An Interactive Character-Encoding Brain–Computer Paradigm Based on Dichoptic Visual Illusion and Dynamic Graphic Construction

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Abstract

In the classic science-fiction film The Fifth Element (1997), an impressive visual-symbolic cognitive-loading device appears: through a high-density, structured, and dynamically reorganized stream of visual symbols, the protagonist accomplishes the cognitive reconstruction of an unfamiliar knowledge system within an extremely short time. This fictional scenario points to a profound question in cognitive engineering: can symbols be written directly into the brain, bypassing the conventional “view-then-memorize” pathway, through the active reshaping of visual structure?

Conventional steady-state visual evoked potential (SSVEP)-based brain–computer interaction paradigms rely on fixed-frequency screen flicker and take passive visual recognition as their core logic, suffering from inherent limitations such as shallow cognitive processing, weak information retention, and a single encoding dimension. Inspired by the cognitive-loading scenario in The Fifth Element, this study proposes a novel interactive character-encoding framework based on dichoptic differential visual-channel isolation and the active construction of dynamic graphics. Drawing on the neuroplasticity principle of visual aftereffects—the classical phenomenon in which the visual cortex remains active after the removal of visual stimulation—the proposed paradigm requires participants to actively synthesize target letter configurations by manually rotating, arranging, and assembling standardized block units. Its core neural logic lies in upgrading conventional single-dimensional frequency recognition into multidimensional spatial-topological encoding through a closed-loop interaction of "manual operation–visual fusion–cognitive verification," and in exploiting the brain's endogenous delayed-afterimage mechanism to transform character information from external physical stimulation into reproducible hallucinatory imprints within the brain, thereby achieving deep internalization of symbolic cognition.

This paper fully discloses the physical-layer isolation architecture, cognitive-layer construction logic, and hallucination-consolidation mechanism of the paradigm, and explicitly points out that the framework still faces open engineering challenges in areas such as visual tolerance, signal decoupling, and individual threshold calibration. The paradigm is intended to provide a disruptive theoretical foundation and an iterable basic-research framework for a new generation of cognitive-implantation brain–computer interaction.

Keywords: brain–computer interface; steady-state visual evoked potential; visual hallucination; dichoptic vision; dynamic graphic encoding; cognitive construction; symbol internalization; visual aftereffect

Contents

1 Introduction

Current mainstream visual brain–computer interaction technologies are represented by the steady-state visual evoked potential (SSVEP) and the P300 visual speller. Their common features are: the system predetermines the stimulation paradigm, the screen outputs standardized flicker frequencies, participants passively fixate and recognize, and the device directly reads steady-state EEG signals. After nearly three decades of development, SSVEP-based BCI has become an important branch of brain–computer interface research with the highest information transfer rate and the shortest training time; nevertheless, the inherent limitations of its underlying cognitive architecture are becoming increasingly prominent. Such paradigms suffer from three fundamental defects:

First, symbolic cognition is passively received. Users need not participate in structural construction; the brain merely performs shallow visual-feature extraction, resulting in weak memory retention and poor transferability. Information stops at instantaneous recognition and can hardly be converted into long-term cognitive resources.

Second, the single-screen global synchronized stimulation mode makes both eyes receive identical information, so the visual dimension is singular. It is impossible to construct a multilevel, composable high-dimensional symbolic encoding space, which severely limits the ceiling of information throughput.

Third, the stimulation form is fixed and interactivity is weak. Training is mechanically repetitive and cannot form endogenous, autonomous neural encoding paradigms; users always remain in the position of stimulated objects rather than subjects of cognitive construction.

In the classic science-fiction work The Fifth Element (1997, directed by Luc Besson), a high-speed, immersive visual-symbolic cognitive-loading device appears. Through an encyclopedic-style visual interface, the protagonist Leeloo accomplishes a structured cognition of the human knowledge system within a short period. The core cognitive-engineering logic of this device lies in the fact that symbols should not be given directly, but should be co-generated by visual dynamic structure, perceptual fusion, and active verification. This is not simple information viewing, but a reshaping of cognitive logic through visual structure.

Based on this science-fiction setting, the present paper performs an academic abstraction and engineering implementation: it strips away the fictional narrative and retains the core cognitive mechanism, constructing a dichoptic-isolated dynamic-graphic visual-hallucination encoding paradigm. Thoroughly distinct from the conventional SSVEP system, this paradigm is presented in an open, reproducible, and iterable manner, providing the academic community with a novel brain–computer interaction framework for sustained research.

2 Fundamental Limitations of the Conventional SSVEP Paradigm

The core logic of conventional SSVEP can be summarized as “frequency-to-symbol mapping”: each letter or command on the screen is bound to a dedicated flicker frequency; when participants fixate on a target, a steady-state visual evoked potential is generated, and the algorithm identifies the user’s intended gaze by discriminating the frequency peak.

The structural defects of this paradigm are extremely prominent:

Zero cognitive participation. Users need not think about structure, adjust form, or perform any kind of verification; pure passive viewing completes the recognition process. Cognitive processing depth remains at the primary visual cortex, with no constructive learning at all.

No symbol generativity. Letters are ready-made forms preset by the system; the brain cannot establish the hierarchical cognitive pathway of “unit composition → symbol generation.” Users recognize only shapes, not structural logic.

Single visual dimension. Both eyes receive homogeneous input from the same screen; the visual system processes only two-dimensional planar frequency information, without the higher-order hallucinatory space brought by dichoptic differentiated fusion. The information-encoding dimension is naturally limited.

Shallow memory. Only transient visual recognition traces are formed, without delayed afterimages or endogenous hallucinatory memory. Once screen stimulation ceases, symbol information fades rapidly, lacking the physiological basis for long-term cognitive consolidation.

Extremely poor scalability. Usable frequency resources are naturally limited within a finite frequency band; once the number of symbols increases, frequency crosstalk, harmonic confusion, and signal-to-noise collapse inevitably arise, placing a physical upper bound on system scalability.

In short, conventional SSVEP is a “recognition paradigm” rather than a “cognitive-construction paradigm.” It optimizes the machine’s classification accuracy for EEG signals, not the depth of the brain’s internalization of symbols.

2.1 The Mechanism of Positively Harnessing Visual Aftereffects

"Tetris Syndrome" (Tetris Effect) is a classical perceptual-aftereffect phenomenon experienced by players after prolonged Tetris play: even after stopping the game and closing their eyes, they still perceive blocks continuously falling, rotating, and assembling as visual hallucinations. Stickgold et al. (2000), in a study published in Science, first systematically reported this phenomenon: participants who had just learned to play Tetris reported intense, stereotyped game imagery before sleep; more surprisingly, three amnesic patients with extensive bilateral medial-temporal-lobe damage, who could not recall having played the game, nevertheless produced similar hypnagogic hallucinations. This finding suggests that such visual imagery may not depend on the contribution of the declarative memory system, but instead originates from independent activity patterns of the visual cortex. Subsequent research further confirmed that during a 90-minute daytime nap, 10% of sleep-onset reports in the experimental group were related to Tetris, versus only 1%–3% in the control group. These hypnagogic hallucinations "reproduced the elements of Tetris precisely, or mixed them with other memory components," and their occurrence is closely related to the high activity of sensory cortices and the default-mode network during sleep onset.

One of the core creative pivots of the proposed paradigm is the reverse engineering of this phenomenon: instead of avoiding this neural aftereffect, we actively domesticate and structurally exploit the hallucinatory mechanism, converting originally disorderly perceptual interference into a controllable cognitive-consolidation tool that serves symbol learning.

The Tetris hallucinations produced by ordinary players are random: blocks fall freely and rotate randomly, carrying no fixed semantics and mapping to no letters or words; they are merely spontaneous neural reverberations produced after the visual cortex is "hijacked" by the game mode. The proposed paradigm achieves the domestication of this mechanism through three modifications:

First, the basic unit form is constrained. Blocks no longer fall randomly but participate in active construction as controllable encoding elements.

Second, target constraints are introduced. Users must actively rotate and arrange blocks and assemble them into specified letter configurations; only after completing cognitive verification does a training round count as passed.

Third, dichoptic independent visual-channel regulation is realized through near-eye display devices. Afterimage hallucinations are no longer chaotic and disordered, but are bound to predefined symbolic encoding rules.

Native Tetris Syndrome is a disorderly hallucinatory interference passively produced by the brain; the proposed paradigm, by contrast, guides users to controllably evoke the same kind of visual aftereffect during the active construction of symbols, using it to consolidate letter-encoding memory and converting an original neural side effect into a vehicle for cognitive implantation.

The underlying reason the paradigm adopts Tetris-like units rather than other unfamiliar geometric shapes is that this neural aftereffect has extensive literature support; the perceptual phenomenon itself is real and reproducible, so there is no need to verify from scratch the feasibility of generating hallucinations, thereby directly lowering the concept-validation threshold of the paradigm prototype. It should be made clear that this paper only reuses the perceptual-aftereffect principle and does not directly transplant the original Tetris game; what is extracted is the neuroplastic aftereffect induced by block-unit rotation and reassembly, from which the entertainment attributes have been stripped and completely transformed into a cognitive-training framework.

3 The Overall Innovative Architecture of the Proposed Paradigm

The overall architecture of the proposed paradigm is divided into three layers: the visual-physical layer, the cognitive-interaction layer, and the hallucinatory-memory consolidation layer. These three layers form a progressive coupling relationship, jointly realizing a full-chain cognitive reshaping from physical stimulus input to internalized memory generation.

3.1 The Visual-Physical Layer: Differential Stimulation and Binocular Rivalry Mechanisms

Relying on the optical-isolation characteristics of near-eye display devices, the paradigm achieves independent image output to the left and right eyes, independent presentation of block units, and independent dynamic temporal control. The two eyes no longer receive a unified screen image, but instead carry different basic graphic units and spatial-layout information respectively.

At the neuroscientific level, the design is based on the classical principle of binocular rivalry. When the two eyes are presented with incompatible images, perception alternates between the two images, a phenomenon known as binocular rivalry. If the two images flicker at different frequencies, the EEG can track, via frequency-tagged SSVEP, how the signals driven by each image compete for perceptual dominance, thereby providing an objective measurement of perceptual-state changes. Jamison et al. (2015) confirmed, through simultaneous EEG–fMRI, that SSVEP can be used to track perceptual alternation during binocular rivalry. Katyal et al. (2016) further found that binocular rivalry depends on a mechanism that actively detects interocular conflict, whose activity level can be measured through the intermodulation frequencies of SSVEP.

The innovation of the proposed paradigm lies in the fact that, rather than passively recording the perceptual alternation of binocular rivalry, it **actively designs** dichoptic differential stimulation to construct a controllable state of binocular conflict. This state breaks the "inertial adaptation" caused by conventional single-screen unified stimulation, forcing the visual system to remain in a highly alert, high-bandwidth processing state during information integration, thereby providing an abundant neural-state substrate for subsequent higher-order symbolic encoding. In recent years, the development of multivariate SSVEP spatial-filtering methods has further made it possible to track perceptual states under "no-report" conditions without self-reporting by participants, providing a technical reference for the automated training assessment of the proposed paradigm.

This design thoroughly breaks through the dimensional limitations of conventional single-screen visual BCIs, creating a novel encoding space of "differential visual input, fused perceptual output," which constitutes the hardware basis for realizing hallucinatory character generation.

3.2 The Cognitive-Interaction Layer: Active Topological Construction Driven by Spatial Working Memory

The paradigm completely abandons the linear "display–recognition" pathway and adopts standardized basic geometric units similar to Tetris blocks as the elementary encoding elements. No letter is directly displayed in its finished form; the system only outputs standard units that can be rotated and translated, and participants must autonomously complete the following sequence of operations:

- rotation-angle adjustment
- positional-layout verification
- structural combination matching
- self-judgment of morphological correctness

Only when users actively adjust to the correct structure and complete the full letter configuration does that training round count as validly passed.

From the perspective of cognitive mechanisms, this process recruits the brain's **spatial working memory** system. Studies have shown that memory-maintenance effects of spatial working memory can be detected in the early visual cortex, and that working-memory-related activity is the dominant signal of prefrontal input to the visual cortex. Spatial working memory and visual-object working memory are processed by separable neural circuits: spatial tasks activate the dorsal-stream network (including the parieto-occipital cortex and the dorsolateral prefrontal cortex), whereas non-spatial tasks activate the ventral-stream network. Visuospatial working memory should be better understood as an operational process that handles sensory information (visual appearance) and spatial location (environmental coordinates) within distributed networks.

When participants actively adjust the spatial orientation of blocks to form a specific letter, the letter is stored not as a planar image but as a set of spatial-topological coordinates—that is, a phase combination of elementary spatial relations such as horizontal, vertical, oblique, and folded segments—encoded into the joint-firing patterns of neurons. This generative-learning effect of "operation-as-encoding" makes the memory strength of symbols far exceed that of previous passive visual recognition.

The core innovation is here: the symbolic outcome is not given directly by the screen but generated by the user's cognitive operations. The conventional paradigm completes recognition with "a single glance," whereas the proposed paradigm holds that "only after operation, construction, verification, and final shaping is cognitive internalization complete."

3.3 The Hallucinatory Memory Consolidation Layer: Endogenous Symbolic Reverberation and Afterimage Encoding

The disruptive breakthrough of the paradigm lies in converting the "visual afterimage" from a cognitive-interference item into an encoding vehicle. After multiple rounds of active-construction training, participants develop stable delayed visual afterimages. In the closed-eye state, floating blocks, reorganized contours, and letter afterimages can spontaneously emerge in the mind—an endogenous visual-hallucinatory memory effect completely absent in conventional SSVEP.

At the neuroelectrophysiological level, the formation of visual afterimages involves dual retinal and cortical mechanisms. The traditional view held that afterimages originate from the bleaching of retinal photochemical pigments or from neural adaptation; however, recent research has found that although afterimage signals are generated in the retina, they can be modulated by cortical processes just like other retinal signals. Cortical dynamical models further indicate that afterimage perception results from the joint action of boundary-segmentation and reset signals—when a reset signal can be grouped by subsequent boundary segmentation, an afterimage with illusory contours is generated. More directly, Kronemer et al. (2024), in a study published in Neuroscience of Consciousness, confirmed that **the vividness of visual imagery is positively correlated with the contrast and sharpness of afterimages**—a finding that provides direct support for the core hypothesis of the proposed paradigm: by enhancing, through active-construction training, the vividness of participants' visual imagery of letter contours, the recognizability and symbolic-carrying capacity of afterimages can be strengthened.

Drawing on the principle of Hebbian plasticity—connections between co-activated neuronal assemblies are strengthened—the originally random visual noise is domesticated into symbol-contour afterimages with specific topological structures. The adult visual cortex retains significant plasticity during perceptual learning, and bidirectional "Hebbian-type" plasticity plays a key role in the modification of visual experience. By causally binding the block-layout logic to specific letter shapes, when the visual cortex reverberates, the excited neuronal assemblies happen to correspond to the contour map of that letter.

As a result, character information no longer depends on external screen refresh but resides, in the form of endogenous neural imprints, in the higher-order integration zones of the primary visual cortex, realizing in the true sense "symbols anchored in visual neural circuits" rather than "transiently stored in the instantaneous visual buffer."

4 Essential Differences Between the Proposed Paradigm and Conventional SSVEP

Table 1 Comparison of essential differences between the proposed paradigm and conventional SSVEP

Dimension	Conventional SSVEP	Proposed paradigm
Cognitive logic	Passive frequency recognition	Active structural construction
Visual dimension	Homogeneous single-dimensional binocular stimulation	Heterogeneous binocular input, differential fusion, multidimensional construction
Memory mechanism	Transient recognition, no residue, no hallucination	Constructive learning, afterimage residue, endogenous hallucination consolidation
Symbol generation	Preset finished characters	Autonomous generation through user-composed units
Neural-plasticity dependence	Low	High (Hebbian plasticity + visual-cortex plasticity)
Scalability space	Limited frequency resources, fixed	Extensible encoding matrix, ample open

ceiling	research space

5 Cognitive Training Effects of the Paradigm

The most prominent characteristics of the proposed paradigm are strong implantability, high engagement, and deep internalization. Theoretically, after short-term training, users are expected to exhibit the following cognitive-representational changes:

- spontaneous emergence of block-structure contours in the closed-eye state
- autonomous mental completion of the spatial configurations of letter combinations
- structured encoded memory of the 26 Latin letters, rather than fragmented visual-shape memory
- the establishment, in the visual cortex, of a novel combinatorial symbol-mapping logic distinct from conventional reading habits

This can be described as a “cognitive-remapping effect”: once users adapt to this construction logic, they develop a mode of symbolic thinking centered on spatial-topological relations, which is distinguishable, at the neural-representation level, from the character-recognition system acquired since childhood. This effect is both the cognitive-training goal of the paradigm and a natural neural marker for subsequent EEG-feature decoding.

6 Public Boundaries and Open Engineering Challenges of the Paradigm

This study discloses only the top-level paradigm architecture, interaction logic, dichoptic visual mechanism, and active-construction training philosophy. To preserve space for technical iteration and research fairness, this paper does not disclose the underlying signal-decoding algorithms, fine-grained temporal-control parameters, hallucination-stability tuning strategies, anti-vertigo solutions, or individual threshold-calibration details.

The paradigm currently faces the following open engineering challenges, which can be tackled continuously by research teams worldwide:

1. optimization of visual-vergence conflict and vertigo tolerance induced by dichoptic stimulation;
2. decoupling of electromyographic and motion noise introduced by dynamic rotation operations from EEG signals;

3. control of endogenous-hallucination stability and suppression of chaotic afterimage residue;
4. optimization of the number of block units, rotation timing, and switching-window parameters;
5. adaptive encoding matching for individualized visual-cortex responses;
6. maintenance of symbol-encoding signal-to-noise ratio and consolidation efficiency under long-term training.

The paradigm is positioned as an open-source innovative framework. Its core ideas are fully disclosed, and all optimization challenges in stability, engineering implementation, and signal analysis are released to the global academic community as open research challenges, encouraging independent reproduction and differentiated iteration.

7 Discussion

This study is the first to perform an engineering abstraction and implementation of a sci-fi-grade cognitive-implantation concept—the fictional setting in The Fifth Element in which knowledge is rapidly cognitively reconstructed through structured visual-symbol streams—thereby stepping out of the nearly three-decade-old fixed research paradigm of conventional SSVEP and upgrading from a “passive-recognition brain–computer interface” to an “active-construction cognitive-implantation brain–computer paradigm.”

Compared with conventional visual BCI technologies, which can only achieve “understanding screen output,” the cognitive goal pursued by the proposed paradigm is that “the brain itself generates symbols, consolidates structures, and forms endogenous hallucinatory memory”—that is, a shift from exogenous stimulus driving to endogenous cognitive construction.

Existing studies on Tetris Syndrome mostly focus on its transient interference with sleep and visual perception as a byproduct of gaming. This study shifts the theoretical perspective and explores methods for structurally guiding this kind of perceptual aftereffect, applying the hallucinatory effects induced by short-term neuroplasticity to symbolic encoding learning. This positive reuse of perceptual side effects constitutes another core innovation distinguishing the proposed paradigm from conventional SSVEP: the conventional paradigm relies on external physical stimulation to forcibly drive neural responses, whereas the proposed paradigm leverages the brain’s own pre-existing perceptual-aftereffect mechanisms, replacing “forced driving” with “following the natural flow,” thereby reducing external stimulation intensity while increasing the depth of cognitive internalization.

Once published, the paradigm can provide a brand-new research track for multiple interdisciplinary fields, including extended-reality brain–computer interfaces, visual cognitive engineering, symbol-learning science, and immersive education. All technical difficulties, engineering optimizations, and signal-algorithm iterations can be continuously improved by subsequent researchers, and the framework maintains full downward compatibility and horizontal extensibility.

8 Conclusion

Based on the conceptual abstraction and engineering deconstruction of a sci-fi cognitive device—the high-speed visual-symbol cognitive-loading scenario in The Fifth Element—and combined with dichoptic visual isolation, dynamic graphic rotation construction, and endogenous visual-hallucinatory memory mechanisms, this paper proposes a novel visual brain–computer encoding paradigm completely distinct from conventional SSVEP.

The core value of the paradigm lies in a threefold upgrade: upgrading passive visual recognition to active cognitive construction, upgrading screen-displayed symbols to in-brain hallucinatory symbols, and upgrading mechanical frequency training to deep cognitive implantation.

The top-level logic of the paradigm is fully disclosed, leaving ample room for engineering iteration, and can provide a new foundational framework for subsequent research on brain–computer interaction, immersive cognitive training, and symbol-internalization learning.

Core positioning of the paradigm: this paper discloses a new-generation visual encoding paradigm abstracted from the cognitive-injection system of The Fifth Element, based on dichoptic visual hallucination and the active construction of dynamic blocks. Distinct from the conventional passive SSVEP system, it possesses the basic attributes of being open, reproducible, and iterable. The core cognitive architecture is originally proposed in this paper, while all engineering-convergence and stability-optimization challenges are left to the global academic community for continued research.

This manuscript presents a theoretical paradigm proposal in cognitive neuroscience rather than an empirical study. The underlying perceptual phenomenon, the Tetris effect, has been repeatedly documented and is replicable. The novelty of this work lies in structuring this visual aftereffect for semantic symbol encoding. Full electrophysiological and behavioral validation requires dedicated research teams, which is beyond the scope of this initial framework. We do not reject SSVEP; the proposed paradigm can work as a complementary or embedded module alongside classic visual evoked potential paradigms. This paper aims to put forward a novel research direction for follow-up independent verification.

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