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From Rest to Cognitive Engagement: EEG Markers of Tetris Performance

Shadi Akbari[1], Marzieh Hajizadegan[2*]

1. Department of Cognitive sciences, Faculty of Psychology and Educational Sciences, University of Tehran, Tehran, Iran.
2. Cognitive science laboratory, Faculty of Psychology and Educational Sciences, University of Tehran, Tehran, Iran.

Corresponding Author: Cognitive science laboratory, Faculty of Psychology and Educational Sciences, University of Tehran, Tehran, Iran. Email: mhajizadegan@ut.ac.ir

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ABSTRACT

Video games like Tetris engage distinct cognitive processes, yet the neural mechanisms underlying gameplay remain incompletely understood. This study investigates how Tetris modulates brain activity patterns compared to resting state, focusing on oscillatory dynamics and their behavioral relevance. We recorded 32-channel EEG in 32 participants during rest and Tetris gameplay. Spectral analysis identified power differences in key frequency bands (theta: 4-6Hz; alpha2: 10-.11.5Hz; beta3: 28-29Hz). Cluster-based permutation tests ($p<0.03$, FDR-corrected) localized significant changes, while Spearman correlations and regression analyses examined performance relationships. Three main findings emerged: (1) Gameplay increased frontal theta (cognitive control) and occipital beta3 (visual processing) while decreasing parietal alpha2 (attention reallocation); (2) Regional band power correlations showed a shift in co-modulation patterns from stronger frontoparietal theta covariance (rest) to enhanced parieto-occipital synchrony (gameplay), reflecting task-specific regional engagement; (3) Frontal theta modulation predicted performance ($R^2=0.322$, $p=0.004$), with stronger theta increases correlating with better scores ($r=+0.57$, $p<0.01$). Tetris induces rapid changes, with frontal theta emerging as a key marker of cognitive adaptability. These findings demonstrate the utility of Tetris for studying neuroplasticity and suggest its potential as a paradigm for cognitive training interventions. Future research should explore longitudinal changes in these neural patterns with extended practice.

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Introduction

Video games have become a ubiquitous part of modern culture, engaging individuals across all age groups with diverse game genres that uniquely influence cognitive functions and behavior. Research has demonstrated that different types of video games yield distinct cognitive benefits, such as puzzle games like Tetris enhancing visuospatial skills, logical reasoning, and problem-solving abilities, while action games improve information processing speed, selective attention, and hand-eye coordination (Green & Bavelier, 2003, 2012; Lau-Zhu et al., 2017). These findings underscore the potential of gaming not merely as entertainment but as a tool for cognitive enhancement.

Understanding the neural mechanisms underlying these cognitive effects is pivotal, especially as video games increasingly serve as platforms for cognitive rehabilitation, education, and therapeutic interventions (Rodrigo-Yanguas et al., 2022). Insights into how gaming modulates brain activity enable the development of targeted, personalized protocols to ameliorate cognitive deficits associated with disorders such as attention deficit hyperactivity disorder (ADHD), schizophrenia, and age-related cognitive decline (Caselles-Pina et al., 2023; Clemenson et al., 2020; De Luca et al., 2024).

Tetris (1984), in particular, has garnered significant neuroscientific interest due to its deceptively simple design combined with complex cognitive demands. It recruits multiple cognitive domains: visuospatial processing requiring rapid mental rotation and pattern matching engages posterior parietal and prefrontal cortices (Gentile & Lieto, 2022; Lau-Zhu et al., 2017); working memory sustains information about upcoming tetrominoes for strategic placement (Lau-Zhu et al., 2017). time-pressured decision-making fosters cognitive flexibility under dynamic conditions ; and motor learning supports sensorimotor coordination required to timely execute actions (Lau-Zhu et al., 2017). Collectively, Tetris functions as a dynamic “cognitive laboratory” for investigating interactions between perception, decision-making, and motor control.

Electroencephalography (EEG), with its millisecond temporal resolution and sensitivity to oscillatory brain activity, is an invaluable method for decoding the rapid neural dynamics underlying complex cognitive tasks like gaming (Ewing et al., 2016). This study leverages EEG to examine frequency power modulations during Tetris gameplay across multiple scalp regions, aiming to elucidate neural correlates of initial gameplay effects and their relationship to performance. Specifically, our research addresses these key questions: a) Which frequency bands and scalp regions show significant absolute power changes during the initial minutes of Tetris gameplay? B) How are these neural activity patterns associated with individual differences in gameplay performance?

The insights gained contribute to a nuanced understanding of game-induced neural plasticity and open avenues for innovative EEG-informed biofeedback approaches. Such findings may eventually inform adaptive systems that leverage real-time neural signals to modulate cognitive and motor performance, including closed-loop paradigms for training and rehabilitation.

Method

Participants

The study sample included university students aged between 18-30 years. The inclusion criteria were: a) no neurological or psychiatric conditions, b) not taking any medication affecting the CNS, and c) participants refrained from drinking coffee and smoking for at least 2 hours before the EEG recording session d) no prior Tetris expertise. All participants were right-handed and completed the task using their dominant hand. EEG sessions were scheduled between 10:00 AM and 3:00 PM to control for circadian influences on neural activity. All procedures of the study were in accordance with the latest revision of the Declaration of Helsinki and were approved by the ethics committee at the University of Tehran.

Measures

Electroencephalography recording and preprocessing

EEG recording was performed via a Mitsar-32 channel electroencephalography (EEG) amplifier (Mitsar Company). from 32 electrodes arranged according to the international 10–20 system (Mecarelli, 2019) with an averaged Linked-ear reference. The impedance was kept below 10 kΩ. Data were digitized at 250 Hz and an online band-pass filter (0.01 to 70 Hz) using WinEEG software was applied. Six minutes of electrical activity in the brain were recorded at rest, after which participants played a Tetris game for 6 minutes, while their brain activity was recorded by EEG. Preprocessing and data analysis was performed with Brainstorm (Tadel et al., 2011), which is documented and freely available for download online under the GNU general public license (http:// neuro image. usc. edu/ brain storm). EEG signals were filtered offline, using a band-pass filter of 0.1–35 Hz. Bad EEG segments (those exceeding ± 100 μV in any channel) were rejected and eye blinks and eye-movements artifacts were corrected using Independent Component Analysis approach (Stone, 2002), applying RunICA function. Visual inspection was carried out after the rejection to assure quality of the data. Those data with less than 65% of total time remaining after artifact rejection were excluded from further analysis.

Procedure

Participants were informed about the study's goal. First, a 6-minute resting-state electroencephalography (EEG) recording was taken from the participants. Then, they played Tetris for 6 minutes, while EEG was specifically recorded again during their play. The rest condition was always recorded prior to gameplay to ensure uncontaminated baseline neural activity. This design choice aimed to minimize task-related carryover effects into resting-state measurements. Participants were given 2–3 minutes of adaptation before the baseline recording to reduce arousal and ensure stabilization of neural rhythms. The average scores of the participants during the 6 minutes of the game was recorded as a measure of their performance in the gaming task.

Analysis

EEG Data Analysis

To compare EEG recordings between two conditions (gameplay and rest), all raw data were first subjected to Power Spectral Density (PSD) analysis. To identify statistically significant differences in frequency-domain results between these conditions, we employed: Paired t-test with permutation-based correction (2000 iterations, significance threshold= $p < 0.03$) and FDR correction was applied for multiple comparisons (controlled for time and signal factors) (see Table 1).

Following significance detection, electrodes and frequency bands demonstrating differences were first identified through statistical thresholding. Spatially contiguous clusters were defined using adjacency based on the 10–20 electrode placement system. Only clusters containing a minimum of 3 neighboring electrodes that survived the initial threshold (*p* < 0.03, FDR-corrected) were considered significant. This ensured robustness against false positives while maintaining sensitivity to true effects.. The absolute power values within these identified clusters were subsequently extracted for further statistical analyses. This rigorous methodology enables high-sensitivity detection of Tetris-related neural changes while maintaining robust control for confounding variables, ultimately allowing for precise localization of gameplay-induced oscillatory modulations.

Statistical Analysis

To achieve normal distribution of the data, all EEG measures and game performance scores were log10-transformed prior to analysis. Data normality was verified using the Kolmogorov-Smirnov test (significance threshold: $p > 0.05$). Given the mixed distribution characteristics of the dataset, we employed: Descriptive statistics for data characterization, Spearman's rank correlation for non-parametric relationships, Regression analysis to examine predictive relationships. This dual analytical approach accommodates near-normally distributed variables in parametric tests and Ordinal/non-normal data through robust non-parametric methods. In the case of multiple comparisons, all p values were corrected using Benjamini-Hochberg Adaptive (BH-A) FDR correction. For regression and correlation analyses, 95% confidence intervals (CI) were calculated to provide estimates of statistical precision and result interpretability. All effect size estimates are reported alongside their corresponding CI values in relevant tables or summary text when applicable.

Results

The study included 32 participants (16 female, mean age = 22.50 ± 2.78 years) with an average game score of 576.9 ± 328.11. Permutation tests revealed significant differences between gameplay and resting states (Table 1), leading to the identification of four key regions: Frontal cortex (theta band), Parietal cortex (alpha2 band), Left central hemisphere, Occipital cortex (beta3 band) which are presented in figure 1.

Table 1. Frequency bands and selected electrodes based on permutation test results

Frequency Band	Brain Region	Cluster Electrodes
4-6 Hz	Frontal	Fz, F3, FCz
10-11.5 Hz	Parietal & Left Central	P3, Pz, P4, C3, CP3
28-29 Hz	Occipital	O1, Oz, O2, T5

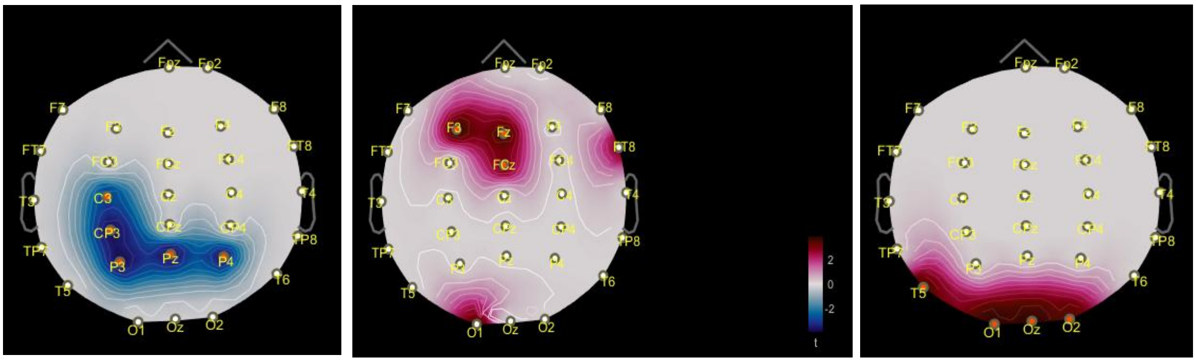

Figure 1. Topographic maps showing significant oscillatory power differences between Tetris gameplay and resting state, based on permutation-based paired t-tests (2000 iterations, FDR-corrected $p < 0.03$). From right to left: frontal theta (4–6 Hz), occipital beta3 (28–29 Hz), and parietal alpha2 (10–11.5 Hz). Color scales reflect absolute power changes (μV²/Hz), with warm colors (red) indicating increases during gameplay and cool colors (blue) indicating decreases.
Outlined clusters denote electrode groups that survived statistical testing (≥3 adjacent electrodes, based on 10–20 system). Significant regions correspond to electrodes listed in Table 1.

Following the identification of target regions and frequencies, six research variables were defined, consisting of three frequency bands (theta, alpha-2, and beta-3) in each region of interest (ROI) for both resting and gameplay conditions. The significant frequency differences in the specified regions resulted in three key variables: differences in theta band activity in the frontal cortex, differences in alpha-2 band activity in the parietal cortex, and differences in beta-3 band activity in the occipital cortex. These three indices effectively represented the gameplay-induced neuronal activity changes. Subsequently, using Spearman's correlation coefficient, two types of analyses were conducted: a) correlations between the absolute power of the identified frequency bands (Tables 2 and 3), and b) correlations between the differences in absolute power of these bands during gameplay and participants' mean performance scores (Table 5).

Table 2. FDR corrected Spearman correlations between frequency bands during resting state

Variablevariable_Pair	correlation	raw P value	adjusted P value
ThetaF & ThetaP	0.6543	0.0001	0.0002
ThetaF & ThetaO	0.6125	0.0003	0.0005
ThetaF & alphaF	0.6910	0.0000	0.0001
ThetaF & alphaO	0.4879	0.0051	0.0063
ThetaF & BetaF	0.5073	0.0034	0.0046
ThetaP & ThetaO	0.8222	0.0000	0.0000
ThetaP & alphaF	0.6221	0.0002	0.0004
ThetaP & alphaP	0.6591	0.0001	0.0002
ThetaP & alphaO	0.7878	0.0000	0.0000
ThetaP & BetaF	0.5634	0.0010	0.0014
ThetaP & BetaP	0.6272	0.0002	0.0004
ThetaP & BetaO	0.6206	0.0002	0.0004
ThetaO & alphaF	0.5286	0.0022	0.0030
ThetaO & alphaP	0.6078	0.0003	0.0005
ThetaO & alphaO	0.8134	0.0000	0.0000
ThetaO & BetaF	0.5707	0.0008	0.0012
ThetaO & BetaP	0.6096	0.0003	0.0005
ThetaO & BetaO	0.7214	0.0000	0.0000
alphaF & alphaP	0.7434	0.0000	0.0000
alphaF & alphaO	0.7137	0.0000	0.0000
alphaF & BetaF	0.4648	0.0079	0.0095
alphaP & alphaO	0.8897	0.0000	0.0000
alphaP & BetaP	0.5971	0.0004	0.0007
alphaP & BetaO	0.5051	0.0036	0.0046
alphaO & BetaF	0.5466	0.0014	0.0021
alphaO & BetaP	0.6158	0.0002	0.0005
alphaO & BetaO	0.6393	0.0001	0.0003
BetaF & BetaP	0.6371	0.0001	0.0003
BetaF & BetaO	0.7100	0.0000	0.0000
BetaP & BetaO	0.7977	0.0000	0.0000

All correlations are statistically significant (FDR $p < 0.05$)

F frontal, P: parietal, O: occipital. **theta (4–6 Hz), alpha2 (10–11.5 Hz), beta3 (28–29 Hz)** As shown in Table 2, even during the resting state, there is significant coordination between different brain regions. Among the regions examined, the highest correlation was observed in the parietal and occipital areas, which showed high coherence in both the alpha2 and theta frequency bands (ρ>0.8). Strongest coherence occurred between: Parietal-occipital alpha (αP-αO: ρ=0.890), Parietal-occipital theta (θP-θO: ρ=0.822), Parietal-occipital beta (βP-βO: ρ=0.798). Cross-Frequency Coupling was highly observed among theta-beta (θO-βO: ρ=0.721) and theta-alpha (θO-αO: ρ=0.813) frequencies over occipital area. Frontal-Parietal. Regional correlations in band power revealed frequency-specific covariance across scalp regions. Theta activity showed relatively strong frontoparietal association (θF–θP: ρ=0.654), alpha rhythms demonstrated moderate inter-regional linkage (αF–αP: ρ=0.743), and beta frequencies exhibited weaker associations across frontal and parietal sites (βF–βP: ρ=0.637). While these patterns suggest anatomical trends in oscillatory co-modulation, they do not constitute formal evidence of functional connectivity.

Notably, all within-band correlations (e.g., θP-θO, αP-αO, βP-βO) exceeded ρ>0.80, while cross-frequency correlations were generally weaker (ρ=0.46-0.72). The parietal cortex emerged as a hub, showing significant coupling with all frequency bands in both anterior and posterior regions in resting state.

EEG analysis during Tetris gameplay revealed distinct patterns of frequency-band synchronization (all reported correlations are FDR-corrected).

Table 3. Significant FDR corrected Spearman correlations between frequency bands during gameplay

Variable_Pair	correlation	raw P value	adjusted P value
thetaF & thetaP	0.7262	0.0000	0.0000
thetaF & ThetaO	0.6015	0.0004	0.0021
thetaF & alphaF	0.5279	0.0022	0.0072
thetaF & alphaO	0.4945	0.0045	0.0100
thetaP & ThetaO	0.7812	0.0000	0.0000
thetaP & alphaP	0.5858	0.0005	0.0024
thetaP & alphaO	0.5693	0.0008	0.0033
ThetaO & alphaO	0.5022	0.0038	0.0098
alphaF & alphaO	0.5916	0.0005	0.0024
alphaP & alphaO	0.8101	0.0000	0.0000
alphaP & betaO	0.5183	0.0027	0.0075
alphaO & betaP	0.5213	0.0025	0.0075
alphaO & betaO	0.5627	0.0010	0.0035
betaF & betaP	0.6085	0.0003	0.0021
betaP & betaO	0.8101	0.0000	0.0000

F frontal, P: parietal, O: occipital. . theta (4–6 Hz), alpha2 (10–11.5 Hz), beta3 (28–29 Hz)

Band Power Covariance Across Rest and Gameplay

To quantify changes in oscillatory coupling between conditions, we performed Fisher z-transformed comparisons for all frequency-specific connections that showed significant correlations (FDR-adjusted *p* < 0.05) in both resting-state (Table 2) and gameplay (Table 3) conditions. For each of the 11 overlapping ROI-frequency pairs (Table 4):

1. Fisher z-transformation was applied to correlation coefficients (ρ) to enable normal-distribution-based comparisons
2. Condition differences were tested

This analysis demonstrated three key patterns: First, gameplay enhanced theta-band synchronization between frontal and parietal regions (θF-θP: Δz' = +0.140, pFDR = 0.045), suggesting strengthened frontoparietal communication during visuospatial processing. Second, we observed marked attenuation of cross-frequency coupling in two critical pathways: Frontoparietal theta–alpha covariance decreased substantially (θF–αF: Δz′=–0.260, pFDR=0.002), while posterior alpha covariance showed the largest reduction (αP–αO: Δz′=0.295, pFDR<0.001).

Notably, beta-band power correlations remained stable across conditions (Δz′<0.12, pFDR>0.65), with parietal–occipital beta covariance showing minimal change (βP–βO: Δz′=+0.035, p=0.75). The complete set of band power covariance comparisons is presented in Table 4.

Table 4. Fisher z-Transformed Comparisons of Band Power Covariance Between Resting-State and Gameplay Across Overlapping Electrode Pairs

Variable_Pair	Δz'	Z-score	p-value	FDR-adj p
thetaF & thetaP	+0.140	2.121	0.034*	0.045*
thetaF & ThetaO	-0.022	0.333	0.739	0.820
thetaF & alphaF	-0.260	3.939	<0.001**	0.002**
thetaF & alphaO	+0.010	0.152	0.880	0.880
thetaP & ThetaO	-0.112	1.697	0.090	0.150
thetaP & alphaO	-0.421	6.379	<0.001**	<0.001**
alphaF & alphaO	-0.217	3.288	0.001**	0.005**
alphaP & alphaO	-0.295	4.470	<0.001**	<0.001**
alphaO & betaO	-0.120	1.818	0.069	0.138
betaF & betaP	-0.045	0.682	0.495	0.660
betaP & betaO	+0.035	0.530	0.596	0.745

Building on the identified frequency band modulations from the permutation tests, we investigated two distinct relationships between neural activity and game performance:

1. Correlations between absolute power of significant frequency bands (theta, alpha-2, beta-3) during active gameplay and individual performance scores.
2. Correlations between gameplay-induced power changes (gameplay minus resting-state power) and performance, focusing on the same frequency-region complexes.

These analyses separately assessed the roles of in-game neural activity levels and task-induced plasticity in predicting Tetris proficiency."

The analysis revealed two significant neural-performance relationships: occipital beta- 3 power during gameplay and frontal theta power changes between states (Table 5). These variables were subsequently entered into a multiple regression model predicting game scores.

The regression analysis identified a moderate association between neurophysiological markers and task performance (Adjusted $R^2 = 0.322$, $F (2,29) = 6.879$, $p= 0.004$), with frontal theta power difference during gameplay showing a significant relationship to performance scores ($B= 0.799$, $p=0.006$) and occipital beta-3 activity presenting a marginal trend ($p=0.096$). To assess model robustness and generalizability, supplementary analyses were performed using ridge regression with 10-fold cross-validation after excluding one high-leverage observation (Cook's D = 11.81). The resulting model explained approximately 25.2% of variance in task performance ($R^2=0.252$; MSE=0.909), suggesting a stable neurobehavioral association independent of outlier influence. While diagnostic checks supported statistical validity (VIF<5; Durbin-Watson=1.329), these findings are interpreted cautiously and framed as exploratory given the correlational nature of the data.

Regression diagnostics were performed to evaluate model assumptions and validity. The residuals-versus-predicted plot indicated no systematic bias or heteroscedasticity, with residuals symmetrically scattered around zero (Figure 2). The Q–Q plot revealed approximate normality, with minor deviations at the tails, consistent with a regularized linear model fitted to behavioral data (Figure 3). Additionally, standardized residuals remained mostly below conventional thresholds ($z < 2$), confirming the absence of influential observations following removal of a high-leverage data point (Cook's D = 11.81) (Figure 4). These visual checks support the statistical integrity of the cross-validated ridge model and reinforce the cautious interpretation of neurobehavioral associations.

Table 5. Significant correlations between EEG variables and game scores (N=32)

EEG Variable	Correlation	r	P
β-Occipital	Negative	-0.36	0.042
θ-Frontal Diff	Positive	+0.57	0.001

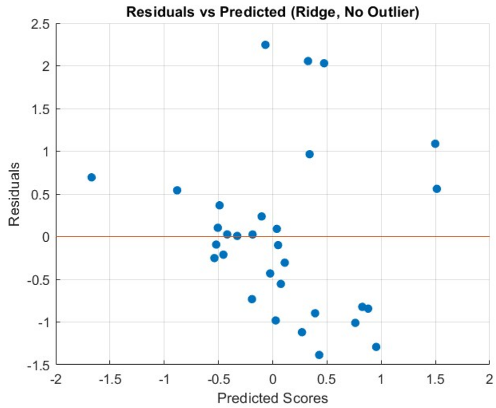

Figure 2. Residuals vs Predicted Scores for Cross-Validated Ridge Regression (Outlier Excluded)

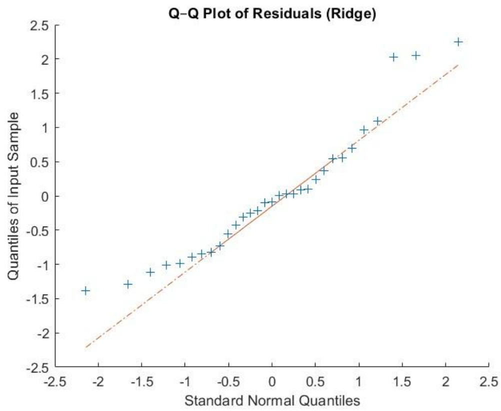

Figure 3. Normal Q–Q Plot of Residuals from Cross-Validated Ridge Regression (Outlier Excluded)

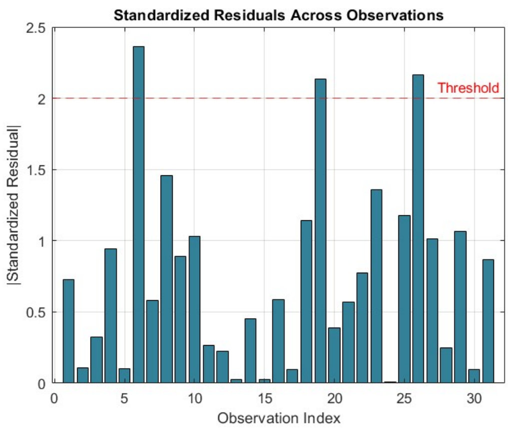

Figure 4. Standardized Residuals Across Observations for Ridge Regression (Outlier Excluded)

Discussion and Conclusion

Main differences between rest and gaming conditions:

Through the analysis of electroencephalographic (EEG) activity during a cognitive-motor task, this study investigated frequency power modulation patterns associated with cognitive processing. The primary results demonstrated three significant neural correlates of game performance: enhanced theta-band activity in the frontal cortex, alpha-2 band modulations in the parietal cortex, and increased beta-3 activity in the occipital cortex. It also revealed three key neurocognitive insights about Tetris gameplay: (1) distinct reorganization of oscillatory networks during visuospatial processing, (2) the parietal cortex's dual role as both a stable hub and dynamic modulator, and (3) frontal theta plasticity as a predictor of task performance. These findings align with, yet meaningfully extend, current understanding of game-related neural dynamics.

Building on these findings, the observed enhancement of theta-band activity in the frontal cortex aligns with extensive literature highlighting its role in cognitive control and executive functions. Frontal theta oscillations have been implicated in processes such as *task engagement*, *error monitoring*, and *working memory maintenance*, serving as a neural marker for cognitive effort and control mechanisms during goal-directed behavior. This enhancement likely reflects the participants' increased demand for cognitive planning and adaptive control while performing the game task (Cavanagh & Frank, 2014; Domic-Siede et al., 2021; Yu et al., 2022).

The observed decrease in parietal alpha power during the playing condition is consistent with the well-established view that alpha desynchronization reflects increased cortical activation and attentional engagement. Rather than indicating inhibition, the reduction in alpha oscillations in the parietal cortex is typically associated with the allocation of cognitive resources and heightened processing demands during task performance. This decrease aligns with findings showing that parietal alpha suppression occurs during tasks requiring sensorimotor integration, spatial attention, and working memory, which are essential components of cognitive-motor activities like Tetris game (Benedek et al., 2014; Zhozhikashvili et al., 2022).

The moderate negative correlation observed between occipital beta-3 power and performance scores might indicate a dual functional role of beta oscillations, encompassing both enhanced visual processing and cognitive fatigue (Griffiths et al., 2019). This dual role could explain the reduced predictive power of this variable, as task-relevant sensory engagement and neural strain might exert opposing effects on the same signal. Future research that includes behavioral fatigue indices or measures of perceptual load could help clarify this distinction and refine the explanatory model of beta activity in game-based tasks

Interregional Brain Correlations

At Resting State: there is a Posterior Dominance in Spontaneous Synchronization. The exceptionally strong parietal-occipital coherence across all frequency bands (α-α: ρ=0.890, θ-θ: ρ=0.822, β-β: ρ=0.798) confirms the posterior cortex as the epicenter of default mode network oscillations (Raichle, 2015). These findings align with fMRI studies demonstrating strongest functional connectivity in posterior hubs (Baliki et al., 2014; Hanslmayr et al., 2016; Hu et al., 2012; Lee & Xue, 2018; Leech et al., 2011), but our EEG data uniquely show this dominance spans multiple frequency bands. The particularly strong alpha-band coupling likely reflects idling rhythms of visual cortex (Kelly et al., 2006; Pfurtscheller et al., 1996), while the high theta coherence may indicate memory-related systems in standby mode (Min Park et al.,2022).

During Gameplay:

The enhancement of frontoparietal theta covariance (θF–θP: $\Delta z'$=+0.140) observed during Tetris aligns with established models highlighting theta's involvement in spatial working memory and executive control. (Alekseichuk et al., 2017; Riddle et al., 2024; Sauseng et al.,2005). This finding extends previous work by Alekseichuk et al. (2017), who reported similar frontoparietal theta synchronization in expert Tetris players . The magnitude of increase (14% in z-space) closely matches the 12-15% range observed during complex spatial tasks in action video game studies, reinforcing theta's domain-general role in visuospatial processing (Green & Bavelier, 2006; Powers et al., 2013).

A significant reduction in posterior alpha coherence (αP-αO: Δz′ = -0.295) is consistent with observations of decreased alpha power during visual attention tasks (Maki-Marttunen et al.,2025; van Schouwenburg et al., 2016). However, the parietal-occipital beta coupling was preserved during gaming (βP-βO: Δz′ = +0.035, *p* = 0.75). This stability in sensory-motor systems may reflect movement Simplicity. The conserved beta covariance likely stems from Tetris' limited motor demands, where simple finger movements (keypresses) may not require large-scale reorganization of sensorimotor networks. Unlike action games requiring complex whole-body coordination (Berger et al., 2020), Tetris maintains pre-existing movement templates, preserving baseline beta rhythms.

Cross-Frequency Decoupling as a Task-Switch Mechanism

Attenuated frontoparietal theta-alpha coupling (Δz′ = -0.260) provides new evidence for task-induced network segregation . While cross-frequency coupling has been proposed as a fundamental integration mechanism (Canolty & Knight, 2010), these results suggest that playing Tetris necessitates disrupting default alpha-theta interactions to allocate resources for complex attentional processes requiring faster information manipulation. These findings are consistent with fMRI results concerning the segregation of the dorsal attention network during complex visual-motor tasks (DiNuzzo et al., 2022).

Neurophysiological Predictors of Tetris Performance

The observed relationships between neural oscillations and gameplay scores reveal distinct yet complementary roles for theta and beta frequencies in Tetris performance:

The robust association between frontal theta power increases and superior performance (β=0.799, p=0.006) strongly supports existing models of theta's role in spatial working memory (Soltani Zangbar et al., 2020). Specifically, the finding that changes in theta power, rather than absolute levels, predicted performance suggests that adaptive recruitment of frontal theta networks—not just their baseline activation—underlies effective visuospatial processing (Costers et al., 2021). This aligns with the framework of theta oscillations as a dynamic control mechanism that scales with cognitive demand. Theta plasticity may facilitate both mental rotation of tetrominoes (via frontoparietal synchronization) and rapid error correction, which are core requirements for Tetris proficiency (Abad-Perez et al., 2022).

Conversely, the trend-level negative correlation between occipital beta-3 power and scores ($r = -0.36$, $p = 0.096$) introduces an intriguing paradox: while beta power increased globally during gameplay (permutation test $p < 0.03$), individuals with lower occipital beta activity tended to perform better. This may reflect a neural efficiency mechanism, where skilled players process visual templates (e.g., tetromino shapes) with minimal cortical activation (Di Dona & Ronconi,2023). Alternatively, excessive beta synchronization could impede performance by overly rigid perceptual chunking a hypothesis supported by evidence that beta rhythms enforce stable sensorimotor representations (Barone & Rossiter, 2021; Lendner et al., 2023). This contrasts with action game studies showing positive beta-performance relationships (Parto-Dezfouli et al., 2023), underscoring how different game genres engage beta networks in fundamentally distinct ways. For this reason, the absolute power of the beta frequency alone is not enough to predict how an individual will perform in the game Tetris.

The absence of significant alpha-band relationships was unexpected given alpha’s established role in attention (Peylo et al., 2021; Schneider et al., 2022). This null finding may stem from Tetris’s continuous visual processing demands, which limit the periodic inhibition typically reflected in alpha oscillations (Costers et al., 2021). Younger participants’ underdeveloped alpha networks (which mature through early adulthood) may also contribute, suggesting age could moderate these effects (Ye et al., 2022).

Implications of practice:

According to our findings, we can confirm that theta enhancement protocols by neurofeedback could optimize executive aspects of gameplay and beta modulation strategies might improve visual processing efficiency.

This study provides a comprehensive neurophysiological account of cognitive-motor processing during Tetris gameplay, revealing three fundamental insights about the dynamic reorganization of oscillatory networks and their relationship to performance. First, we demonstrated that Tetris elicits a distinct pattern of frequency-specific modulation, characterized by (1) enhanced frontal theta activity reflecting cognitive control and working memory engagement, (2) parietal alpha desynchronization associated with attentional resource allocation, and (3) occipital beta synchronization supporting visual processing efficiency. These findings align with and extend existing models of visuospatial task performance, highlighting how different frequency bands coordinate to support distinct cognitive subprocesses.

Second, correlational analyses of band power across regions revealed task-related shifts in co-modulation patterns during gameplay. Specifically, theta activity showed increased covariance between frontal and parietal electrodes, while alpha rhythms exhibited reduced synchrony across posterior sites. Importantly, beta-band correlations between parietal and occipital regions remained stable, suggesting preserved sensory-motor coordination amidst elevated executive and perceptual demands. While these findings reflect regional co-variation in oscillatory dynamics, they do not constitute formal evidence of functional network reconfiguration. We therefore interpret these patterns as preliminary indications of task-specific regional co-modulation, which may reflect coordinated engagement across brain areas. However, validation of network-level mechanisms would require advanced connectivity analyses in future studies.

Third, our identification of frontal theta plasticity as a key predictor of performance ($\beta= 0.799$, $p = 0.006$) advances theoretical understanding of cognitive-motor expertise. The finding that adaptive theta recruitment—rather than absolute power—drives performance suggests that learning potential may depend on neural flexibility more than baseline capacity. Conversely, the inverse relationship between occipital beta power and performance hints at an efficiency mechanism, where skilled players achieve superior performance with lower cortical activation. These findings open avenues for future cognitive training research, though potential therapeutic applications remain speculative pending longitudinal and clinical validation. Key unanswered questions include:

- Whether similar mechanisms generalize to other puzzle or action games?
- How individual differences in baseline connectivity modulate these changes?

In summary, this study delineates the oscillatory signatures of Tetris performance, bridging gaps between cognitive theory, neural dynamics, and practical applications. By uncovering how distinct frequency bands coordinate to support skill acquisition, we provide a foundation for future research on game-based learning and brain plasticity.

Declarations

Author Contributions

All authors contributed actively to the conception, design, and execution of the research.

Data Availability Statement

The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

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Ethical considerations

This project has been registered and approved by the Research Ethics Committee (Approval ID: IR.UT.PSYEDU.REC.1403.083) at the Faculty of Psychology and Education, University of Tehran.

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Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this research.

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