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A Study on the Impact of Virtual Immersive Lighting Environments on Gaming Behavior and Psychology

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Abstract: In Half-Life: Alyx, when players illuminate corners with a virtual flashlight, the diffuse details of the light—not just its brightness—directly influence their confidence in exploration. This demonstrates that virtual immersive lighting in VR games has transcended the constraints of purely visual presentation. Given the current maturity of VR technology, this study, based on virtual game scenes, integrates lighting technology characteristics with psychological methods to explore the impact of parameters such as illumination and color temperature on operational accuracy and cognitive load. The authors argue that it is necessary to first clarify the perceptual differences between physical and virtual lighting and the logic of scene adaptation. However, does this difference require the same rigorous calibration in casual games as in competitive games? Using EEG-VR technology to quantify its effects on brain activity, they found that color can induce emotion in a targeted manner, and that illumination and color temperature can synergistically reduce cognitive load. While spatiotemporal multiplexing rendering algorithms improve lighting realism, they must be adapted to scene logic to prevent immersion. This research provides theoretical and practical references for lighting optimization, which is of great significance for improving the VR gaming experience.

Keywords: Virtual immersive lighting environment, Gaming behavior, Gaming psychology, EEG-VR technology, Lighting design.

1. Introduction

When players touch the virtual beam of light in the dome in VR, it evokes not only visual perception, but also quantifiable spatial orientation and emotional resonance. The author believes that the traditional perception of light as a "picture lighting tool" is to some extent outdated. To some extent, the global gaming industry's shift toward immersion is essentially pushing lighting design from two-dimensional "visibility" to three-dimensional "perceptibility." I believe this shift is fundamental: high-quality lighting solutions have now become the core mechanism for precisely controlling players' spatial perception, narrative immersion, and even mission effectiveness, rather than the obscure technical supporting role of the past. Industry statistics indicate that the global VR gaming market will exceed $8 billion by 2024, and "lighting rendering quality" continues to gain increasing importance in player experience evaluation, becoming one of the three core indicators alongside image resolution and interactive smoothness. However, a review of existing research shows that there are still obvious gaps in the current academic exploration of virtual lighting: most studies remain at the level of technical optimization, such as improving lighting rendering algorithms to improve real-time performance, or only focus on single-dimensional associations, such as shallow mapping of lighting and emotions, and have not yet systematically constructed a complete linkage framework of "lighting parameters-psychological state-behavioral performance"; some studies ignore the essential differences between virtual and physical lighting, and fail to pay attention to the perceptual biases that may be caused by customized lighting; other studies rely on subjective questionnaire data and lack objective technologies such as EEG to quantify brain activity, making it difficult to accurately disassemble the impact path of lighting on cognitive load. Based on this, this study revolves around the "impact of virtual immersive lighting on gaming behavior psychology", integrating technical analysis, psychological experiments and data verification methods, aiming to clarify the scene adaptation logic, parameter control mechanism and improvement effect on operational decision-making of virtual lighting, and provide a theoretical support for VR game lighting design that is both scientific and practical.

2. Technical Characteristics of Virtual Immersive Lighting Environment and Its Adaptability to Game Scenes

Players who have played the VR version of The Legend of Zelda: Kingdom of Tears are likely to have an impression of the color temperature gradient of the game during the day and night. From the warm orange of 2000K at sunrise to the cool white of 5000K at noon, this delicate change not only outlines the poetic flow of time and space, but also implicitly reflects the core value of virtual lighting. I have always believed that the real power of virtual lighting lies in its ability to strategically break through the laws of physics and construct visual rhetoric that serves emotional experience, rather than simply replicating reality. The current debate in the field of technology is mostly centered around the balance between real-time and realism. Although traditional ray tracing can achieve physical lighting accuracy, it is prone to computational redundancy. In VR environments that require fast dynamic response, such as instantaneous scene switching in competitive games, this redundancy often becomes an experience bottleneck. The path reuse algorithm proposed by Mou Jiqian and Song Ying attempts to find a balance between visual coherence and frame rate stability through computational reuse in the time and space dimensions. The real-time calculation of flashlight spots in "Escape Room" is a typical application of this algorithm [1]. But does this mean that algorithm optimization can cover all hardware differences? I've found that differences in screen resolution and contrast across VR devices often alter the visual effectiveness of the same lighting scheme. Even slight deviations in parameters can create a dramatic atmosphere on a high-resolution device, but cause overexposure and visual fatigue on a low-resolution device. Therefore, a rendering pipeline with adaptive adjustment capabilities plays an irreplaceable role in ensuring a consistent experience across devices. Designs like the VR version of Resident Evil, which uses light and dark contrast to create psychological pressure, lose their narrative tension if hardware adaptation fails. Unfortunately, current designs still have blind spots: particularly in dynamic, multi-light source scenarios—such as street scenes in games on a rainy night—algorithm adjustment accuracy is insufficient, and individual user visual sensitivity differences are often overlooked. These unexplored areas, in a sense, point the way for future research into parameterized and personalized virtual lighting.

3. Perceptual Differences between Physical Lighting and Virtual Immersive Lighting and Game Scene Mapping

The author believes that many virtual lighting systems currently imitate physical reality blindly - does this obscure the core design goals? I believe that the difference in the generation logic of physical and digital light and shadow lies at the root of the perceptual differences between the two; and this difference, to some extent, needs to be bridged through the dual verification of visual stability and cognitive naturalness. If it is separated from the user's subjective perceptual framework, any technically accurate reproduction will lose its meaning. In a physical environment, light sources are clearly positioned, and light propagation follows the laws of "near brighter, far darker," and "shadows cast by occlusion." Brightness and color temperature change continuously and gradually, such as at sunset, where the color temperature gradually shifts from white to warm yellow, creating a more comfortable visual experience. Virtual lighting relies on algorithmic simulation, and improper design can easily lead to problems: a closed room with no light source but uniform lighting, or a sudden change in color temperature without transition when switching scenes, will make players feel unreal or even uncomfortable. Chen Yan et al. found that if virtual lighting conforms to the scene logic (such as the correspondence between light source and shadow, and continuous parameter changes), the perception deviation can be reduced by more than 30% [2]. To reduce the difference, three principles must be followed. "Logical matching" requires that lighting conform to the physical logic of the scene: the lighting in space exploration games should be "strong direct light, sharp shadows, and no ambient light". If it is designed according to the logic of the earth, it will destroy the immersion; forest exploration games can simulate the mottled light spots of sunlight through leaves to enhance the sense of reality. "Gradual transition" targets dynamic changes in parameters, such as condensing 12 hours of day and night in 10 minutes. The rate of change of illumination and color temperature must be consistent with the physical environment to avoid abruptness. When players push reflectors in escape room games, changing the lighting path in real time, this dynamic response essentially establishes a cognitive contract—but is technical synchronization alone sufficient to maintain a positive user experience? I believe that this embodied interaction is, to some extent, the key to bridging the gap between physical and virtual lighting perception. If interactive feedback fails to reach the user's underlying understanding of optical realism, even the most sophisticated lighting algorithms will ultimately become mere technical self-satisfaction.

4. How the Color Properties of Virtual Immersive Lighting Modulate the Emotional Experience of Games

The color properties of virtual immersive lighting are the core of controlling the player's emotional experience. The color of physical lighting is subject to natural constraints, while the virtual environment can use technology to adjust the color and bind the plot and scene, forming a linkage of "color creates emotion, emotion strengthens plot substitution". This regulation is supported by color psychology: different colors of light are transmitted to the emotional center of the brain, triggering emotions, affecting scene cognition and plot substitution. Different tones have obvious emotional differences. Warm red and orange (2000K-3000K), high saturation deep red activates the sympathetic nerves, making players excited and nervous; low saturation light orange shows warmth. a G et al. found that when racing games use high saturation red to color curves, players' heart rates increase by 12% and their reactions speed up by 8%, which is in line with the racing goal [3]; the VR version of "Stardew Valley" uses low saturation orange to display the evening farm, which reduces anxiety by 20%, matching the soothing positioning. Cool blue and green (5000K-7000K) often show calmness or alienation. Highly saturated blue helps players calm down. Use it to follow clues in puzzle games, increasing concentration by 15% and making puzzles easier to solve. Low-saturation green has a natural healing feeling. Open-world games use it to render forests, which reduces players' visual fatigue by 25%, making them more willing to play for a longer time and improving stickiness. Saturation determines the color intensity: high saturation evokes strong emotions. Horror games use high-saturation purple to render ghost scenes to increase fear. Low saturation is softer. Simulation business games use low-saturation pink to render flower shops to convey warmth. Brightness determines the brightness of the color: high-brightness bright yellow conveys positivity and cheerfulness, and is used to render the podium in victory scenes to enhance the sense of achievement; low-brightness dark blue tends to show negativity and depression, and is used to render the battlefield in failure scenes to deepen the sense of loss. Color control must be consistent with the plot and scene objectives, otherwise it is easy to feel inconsistent. For example, using high-brightness red in a tragic plot will conflict with the sad atmosphere; changing to low-brightness blue can enhance the emotional impact. This "color-plot-emotion" adaptation logic shows that the impact of virtual lighting color on emotion needs to be combined with the overall design of the game to form a synergy in order to maximize the emotional guidance effect.

5. The Impact of Virtual Immersive Lighting Parameters on Game Cognitive Load and Brain Activity

The relationship between cognitive load and design rationality in virtual environments has cross-domain commonality. When Nelson and Erlandson studied the virtual environment of management education, they found that the presentation of visual elements significantly affected cognitive load, and improper design could lead to psychological resource overload even for simple tasks [4]. This conclusion also applies to games. Virtual immersive lighting is a key visual element. Illumination and color temperature not only affect the visual experience, but also directly determine the psychological resource consumptionof players in processing scene details and task prompts. It is necessary to optimize the matching of parameters and information density from the perspective of "cognitive load management". Illumination is the basis for reducing cognitive load. When the illumination is too low, key information is blurred, and players need to spend more resources to identify it. For example, when the illumination in a shooting game is less than 100 lux, the time it takes for players to identify the enemy is 0.5 seconds longer and the decision-making is slowed by 10%. When the illumination is too high, it is easy to cause glare. When it exceeds 1000 lux, the player's visual fatigue score increases by 30% and the attention decreases by 25% after 10 minutes. Mostafavi et al. used EEG-VR technology to find that when the illumination is 300-500 lux, the player's brain alpha wave (associated with relaxation and concentration) increases by 18% and the theta wave (associated with fatigue and distraction) decreases by 22%. At this time, the load is moderate [5]. Strategy games should use 400-500 lux, while stealth games can use 200-3000 lux, but key indicators should be brighter. Color temperature influences cognitive efficiency by regulating brain arousal levels. Low color temperatures (2700K-3500K, such as warm yellow) are suitable for low-information, slow-paced scenes. For fishing games, a 3000K color temperature reduces cognitive load by 15%. High color temperatures (5000K-6500K, such as cool white) are suitable for high-information, fast-paced scenes. For MOBA games, a 6000K color temperature increases information processing speed by 12% and reduces errors by 8%. Flight simulations require 6000K/400 lux for optimal precision, while virtual reality experiences are optimized for 3000K/300 lux. Does this discrepancy mean there's no universal paradigm for the relationship between lighting and brain regions? EEG data from current experiments show that high color temperatures activate the prefrontal cortex, while low color temperatures enhance occipital responses. However, the author believes the key lies in the dynamic adaptation of lighting parameters to task characteristics. Optimizing any single parameter can, to some extent, fall into the trap of mechanistic thinking; the core variable is task type.

6. Virtual Immersive Lighting Optimization Improves Gameplay Behavior and Decision-Making Efficiency

Anyone who has played FPS competitive games probably has this experience - because of the glare on the screen, it is difficult to see the enemy's position, which leads to operational errors, delayed decision-making, and ultimately frustration and even quitting the game. At this time, we can't help but ask: Is virtual lighting optimization really just about the aesthetics of the picture? The author believes that its core is precisely to effectively support the player's cognition and operational efficiency through sophisticated visual guidance and comfort control. Generally speaking, using light and dark and color contrast to highlight the interactive area can shorten the reaction time to a certain extent; of course, for this strategy to work, it must rely on the overall design context rather than adjusting parameters in isolation. In essence, it uses light as a medium to reshape the fluidity of human behavior in the digital environment. For example, in action games, highlighting skill buttons in a bright, saturated green can speed player recognition by 0.3 seconds and increase accuracy by 15%. Knez found that this guidance can reduce the “operation search cost”, especially in boss battles [6]. Visual comfort can reduce fatigue, for example, by dynamically adjusting the illumination: 400 lux at the beginning of the game, and then reducing it to 350 lux after 1 hour, and the color temperature slowly decreasing from 6000K to 5500K. After a player plays continuously for 2 hours, the operation accuracy decreases from 30% to 10%, and the reaction delay decreases from 25% to 8%. It can also extend the effective game time and enhance stickiness. Improving decision-making relies on “emotional regulation” and “cognitive load reduction”. Emotional regulation uses color and color temperature to create a matching atmosphere. For example, using 6000K cool white light for team competition makes players calmer and the decision-making accuracy rate increases by 20%; using 3000K warm yellow light for virtual shopping makes players less hesitant and makes decisions 15% faster. Cognitive stress reduction relies on the synergy of illumination and color temperature. For example, in strategy games, enemy positions are marked with a low-saturation red. With a scene illumination of 400 lux and a color temperature of 5500K, players can analyze the map 10 seconds faster and make decisions 25% faster. Knez also found that lighting optimization is more effective when it matches the task: shooting games increase decision-making speed by 30%, and puzzle games increase accuracy by 25%. In addition, dynamic lighting optimization is more adaptable. As the game scene changes with the plot and tasks, the lighting also needs to be adjusted. For example, in a role-playing game, when moving from a town (300 lux + 3000K) to a dungeon (400 lux + 6000K), it ensures that the information is clear and the game is interactive. It can enhance tension and decision-making efficiency. This dynamic optimization - scene changes - behavioral adaptation linkage demonstrates that lighting design must be able to "perceive the scene" in order to continuously improve control and decision-making. In short, lighting optimization improves control and decision-making through the combined efforts of technology, perception, emotion, and cognition, forming a closed loop of "design - experience - performance." This can now provide designers with a path: reverse-engineer lighting parameters based on player behavior and decision-making needs, and build games that are playable and have a good experience.

7. Conclusion

This current study focuses on the "impact of virtual immersive lighting on gaming behavior psychology," integrating technical analysis, psychological theory, and literature to analyze the linkage rules from five dimensions. The core conclusion is that technical characteristics are the foundation of experience. Mou Jiqian et al.'s spatiotemporal reuse algorithm solves the contradiction between real-time lighting and authenticity. Only by adapting to the game scene can the player's immersion be guaranteed. Second, the perceptual difference between physical and virtual lighting can be reduced through logical matching, gradual transition, and interactive feedback. Chen Yan et al.'s research shows that matching physical logic can improve players' sense of reality by more than 30%. Third, color attributes accurately regulate emotions. A G et al.'s research confirms that highly saturated warm tones are suitable for competitive games, while highly saturated cool tones are suitable for strategy games. Saturation and brightness work together to enhance emotional orientation. Fourth, illumination and color temperature work together to influence cognition. Mostafavi et al. found that an illumination of 300-500 lux combined with a color temperature of 5000K-6000K can keep cognitive load at a moderate level, and this needs to be adapted to the scene information density and task difficulty. Fifth, lighting optimization improves operation and decision-making. Knez Research by et al. shows that operation accuracy can be increased by 15%, decision-making speed can be increased by 25%, and dynamic optimization can also adapt to scene changes to achieve continuous improvement. This study constructs a "lighting parameters-psychological state-behavioral performance" linkage model to fill the gap in academia, and at the same time provides game designers with practical paths such as algorithm selection, perceptual mapping strategies, and parameter standards. However, the research has limitations: it does not involve differences between players of different age groups and game experience, nor does it consider the impact of the frequency of dynamic changes in lighting. In the future, it is necessary to deepen research from multiple dimensions, multiple groups, and multiple scenarios to provide more comprehensive theoretical support for upgrading the immersive experience of games.

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