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Research on Design Principles of Vehicle-Mounted Command Cabin Environment under Visual Perception

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Abstract

To enhance the operational efficiency of military command and crew performance, thereby strengthening overall military combat effectiveness, this study focuses on vehicle-mounted command cabins within military equipment. It explores the integration of visual perception theory into the design of vehicle-mounted command cabins. Aiming to fulfill crew requirements for cabin environment based on the characteristics of the human visual perception system, this research attempts to establish a comfortable, efficient, and harmonious relationship between the crew and the cabin environment to enhance work efficiency and augment combat soft power, providing a reference for future command cabin design. In this study, the first phase investigates the relationship between the crew and the spatial environment of the command cabin, exploring from the perspective of vision and cognition, and analyzing factors in the cabin environment that affect crew psychology and behavior. During the second phase, integrating environmental psychology, cognitive psychology, and ergonomics, the authors propose holistic, comfortable, experiential, and efficient design principles for the command cabin environment based on visual perception theory, offering theoretical support for later design practices.

Keyword: Vehicle-Mounted Command Cabin, Visual Perception, Design Principles, Environment, Crew Performance

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Introduction

The command cabin is a specialized compartment equipped with numerous control devices and advanced command systems, independently utilized as a command room under unique environmental conditions. It serves as an information system for commanding and controlling military forces and fire control weapon systems (Bai, 2011). The establishment of command systems aims to enhance military command and management efficiency, thereby bolstering overall military combat capability. With the rapid development of China's weapon command system industry, the focus of command cabin design has gradually shifted from traditional ergonomics, emphasizing safety and comfort, to a more holistic approach encompassing emotional needs and perceptual studies. This not only requires ensuring functionality and scale that align with crew behavioral patterns but also providing a comfortable environment that meets their basic psychological needs. Hence, cabin interior space design transcends physical space considerations, evolving into a process of creating emotional experiences. Therefore, alongside improving military hardware conditions, it is essential to enhance the soft power of China's military combat equipment environment. The atmosphere within the cabin is closely linked to human comfort. Effective environmental design not only offers aesthetic pleasure but also enlarges visual perception, mitigates factors like crew fatigue and fear, enhances operational efficiency, and alleviates psychological stress associated with combat fears. In shaping the interior environment of the cabin, elements such as spatial design, functionality, color, materials, and lighting constitute the material basis for creating an environmental ambiance and play a key role in its expressiveness. They directly affect the crew's psychological and emotional states, and even their physiological responses (Wei et al., 2020). A comfortable environment encompasses not just a functional physical space but also constructs an emotional space. Thus, in environmental design, addressing crew comfort needs through appropriate functional zoning, a reasonable color scheme, and the selection of materials and lighting conducive to comfort can make the space seem more expansive and layered, reducing the sense of claustrophobia in confined areas. Proper environmental design also enhances the experiential aspect of human activities within the cabin. Since the fulfillment of crew needs is a continually evolving process from basic to advanced, from material to spiritual, this manifests in the expansion from functional and comfort requirements of the cabin to experiential, virtual, and ultimately, the experiential expansion of its spiritual content. Consequently, catering to the emotional experiences of the crew is an inevitable development in the research of comfort design in command cabin environments. Based on this, the first research objective of this study is to investigate the relationship between crew members and the spatial environment of the command cabin, to analyze the factors within the command cabin environment that impact the psychology and behavior of the crew, and to construct a comprehensive design framework that fosters an increase in cabin environmental comfort, operational efficiency, and the harmonious coexistence of the human-machine environment. The second research objective is to deduce, from the aforementioned research framework, design principles for the command cabin that enhance its functionality and diversity, thereby improving the operational efficiency and work performance of military command cabin personnel. This translation is crafted to meet the rigorous standards of academic discourse and journal paper requirements.

Theoretical Foundations and Related Research

Concepts of Visual Perception Theory

The process of vision is described as "the complex processing of information generated when the visual organs receive light, exciting the sensory cells, and this information is then processed by the visual nervous system to produce vision"(Cornsweet, 2012). Studies indicate that people rely on their eyes to receive 87% of external information. The size, distance, shape, color, and lighting of objects are conveyed to the brain through vision, transforming "what is seen" into biological signals that form "what is felt"-related perceptual experiences. "Perception" refers to the psychological activities of joy, happiness, sadness, and melancholy produced when humans receive, store, and process information. Visual perception is a form of visual thinking that extracts relevant information from the scenes our brain sees for analysis. The characteristics of visual perception include light and dark adaptation, photopic and scotopic vision, color vision, spatial sensitivity, motion sensitivity, visual illusions, form perception, field of view, eye movement, visual afterimages, and flicker fusion, among others(Bruce et al., 2003). Some of these visual characteristics are key determinants in the spatial environment of command cabins. In the design of command cabin environments, these characteristics are often subconsciously underutilized by designers.

Basic Features of Visual Perception

Wholeness

In the characteristic of wholeness, visual elements are not the most fundamental basis of vision but rather the entire structure. When people are in a space, they rely more on visual activities and organization, based on experiential perception, forming a complete space. This experience is characterized by completeness, where the whole precedes and determines the parts, but cannot be subjectively analyzed down to the individual. In the application of Gestalt psychology, the Gestalt is often equated with an "organized whole." In the process of perceiving things as a whole, the complexity of the figure also causes different cognitive responses. Simple figures may produce a sense of monotony; complex figures, starting from the whole, stimulate cognitive interest and engage the observer’s interest. Observers experience pleasure in observation through the process of "visual tension, visual reorganization, and restoration of visual balance," enhancing experiential emotions.

Figure-Ground Relationship

A figure does not exist independently; it is recognized in contrast with the background. The figure-ground relationship primarily concerns the interrelation between the figure and its background. In a given space, when selecting a perceptual object, people emphasize smaller, denser, and more clearly contoured objects as the visual center, the figure, while the larger, boundary-reaching objects become the background. Therefore, the relationship between figure and ground can be interchangeable. From a visual perception standpoint, when the visual proportion of the figure-ground is significantly different, people can easily discern the relationship; otherwise, it may create difficulty in distinguishing figure from ground, leading to visual challenges.

Organizational Principles

The organizational forms of vision include the characteristics of gestalt, similarity, proximity, and closure. The principle of gestalt is based on people simplifying and holistically processing the images seen through visual perception, resulting in an understanding and cognition of a

most simplified form. The principle of similarity categorizes visual elements into simple similarity, gradient similarity, and disorderly similarity, where similar elements are perceived as a whole in the cognitive process. The principle of proximity: when visual elements are placed in a holistic area, proximity is divided into hierarchical proximity and directional proximity, perceived as a whole when multiple systems are close to each other. The principle of closure: when there is a slight change in the boundary contour, the observer automatically regularizes the secondary contour to simplify the figure for easier cognition(Hörhan & Eidenberger, 2021).

Formation of the Command Cabin Environment

The command cabin is a mobile command chamber for commanders, serving as a movable site for communication, command, and emergency operations in modern warfare. Its primary function is to conduct multi-domain command, integrate multi-domain operational plans in terms of time, space, and objectives, and synchronize multi-domain operations, fulfilling the commander's intent. Inside the cabin, a closed working environment is formed, and depending on different cabin configuration standards, the personnel and facilities vary. The main functional facilities include command and control equipment, emergency equipment, firearm equipment, and other auxiliary facilities (Sun, 2015).

In the command cabin environment, the activities of the crew directly influence the design of the cabin space. Specific equipment is used in different environments, and the equipment used by the crew during work should be more convenient. These environments and facilities, combined with the crew, constitute the command cabin environment, while the formation of the cabin space is subject to various constraints. In external environments, when the command cabin is affected by special conditions like naval, aerial, explosive, extreme climate influences, the cabin environment features high pressure, humidity, vibration, etc. In the internal environment, the cabin includes lighting, color, noise, air quality environments, etc. These factors directly impact the comfort and efficiency of the crew. Therefore, in designing the cabin environment, it is necessary to consider the internal and external environmental factors, define the constraints, and then proceed with the design.

Command Cabin Environment Design and Its Visual Relationship with Crew

The Visual Psychological Relationship Between the Command Cabin Environment and the Crew

The Relationship Between Cabin Color Environment and Crew's Psychological Perception

Color perception involves studying human psychological activities through colors, initiating from vision to perception, emotion, and thought, thereby generating delicate cognitive associations(Sheng et al., 2020). Color possesses a communication ability that is swifter than language. It plays a critical role as an information-transmitting medium, wielding immense emotional influence over humans. As the "primary visual" element for humans, its symbolic significance and emotional impact surpass those of shape and material (Smithson, 2019). he effects of color are direct and spontaneous, with color psychology and physiology accompanying each other, alternating to fulfill a sense of comfort. Crew members, spending extended periods in the cabin work environment, inevitably require a cabin color environment that satisfies emotional needs and mitigates negative emotions and psychological stress resulting from prolonged work. The psychological perceptions of color in the command cabin environment are illustrated in Table 1. The color environment perceived

by cabin crew mainly includes aspects of warmth, coolness, stability, harmony, functionality, etc.

Table 1
Psychological feeling of color

Warm/Cool	Color	Visual Characteristics	Psychological Perception of Vision
Warm	Yellow	Strong attention, high brightness	Warm, confident, healthy, happy, cozy
	Red	Eye-catching, highly stimulating	Stimulating, impulsive, active, enthusiastic, lively
	Orange	Strong attention, high brightness	Light-hearted, passionate, fashionable, graceful, gentle
Cool	Blue	Lower attention	Cold, light, distant, romantic, fresh
	Green	Low stimulation	Healthy, tranquil, energetic, comfortable, smooth
Neutral	Black	Strong attention, lowest brightness	Mysterious, powerful, extreme, awe, profound
	White	Strong attention, highest brightness	Pure, dignified, fair, positive, elegant
	Grey	No stimulation	Confused, stubborn, resolute, persistent, simple

The Relationship Between Cabin Lighting Environment and Crew's Psychological Perception

Light, in the form of electromagnetic radiation, varies in wavelength and evokes different visual responses in the human eye (Yang & Jeon, 2020).The lighting environment is composed of light, media, and space, where the media are divided into solid and virtual types, manifesting in the phenomena of reflection and refraction of light traversing through space. For crew members working meticulously in the command cabin, the lighting environment significantly impacts their psychology(Wang et al., 2021). When designing the lighting environment, it is essential to consider the difference in perception caused by light color, as poor lighting design can lead to eye dryness, soreness, headaches, nausea, fatigue, and other psychological and physiological sensations. Good lighting enhances the crew's recognition ability, reduces visual fatigue, and improves work efficiency. Factors such as illumination, uniformity of illumination, color temperature range, and glare control are critical in affecting the visual functions of the crew (Zhang, 2019).

The cabin lighting environment utilizes artificial illumination, blending both general and localized lighting forms. This type of lighting can adapt to the variability of multiple environments, autonomy in lighting distribution, and precision in illumination. Given the complex nature of the cabin environment, artificial lighting is also complex. When crew members are working, in addition to the display screens, areas like the workspace, interior walls, ceiling, other crew members, and other furnishings all fall within their field of vision. These levels of illumination and methods of lighting all impact the crew's visual function. Excessive uneven illumination can stimulate physical and mental responses, causing discomfort, whereas appropriate brightness variations can create a harmonious atmosphere

inside the cabin. The recommended brightness levels relative to the command cabin environment are illustrated in Table 2.

Table 2
The recommended brightness levels relative to the command cabin environment

Comparison	**Environmental Classification**		
	A	B	C
Work Area vs. Adjacent Dark Environment	3:1	3:1	5:1
Between work area and adjacent bright environment	1:3	1:3	1:5
Between work area and distant dark area	10:1	20:1	②
Between work area and distant bright area	1:10	1:20	②

Notes: ① A: Reflective light within the entire workspace can be controlled, providing optimal visual conditions. B: Reflective light in the direct workspace can be controlled, but limited control is possible for more distant environments. C: Reflective light in this area cannot be fully controlled, and it is difficult to change environmental conditions. ② The brightness ratio cannot actually be changed.

The Relationship Between Cabin Spatial Layout and Crew's Psychological Perception

In the mid-20th century, Hall proposed that "people's emotions are closely related to interpersonal distance" (Jansson, A., 2013). The layout within the cabin environment directly affects the crew's psychological state inside the cabin. Different distances create different psychological effects, and exceeding standard distances can lead to psychological discomfort, stress, and ultimately reduce work efficiency (Mastrigt et al., 2017). Spatial distance is categorized into perceptual distance, social distance, internal distance, and external distance. Each type of distance correlates with a different psychological impact. For example, a too-close distance among crew members can lead to psychological crowding and cause moodiness. When crew members feel a lack of personal space or hierarchical space due to rank differences or inappropriate positioning, it leads to increased psychological stress (Wu et al., 2017).

Dissatisfaction among crew members primarily arises from irrational unit layouts and varying spatial positions within the space. When unit distances are too close, they exceed the psychological safety distance of the crew. Due to the cabin's unique environment-cramped and enclosed with weak natural lighting, challenging oxygen supply, insufficient activity space, and frequent involvement in combat missions-movement or crowding among crew members can generate negative emotions. Prolonged time in different spatial positions also leads to discomfort, as different locations are closely linked to privacy. Improper use can result in a loss of personal territory privacy for the crew. Therefore, the personal space of unit layouts and appropriate positioning within the cabin environment is crucial.

Research on the Design Principles of Command Cabin Environment Under Visual Perception

Theory Analysis of Visual Characteristics in Command Cabin Environment

The Relationship of Whole and Part in the Command Cabin Environment

From a visual theory perspective, perceptual elements are not the most fundamental component of vision; instead, the focus is on the holistic structure, where elements represent points, lines, and planes that constitute the cabin space environment, and the whole represents the entire cabin space environment. When crew members observe the entirety of the command cabin environment, they rely more on the organization of visual elements to perceive the overall space, which is not merely a sum of its elements but a novel whole composed of distinct formal elements. The cabin space environment exists as a Gestalt, characterized by completeness, where form refers to the organization and structure in experience. Different Gestalts have varying organizational and structural forms. For instance, the relationships between the cabin's ceiling and lighting equipment, side boundaries and control equipment, bottom boundaries with seats and auxiliary equipment, and the entire cabin environment with its elements are all relationships of whole and part. If the command cabin environment is to exhibit a pleasing richness of the whole, it must be represented by the diversity of internal parts, organizational structure, and the independent characteristics of the cabin environment.

Figure-Ground Relationship in Command Cabin Environment

The figure-ground relationship is both a relation of emphasis and background and a co-constituent of the whole. They complement each other and cannot exist independently. In the cabin environment, the figure-ground relationships of the floor, ceiling, and side boundaries constitute the artistic effect of the rich spatial environment. In the installation of flooring, the floor itself has a figure-ground relationship with various structures, materials, and colors. If emphasizing the furnishings in the command cabin space, furnishings as the "figure" on the floor background can use monochrome, low-reflective and refractive materials to highlight the furnishings. Also, the floor's directional and typographic signs can form a figure-ground relationship with itself, adding to the spatial layering. As for the floor itself, it belongs to the "figure" of the space environment and can be functionally divided to strengthen the command cabin's function. The figure-ground relationship of the side boundaries includes walls, storage cabinets, signage, display control screens, doors, windows, and special fixtures. In the entire cabin environment, windows and doors form the "figure," with the wall as the background, playing a decorative role. Equipment storage cabinets, display control screens, and other special fixtures as the "figure" make the wall a background, enhancing the space environment's thematic atmosphere. The visual focus of the crew is mainly on the side boundaries. Therefore, relative to the background of the command cabin space, the ceiling as the "figure" needs to be expressed in a simple and elegant form. Due to the low height of the entire cabin, color becomes the "figure," and effective color changes contrast with the background, expanding the sense of space. On one hand, it highlights its existence, and on the other hand, it aids in the psychological health of the crew.

Organizational Principles in Command Cabin Environment

The entire cabin is organized through elements such as "form" and "figure" present in the cabin environment, perceived by the crew's vision through internal functions and external structural forms. Hence, the "figure" in the cabin is expressed in one or several organizational ways. When designers redesign, they organize individual or multiple elements according to

visual principles to express the spatial environment's sense of order. Only orderly designs create more visual tension, making the entire cabin environment more easily received, felt, recognized, and accepted.

Analysis of Crew Member Needs in the Command Cabin

Crew members in the cramped command cabin space under special environmental backgrounds experience oppression, personal space invasion, leading to psychological states of tension, fatigue, fear, and other negative emotions. Command cabin environment design should be redesigned from a psychological perspective, considering the main visual tendencies involved in the environment, such as lighting, color, furnishings, layout, material, and auxiliary tendencies like noise, air quality, to mitigate adverse effects on the crew. In command work, adverse reactions also occur, such as headaches, irritability, tinnitus, and motion sickness in special environments like high altitudes and snow-capped mountains. These symptoms are caused by nervous tension, so command cabin environment design should consider alleviating crew tension.

Analysis of Command Cabin Environment Design Model Under Visual Perception Theory

Research Methods and Design Analysis

The research methods for command cabin environment under visual perception theory include survey research, interviews, observations, cognitive psychology theory, and design feedback evaluation. By using observation methods to examine the current state of the cabin environment and summarizing findings, identifying crew feedback based on survey and interview methods, fulfilling basic crew needs for the cabin environment in line with cognitive psychology theory, and finally, improving design schemes through design feedback methods. The specific research method process is illustrated in Figure 1.

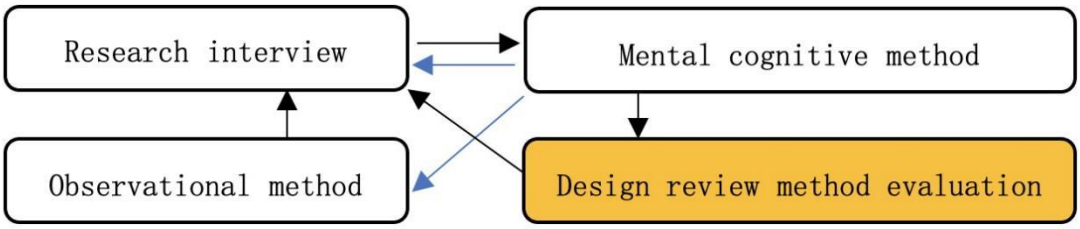

Figure 1：Research method flow chart

Based on the aforementioned methods, the specific research content for the design subject is derived. Guided by theories of visual perception, human-machine engineering, kansei engineering, and Gestalt principles, the study analyzes the main factors affecting the crew's visual psychology and physiological characteristics within the cabin environment, including functionality, color, layout, and lighting. The analysis also considers auxiliary factors such as air quality, noise, pollution, and temperature. The primary goal of the design is to create a comfortable, efficient, experiential, and safe cabin environment, forming a design solution suitable for specific cabin settings.

Research Framework Diagram

The design of the command cabin environment under visual perception theory should be based on the analysis of the cabin's visual characteristics to develop the environmental design. The research involves analysis methods for command cabin design, survey analysis,

design analysis, and the design subject, all directed towards the cabin environment design. This is combined with specific command cabin environmental considerations to develop the design, and the research framework is as shown in Figure 2.

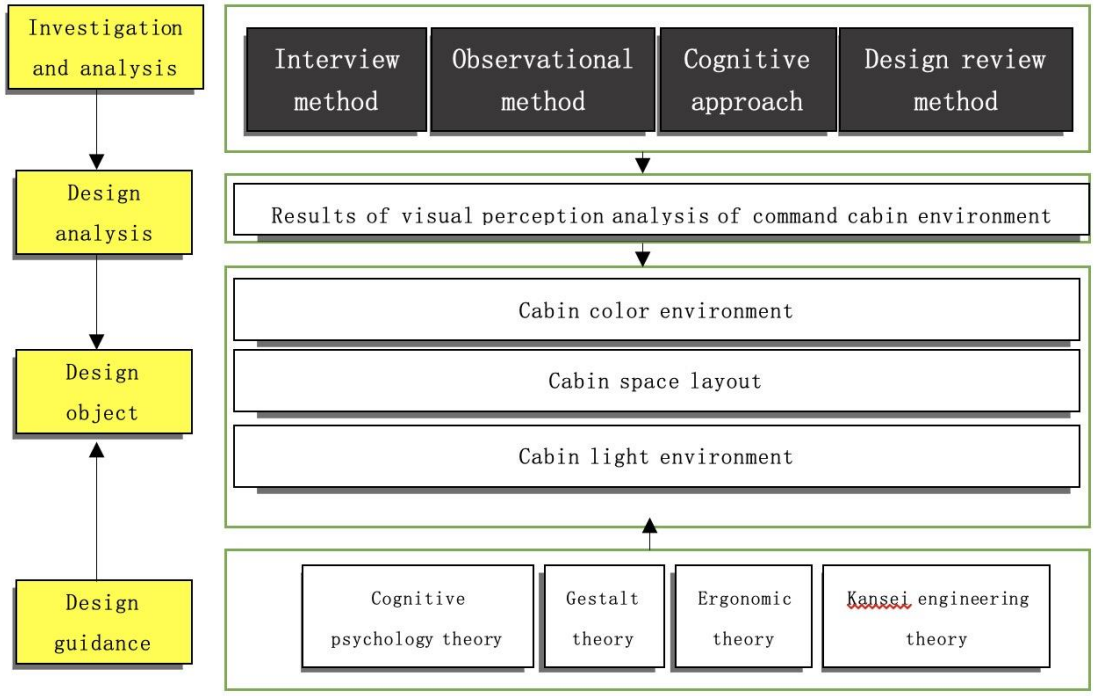

Figure 2： research framework

Analysis of Principles for Command Cabin Environment Efficiency Design Based on Visual Perception Theory

Wholeness Design Principle

This paper applies research methods of visual perception theory to command cabin environment design, summarizing principles based on visual perception theory derived from the aforementioned research methods. According to the visual psychological needs of the command cabin crew, corresponding design strategies for cabin environment design are proposed. Specific design principles are as follows

Safety Efficiency: Cabins are classified as general or high-risk, with command cabins belonging to the high-risk category. Visually, the cabin's equipment and facilities are complex, with many sources of danger, and under special environmental conditions, it is highly susceptible to fires, explosions, and other safety incidents. Therefore, ensuring safety is the primary issue in the overall design of the cabin, with the design addressing unsafe factors as much as possible, fully considering potential safety hazards in the crew's daily work, while also providing auxiliary safety features to enhance the crew's sense of security and confidence.

Environmental Attraction Efficiency: Applying principles of wholeness, organization, and homogeneity from visual perception to the environment design allows the cabin environment to foster positive psychological emotions among the crew, stimulating work interest and improving efficiency. Therefore, the command cabin should offer environmental factors conducive to the crew’s work, reducing atmospheres of tension, fear, and loneliness, and creating an environment that encourages the crew to love their work and life.

Comfort Design Principle

Lighting and Noise Controllability Efficiency: Lighting intensity varies according to the command cabin environment. Too bright or too dim lighting can affect the crew's visual psychology, leading to discomfort and inefficiency. Hence, in arranging light sources, indirect and semi-indirect lighting methods are favored, using a combination of auxiliary fixed light sources and continuously adjustable light sources, providing supplemental lighting in too dark areas and adjusting overly bright sources to avoid glare. Noise is a significant source of environmental perception, and excessive noise can induce anxiety and restlessness in the crew.

Noise originates from two aspects: one from the command cabin being in a special environment with many uncontrollable external factors, and the other from internal control equipment, air conditioning systems, doors, and windows facilities. Therefore, in controlling noise, materials that absorb or insulate sound should be selected, or small, integrated facility equipment designed, to minimize noise and alleviate the crew's negative emotions, serving a comfortable function.

Color Coordination Efficiency: Color gives the entire command cabin its personality and characteristics. The effects of color are direct and spontaneous, with color psychology and physiology accompanying each other, alternating to produce effects. Inappropriate color combinations can depress, emotionalize, and create visual discomfort in the crew, potentially directly or indirectly affecting judgment and operation. Thus, the crew working long hours in the command cabin must create a color environment that satisfies emotional needs, reducing negative emotions and psychological stress from prolonged work.

Experiential Design Principle

Operability Efficiency: Many facilities in the current command cabin are visually complex, with the facility "figures" being large and difficult to operate, poor in experience, and low in psychological reception by the crew, unfavorable for operations, ultimately leading to inefficiency. Therefore, in the study of facility forms in organizational principles, crew subjective factors should be incorporated, designing "figures" that are portable, simple, and easy to operate, which can increase the crew's experiential feeling and enhance the aesthetic quality of the cabin environment.

Multifunctionality Efficiency: The design of a cramped space environment in the command cabin means that the crew consciously arranges and sets up the cabin space to meet work needs, forming a multifunctional space and increasing the crew's experiential feeling within the cabin space. The multifunctional design method in the cabin environment reflects the diversity of lighting to show the multifunctionality of space, movable facility systems to show the multifunctionality of space, similar color tones to reflect multifunctionality, and auxiliary partitions to demonstrate multifunctionality, making one cabin space have multiple functions, without wasting space and meeting the crew’s work needs, enhancing the experience.

Efficiency Design Principles

Modularity: Integration of certain elements of facilities and environment within the cabin to form a new system. In the design of the command cabin environment, the use of modularity clarifies the logical organization of cabin space, breaking the confines of the original space, and achieving maximal space utilization. This gives a visually and sensationally expansive feeling; moreover, modularity also imparts a sense of novelty to the cabin and enhances the crew’s work efficiency.

Multifaceted Composite Layout Efficiency: The command cabin can employ diversified and composite functional layouts, enabling functional spaces to be independent, interpenetrating, and interconnected. The functionalities of the command cabin environment intersect and partially overlap, serving as command and control workspaces, negotiation and meeting spaces, informal communication spaces, and even as rest areas for the crew. There are no clear boundaries between various functionalities; the overall function is shared, thus making the use of each function highly efficient.

Conclusion

In this study, we are dedicated to exploring the application of visual perception theory in the design principles of vehicle-mounted command cabin environments. In addressing research objective one, our study employed a comprehensive methodological strategy, including survey research, interviews, observation methods, cognitive psychology theory analysis, and design feedback assessment. We conducted an in-depth analysis of the key factors influencing command cabin environment design, such as functionality, color selection, layout optimization, and lighting design, as well as considering auxiliary environmental factors like air quality, noise pollution, and temperature control. This approach aimed to construct an integrated design framework that promotes comfort, operational efficiency, and harmonious human-environment interaction within the cabin space.

In addressing research objective two, our study not only underscored the applicative value of visual perception theory in the design of vehicle-mounted command cabin environments but also proposed a set of design principles based on this theory. Principles such as safety efficiency, environmental attraction efficiency, lighting and noise controllability, color coordination, operability, and multifunctionality were formulated. These principles take into account the crew's visual psychological, physiological needs, and emotional responses, with the objective of enhancing the functionality and diversity of the command cabin; thus, improving the operational efficiency and work performance of military command cabin crew members.

The outcomes of this research not only effectively achieved the set research objectives, enhancing operational efficiency and crew work performance, but also provided theoretical and practical guidance for future cabin design. By addressing gaps in current research, this study offers valuable insights for subsequent military equipment design research, having a lasting impact on enhancing military combat efficiency.

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