psychophysiology" OR "ECG") AND ("emotions" OR "consumer behavior" OR "neuromarketing").

The inclusion criteria for this study included: (a) Articles from reputable indexed national and international journals; (b) Discussing the interaction between lighting stimuli and psychophysiological responses, particularly HRV; (c) Emphasizing outcomes in the form of emotional states or consumer behavior. Conversely, exclusion criteria were applied to articles that relied solely on self-report data (questionnaires/interviews) to measure

emotions without objective biometric validation. This systematic review followed the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines for selecting research articles. The PRISMA protocol consists of four stages: identification, screening, eligibility, and inclusion. The extracted data were then analyzed qualitatively to build a theoretical framework regarding the influence of light on the activity of the autonomic nervous system and the emotional state of room users.

SYSTEMATIC REVIEW

Neuromarketing is an excellent tool to "read" the customer's mind and address questions about buyer's behavior. Neuromarketing uses both psychological and Neuroscience techniques to analyse the neurological and psychological mechanisms that underlying human decisions and behaviours. Hence, studying these mechanisms is useful to explain consumers' responses to marketing stimuli (Alvino et al., 2018). In researching this field, a substantial amount of literature has been published to contribute to our understanding of consumer behavior. This systematic review examines various articles published over the past ten years. This section will explore trends in neuromarketing research using environment stimulus and answer the review's research questions.

Fig. 1 PRISMA flow chart for selecting publications for the systematic review

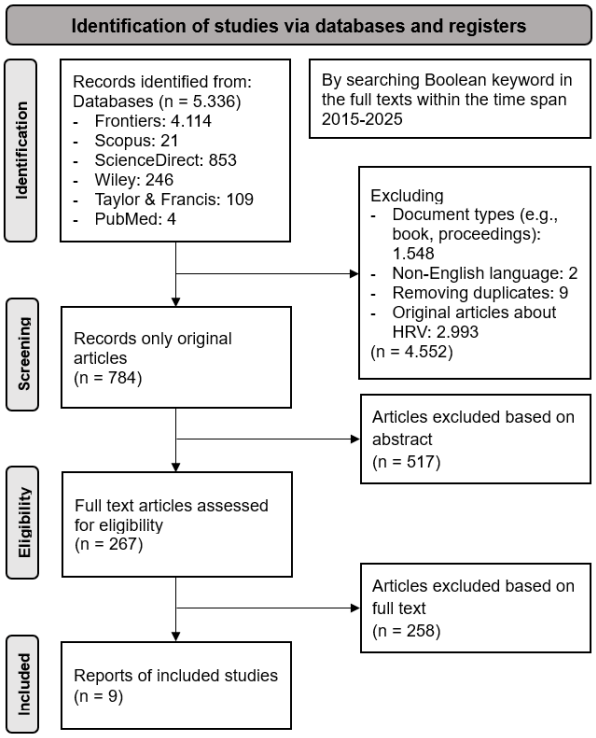

Table 1. Previous literature review

Article	Sampling	Conditions	Measure	Findings
D'Agostin et al. (2020)	20 (14 F, 6 M) Age (M = 22)	2 lighting conditions (blue light/ red light)	SDNN, RMSSD, pNN50,	Colored lights produced significant changes in HRV
		White light as baseline	LF, HF, LF/HF	metrics (LF/HF) indicating an autonomic response
Xie et al. (2023)	16 (8 F, 8 M) Age (20-35)	4 lighting conditions (green, blue, red, yellow)	HR, HF, LF, LF/HF, GSR_{max}, GSR_{mean}, ΔGSR	Colored light has a regulating effect on emotional perception.
Cai et al. (2024)	12 (6 F, 6 M) Age (21-26)	6 illuminances (300, 400, 500, 600, 700 & 800 lx) and 4 CCT (3000, 4000, 5000, & 6000 K)	ECG (SDRR, LF, HF), EDA (SCL, SCR), SKT, SpO2	Illuminance and CCT significantly affected subjective perception
Li et al. (2025)	33 (21 F, 12 M) Age (18-36; M = 22.5; SD = 3.3)	6 colors (red, white, blue, yellow, green & purple) and 3 illuminance (20, 100 & 180 lx)	EEG, ECG (SDNN, NN50, LF/HF)	The effect of stress on cardiac dynamics can differ substantially between males and females
Zeng et al. (2025)	30 (12 F, 18 M) Age (21-29; M = 24.6; SD = 2.0)	6 lighting conditions; melanopic EDI (694, 417, 250, 150, 90 & 54 lx)	HR, SDNN, LF/HF, HRV, SKT	Lighting influence comfort, satisfaction, brightness perception, and cognitive task in problem solving
Kuijsters et al. (2015)	38 (19 F, 19 M) Age (66-94; M = 78.8; SD = 6.8)	3 ambiences: cozy (120 lx; 2700 K), activating (325 lx; 4000 K), neutral (150 lx; 3400 K)	SCR, HR, HF	We can improve the mood of elderly by expo--sing them to lighting ambien--ces with a clear, positive affective meaning
Sun et al. (2025)	30 (14 F, 16 M)	2 illuminances (300, 500 lx) and	SDNN, rMSSD, NN50, LF, HF, LF/HF	There is higher subjective alertness

	Age (21-36; M = 28.2; SD = 3.97)	3 CCT (2800, 5000, 6500 K)		during work with 300 lx and 5000 K.
Agustí et al. (2022)	70 (39 F, 31 M) Age (19-24)	5 public spaces (square; narrow street; green space without trees; green space with trees; city's main street)	rMSSD	There are significant differences in the perception of space according to gender.
Adjei et al. (2018)	20 (10 F, 10 M) Age female (21-26; M = 23.3; SD = 1.3) Male (23-38; M = 28.6; SD = 5.6)	Mental math task in pairs, against sex-matched opponents. All female were in the follicular phase of menstrual cycle.	HR, HF, LF	The effect of stress on cardiac dynamics can differ substantially between males and females.

Abbreviation: SDNN (ms): Standard deviation of NN intervals; SDRR (ms): Standard deviation of RR intervals; pNN50 (%): Percentage of successive RR intervals that differ by more than 50 ms; RMSSD (ms): Root mean square of successive RR interval differences; LF (nu): low frequency; HF (nu): high frequency; LF/HF (Ratio of LF-to-HF power; NN50 (ms):: pNN50: NN50 (ms): The number of adjacent NN intervals that differ from each other by more than 50 ms (NN50) requires a 2 min epoch; HR (bpm): Number of R-peaks per minute; GSR: Galvanic Skin Response; EEG: Electroencephalogram; ECG: Electrocardiogram; EDA; Electrodermal Activity, GSRmax: Highest peak of skin conductivity (lowest resistance) achieved during an event or task, signifying high arousal or stress., GSRmean: Skin conductivity in the calm state; ΔGSR: change in the electrical conductance of the skin compared to a baseline; SCL: Skin Conductance Level; SCR: Skin Conductance Responses; SKT: Skin Temperature; SpO2: Blood oxygen saturation; EDI: Equivalent Daylight Illuminance.

Different light colours produced a significant change in HRV metrics. In D'Agostin et al. (2020), exposure to blue light could reduce discomfort and improve well-being, whereas red light could evoke anxiety and other unpleasant feelings. It suggests a relationship among arousal (sympathetic or vagal), mood (stressed or relaxed, anxious or calm), and exposure to different-coloured lights (red or blue). The same thing also happened in Xie et al. (2023), which results in different light colours significantly affecting mood, with red light having the most substantial emotional arousal, followed by blue and green. In contrast, yellow light has minimal effects. However, the energetic mood was significantly increased under yellow light. Notably, the change of HF and LF before and after light stimulation is significantly negatively correlated with the mood of energy. Both GSR and ECG signals may undoubtedly reflect an individual's mood.

Illuminance and CCT also play important roles in people. Cai et al. (2024) shows both illuminance and CCT significantly affected subjective perception. Low illuminance and CCT tended to result in lower pleasure, calmer arousal, and more sleepiness, which would lead to a significantly lower willingness to work and study and a greater tendency to rest. Arousal and alertness increased with high illumination and CCT. Participants had better visual comfort in a light environment of 500–700 lx and an intermediate CCT than at lower illumination and CCT. While Li et al. (2025) shows low illuminance generally impairs emotional regulation ability; however, this effect varies significantly depending on the interaction between illuminance and light color. The combination of illuminance and light colour regulates emotions through dual pathways involving central nervous system mechanisms (EEG) and autonomic nervous system mechanisms (HRV). The effect of stress on cardiac dynamics also differs substantially between males and females.

Both light intensity and CCT also play important roles in modulating alertness and cognitive performance, while physiological responses appear less sensitive to these variations (Sun et al., 2025). Subjective alertness during the working condition was influenced by the combined effects of light intensity and CCT, with the highest alertness observed under lighting conditions of 3000 and 5000 K. In terms of objective alertness, optimal performance occurred at a light intensity of 300 lx, while a CCT of 2800 K resulted in better performance compared to 5000 K. Zeng et al. (2025) show that lighting influences comfort, satisfaction, brightness perception, and cognitive tasks performance in memory and problem solving. The 150 lx melanopic EDI condition was the most preferred by participants, while cognitive task performance improved at 250 lx melanopic EDI, consistent with the recommended melanopic EDI value for daytime lighting.

Lighting also influences ambience, which was used in Kuijsters et al. (2015). The low-arousing, pleasant ambience (i.e., cozy) was found to be more effective in reducing a high-arousing negative mood state (i.e., anxiety) than the neutral ambience. The high-arousing, pleasant ambience (i.e., activating) was found to increase the physiological arousal of sad elderly people more than the neutral ambience. Sad elderly who were immersed in a positive, high-arousing (i.e., activating) ambience were physiologically more aroused than sad elderly who were immersed in a neutral ambience.

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While Agustí et al. (2022) used HRV to see the difference between genders in expressing feelings in public spaces. In the RMSSD, the value for women was 14.19% lower than that for men. Low RMSSD values are synonymous with situations of stress. In the case of men, open spaces tended to cause a higher degree of stress, while in women, narrow streets with the presence of other people were what generated the greatest stress. Women more readily identified and expressed feelings of fear and sadness, while men expressed more happiness and anger more frequently. Adjei et al. (2018) also used HRV to show that the effect of stress on cardiac dynamics can differ substantially between males and females, which calls for a re-evaluation of our understanding of how stressful events affect cardiac dynamics in females in the follicular phase of their menstrual cycle. The expected increase in HR in response to stress is not universal; while every male experienced an increase in HR of at least 11%, only half of the females experienced increases of at least 5%. The overall stress-induced decrease in LF and the increase in HF in the females is a finding that contradicts the conventional understanding of the relationships between stress and the low-frequency and high-frequency components of HRV.

The reviewed literature consistently proved that lighting is not merely a functional element but a powerful neuromarketing tool that modulates the autonomic nervous system. Besides lighting, some aspects, such as gender and age, also need to be considered in neuromarketing. HRV metrics, particularly RMSSD and the LF/HF ratio, serve as primary indicators of these shifts.

Effect of CCT and Illuminance on HRV

The literature reviewed indicates that specific lighting variables act as significant triggers for emotional shifts that affect not only psychological effects, but also physiological effects on the mood of people. CCT, measured in Kelvin, refers to the color appearance of light, with lower values indicating a warmer tone of white light, while higher CCT values correspond to a cooler tone of white light. Illumination intensity, or illuminance, represents the brightness of the light, where higher illuminance means brighter lighting and lower illuminance means dimmer lighting (Awada et al., 2025). CCT is a highly significant variable; for instance, blue light consistently correlates with increased well-being and reduced discomfort, while red light evokes higher arousal and anxiety (D'Agostin et al., 2020). Interestingly, while red and blue produce strong shifts in emotions, yellow light was found to have minimal effects on most emotional dimensions except for a significant increase in energetic mood (Xie et al., 2023).

From a methodological perspective, the significance of these findings often depends on whether researchers use single or combined stimuli. Recent data suggest that the interaction between CCT and illuminance provides a more significant impact on emotional regulation than either factor alone (Cai et al., 2024; Li et al., 2025; Sun et al., 2025). High illumination (500-700 lx) combined with intermediate CCT (4000-5000 K) is significantly linked to better visual comfort and alertness (Cai et al., 2024), whereas low illuminance (20 lx) generally impairs emotional regulation, leading to increased sleepiness and decreased task willingness (Li et al., 2025). Subjective alertness during the working condition was influenced by the combined effects of light intensity and CCT, with the highest alertness observed under lighting conditions of 3000 and 5000 K. In terms of objective alertness, optimal performance occurred at a light intensity of 300 lx, while a CCT of 2800 K resulted in better performance compared to 5000 K (Sun et al., 2025).

CCT and illuminance also influence ambience and even the function of a room, which was used in Kuijsters et al. (2015), who used both combinations to make three ambiences: cozy, activating, and neutral ambiences. The results show that we can improve the mood of the elderly by exposing them to lighting ambiences with a clear, positive affective meaning. Sad elderly who were immersed in a positive, high-arousing (i.e., activating) ambience were physiologically more aroused than sad elderly who were immersed in a neutral ambience, while the anxious elderly could be effectively calmed with a cozy ambience.

Lighting not only could affect someone's mood, but it could also significantly influence color preference and purchase intention (Tian et al., 2023). Light is also a “cognitive map” that is able to guide and direct the individual in the exploration and discovery of the surrounding environment (Tomassoni et al., 2015).

This proves that lighting aspects, such as CCT and illuminance, are vital in retail lighting design.

Demographic and Contextual Nuances

The systematic review also highlights that psychophysiological responses are not universal but vary based on demographic factors, such as gender and age (Agustí et al., 2022; Sun et al., 2025; Kuijsters et al., 2015). Experimental data show a significant difference in how genders experience environmental stressors. Agustí et al. (2022) show that women often exhibit higher physiological stress—indicated by a 14.19% lower RMSSD—compared to men in similar spatial configurations. Women also tended to express fear and sadness more, while men tended to express happiness and anger more readily than women. The effect of stress on cardiac dynamics can also differ substantially between males and females (Adjei et al., 2018).

Adjei et al. (2018) show that the stress-induced changes in the power of the high-frequency component were even more profound; it greatly decreased in the males but increased in the females. It has been argued that estrogen attenuates the effect of catecholamine stress hormones; the findings from this investigation suggest for the first time that the conventionally cited cardiac changes, attributed to the fight-or-flight stress response, are not universally applicable to females. Instead, this pilot study provides an alternative interpretation of cardiac responses to stress in females, which indicates a closer alignment to the evolutionary tend-and-befriend response.

This shows that gender is an important variable that must be considered in interior design, especially in retail store which needs quick purchases. Women were also found to be more sensitive to different light sources and hold different attitudes toward different lipstick colors under different CCTs (Tian et al., 2023). Not only gender, but the effectiveness of lighting ambience is also highly age-dependent. In elderly populations, "cozy" (120 lx; 2700 K) settings are more significant for reducing anxiety, whereas "activating" (325 lx; 4000 K) settings are needed to increase physiological arousal in those in sad mood states (Kuijsters et al., 2015). Age also influences a lot in retail settings, such as impulsive buying occurring more frequently in people aged 18 to 39 years (Ünsalan, 2016).

Duration of HRV Measurements

In assessing consumer emotional responses to retail lighting stimuli, the duration of the ECG signal recording for HRV analysis is a critical parameter that determines data validity. According to Shaffer and Ginsberg (2017), there are three standard measurements: 24 h, short-term (ST, ~5 min), or ultra-short-term (UST, <5 min). Clinicians and researchers measure HRV using time-domain, frequency-domain, and non-linear indices. Time-domain values measure how much HRV was observed during the monitoring period. Frequency-domain values calculate absolute or relative signal power within the ULF, VLF, LF, and HF bands. Recording period length limits HRV frequency-band measurement. Minimum recommended periods include: ULF (24 h), VLF (5 min, 24 h preferred), LF (2 min), and HF (1 min). Non-linear indices measure the unpredictability and complexity of a series of IBIs (Shaffer and Ginsberg, 2017).

In the context of retail environments and laboratory-based experimental designs, short-term measurement (5 minutes) is the most widely adopted standard because of its relatively easy recording. This duration is considered sufficient to capture the equilibrium of the Autonomic Nervous System (ANS), particularly for accurately evaluating Low Frequency (LF) and High Frequency (HF) components. Measurements that are too brief (<2 minutes) are often unstable for frequency-domain analysis, as the LF component requires a longer respiratory cycle to achieve stabilization. However, recent studies investigating the effects of colored lights have begun to implement ultra-short-term measurement (<5 minutes) to increase experimental efficiency and mitigate participant fatigue. For instance, Xie et al. (2023) utilized stimulus exposure and signal recording durations of 1 minute for each lighting condition, closed their eyes for 1 minute, did a task, and lastly rested their eyes for 2 minutes before another task. This abbreviated duration is effective for capturing immediate affective impressions and physiological shifts in response to ambient changes, such as variations in CCT or illuminance.

The application of measurement duration in the studies reviewed for this SLR is typically divided into three essential phases:

1. Baseline/Adaptation: Mostly from 1 to 5 minutes, or longer, 10 minutes, where the subject remains under neutral lighting to stabilize the heart rate before treatment.
2. Stimulus Exposure (Task): The duration during which the subject is exposed to specific retail lighting. Literature suggests a range of 5 to 10 minutes is optimal for recording significant changes in RMSSD and LF/HF ratios (sometimes more, depending on the task).
3. Rest: A rest period (typically 1–2 minutes) between different lighting conditions to eliminate residual effects from the previous stimulus.

The selection of duration in the reviewed studies indicates a trend where shorter durations are preferred in neuromarketing research to stimulate the actual time a consumer spends browsing products at a retail shelf, while the 5-minute standard remains the benchmark for analyses requiring higher clinical precision.

HRV in Retail Design and Consumer Behaviour

The goal of analyzing HRV in the retail context is to bridge the gap between autonomous physiological states and overt consumer behaviour. The literature suggests that the “affective impressions” captured through HRV are not merely internal states but are precursors to behavioral intentions, such as time spent in the store and purchase urgency. While traditional retail research relies on subjective self-reporting, the integration of HRV provides a more

objective approach, providing tools for neuromarketing for atmospherics design. Previous studies indicate that positive emotions such as excitement, pleasure, and enthusiasm can increase the tendency for impulse buying, especially when consumers are exposed to external stimuli like sales promotions, a pleasant retail atmosphere, or products with high hedonic value. Conversely, negative emotions such as stress or boredom can also drive impulsive purchasing behavior as a form of emotional compensation (Layali, 2022). The dual-process theory shows that consumer decision-making fundamentally involves the interaction between emotional and rational processes. The rapid emotional pathway, mediated by the limbic system and amygdala, drives instinctive motivation and reward-seeking behaviors, while the slower rational pathway engages the prefrontal cortex (PFC) to systematically assess product utility and functionality. This neurobiological distinction explains why consumers often make emotional choices despite having access to rational product information (Wang et al., 2025).

Furthermore, this SLR identifies a shift toward "Neuro-retail" strategies, where environmental stimuli are no longer static. By understanding HRV metrics discussed in previous sections, retail designers can:

- Modulate purchase intention, by using specific CCT and illuminance levels to shift the consumer's emotional state to modulate consumer purchase intention.
- Targeted demographic, by recognizing that specific groups, such as women, may experience higher physiological stress (Adjei et al., 2018), retailers can implement "comfort-centric" lighting zones to mitigate anxiety and prolong shopping duration.
- Predictive ambiences design, moving toward responsive lighting systems that adjust based on real-time physiological feedback to optimize the consumer's emotional journey.

In conclusion, the strategic manipulation of retail lighting—guided by psychophysiological data—allows for the creation of environments that do not just look aesthetic but actively modulate the consumer's autonomic nervous system to drive economic outcomes.

The synthesis of these results reveals a clear trend in this field; while we understand lighting in controlled office or urban settings, there is a gap in applying this to consumer behaviour in retail design. Most existing studies rely on task-based performance or subjective comfort. Future research needs to pivot toward using HRV as an objective neuromarketing tool to measure real-time emotional manipulation in stores. To advance even further, future studies must prioritize the interaction effect of CCT and illuminance, while treating gender and age as primary factors, rather than secondary demographics. This will allow researchers to uncover how specific lighting parameters can trigger physiological states that lead to immediate purchase decisions.

CONCLUSION

Neuromarketing, specifically through the analysis of Heart Rate Variability (HRV), enables researchers to understand consumers' emotional states, particularly the unconscious responses of individuals exposed to environmental stimuli, such as lighting. The synthesis of recent research confirms that lighting is a powerful psychophysiological stimulus rather than merely an interior element, with HRV metrics serving as indicators of shifts in the autonomic nervous system, specifically RMSSD for parasympathetic activity and the LF/HF ratio for sympathovagal balance. While specific colors like blue and red evoke strong emotional responses—ranging from comfort from blue, and anxiety from red—the most significant impact on emotional regulation arises from the interaction between CCT and illuminance. Furthermore, these psychophysiological responses are significantly moderated by demographic factors such as gender and age; for instance, women often exhibit higher physiological stress, requiring gender-aware experimental designs, whereas elderly populations require specific lighting ambiences to effectively manage their mood. Despite the depth of understanding in office and urban contexts, a major research gap exists in the retail sector, as most studies have focused on functional outcomes such as task performance or general comfort rather than on the strategic manipulation of environmental stimuli to influence consumer behaviour. To advance this field, researchers must adhere to HRV measurement standards; while short-term recording still remains the benchmark, ultra-short-term recordings are also used for capturing immediate affective impressions in fast-paced retail settings. Future research should therefore focus on how to take neuromarketing tools to retail design. By leveraging these neuromarketing insights, retail designers can move beyond aesthetic lighting toward environments that actively modulate consumer behavior to prompt quick purchase intentions.

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