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Research Article

BACKGROUND MUSIC, COGNITIVE TASK DEMANDS, AND PREFRONTAL EEG OSCILLATIONS: A COMPARATIVE ANALYSIS OF TWO PILOT STUDIES USING AN EEG

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Abstract

Background: The cognitive effects of background music are mediated by the interaction between music's structural properties, the cognitive demands of the concurrent task, and the individual's attentional and working memory resources. While behavioural evidence has accumulated extensively, comparatively few studies have simultaneously characterised how music modulates the full landscape of prefrontal EEG oscillations during distinct types of cognitive work. **Objective:** This comparative analysis synthesises data from two within-subjects pilot studies conducted in the same laboratory using the same EEG platform. Study 1 examined the effects of electronic dance music (EDM) on word recall and prefrontal brainwave activity during verbal memorisation (N = 10). Study 2 examined the effects of hip-hop music on prefrontal EEG during Sudoku puzzle-solving (N = 4). Together, the studies offer a unique opportunity to compare how background music of related genres modulates prefrontal oscillatory activity across two fundamentally different cognitive domains. **Key Findings:** A convergent pattern emerged across both studies: gamma band power was directionally lower with music than without (EDM: 7.38% vs. 8.96%; Sudoku: 4.50% vs. 7.26%), suggesting consistent music-associated suppression of higher-order prefrontal perceptual binding. Beta power diverged between studies: lower with music in the EDM study (13.28% vs. 16.01%) but higher with music in the Sudoku study (13.11% vs. 9.55%), pointing to task-type moderation of executive attentional responses to music. Neither study had sufficient statistical power to detect significant effects. Effect sizes were small-to-medium in the EDM study and medium-to-large in the Sudoku study. **Conclusion:** These pilot data reveal that the nature of the cognitive task verbal memorisation versus spatial reasoning is a critical moderator of how background music shapes prefrontal oscillatory dynamics, particularly for beta-mediated executive attention. The convergent gamma suppression across both studies warrants specific attention in future adequately powered research.

Keywords: EEG, Gamma oscillations, Beta oscillations, Prefrontal cortex, Background music, EDM, Hip-hop; working memory, Executive function, Word recall, Sudoku, Cognitive load, Consumer EEG.

INTRODUCTION

Whether background music helps or hinders cognitive performance is a question with significant practical implications for educational and occupational settings, where music-accompanied work is increasingly common. The accumulated literature on music and cognition presents a nuanced picture: music can enhance performance on some tasks under some conditions for some individuals, while impairing performance in other configurations. (Kämpfe *et al.,* 2011; Schellenberg, 2005) Two theoretical frameworks have dominated this debate. The Arousal and Mood Hypothesis proposes that music benefits performance by optimising the listener's arousal level for the task at hand, particularly for monotonous or under-stimulating work. (Schellenberg, 2005) The Irrelevant Sound Effect, in contrast, predicts that any structured auditory input including music will disrupt the maintenance of verbal material in the phonological loop component of working memory (Jones & Macken, 1993). Critically, these two frameworks predict different outcomes depending on the nature of the concurrent cognitive task. For tasks relying heavily on verbal working memory such as word memorisation the Irrelevant Sound Effect predicts impairment. For spatially organised tasks with minimal verbal working memory demands such as Sudoku arousal-mediated benefits may predominate without the phonological interference cost.

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Yet despite the theoretical importance of task type as a moderating variable, very few studies have directly compared music's effects across both verbal and spatial cognitive domains within the same laboratory, using the same participants or measurement tools. (Furnham & Strbac, 2002)
The prefrontal cortex (PFC) sits at the heart of both task types: coordinating phonological working memory for verbal tasks (Baddeley, 1992) and executive problem-solving networks for spatial reasoning. (Miller & Cohen, 2001) EEG oscillations generated in and around the PFC provide a high-temporal-resolution window into these processes. Beta oscillations (13–30 Hz) index top-down executive maintenance and attentional control; (Engel & Fries, 2010) gamma oscillations (>30 Hz) support perceptual binding, memory integration, and cross-regional coordination; (Fries *et al.,* 2007) theta oscillations (4–8 Hz) reflect hippocampal-prefrontal communication during encoding; and delta oscillations (0.5–4 Hz) have been linked to inhibitory coordination under demanding cognitive conditions (Harmony, 2013). The present article provides a comparative analysis of two original pilot studies conducted in our laboratory that are ideally positioned to address the question of task-type moderation of music's effects on prefrontal oscillations. Study 1 henceforth the EDM Study measured prefrontal EEG and word recall in ten student participants while they memorised 12-item word lists under EDM or silence. (Shaw, 2026a) Study 2 the Sudoku Study recorded prefrontal EEG in four female high-school students while they solved Sudoku puzzles with and without hip-hop

music. (Shaw, 2026b) While both studies are underpowered as standalone investigations, their combined dataset enables a theoretically informative cross-study comparison of the direction, magnitude, and task-type dependence of music's effects on prefrontal EEG.

OVERVIEW OF THE TWO STUDIES

Comparative Design Features

Table 1 provides a side-by-side comparison of the key design, sample, and outcome features of both studies. The studies share three methodologically important features: (1) both used a within-subjects design with music and no-music conditions; (2) both recorded prefrontal EEG using BrainLink headbands and the same band-power decomposition algorithm; and (3) both were conducted by the same research group, minimising laboratory-specific confounds. The critical differences are the cognitive task type (verbal memorisation vs. spatial problem-solving) and the music genre (EDM vs. hip-hop), both of which serve as the primary dimensions of theoretical interest in this comparison.

EEG Data Summary

Table 2 presents the group mean EEG band power (±SEM) for all measured bands across both studies, with directional consensus indicated.

COMPARATIVE ANALYSIS OF EEG FINDINGS

Gamma Power: A Convergent Suppression Effect

The most robust cross-study finding is the convergent direction of gamma power change: music was associated with lower gamma power than silence in both studies (Figure 1a).

In the EDM Study, group mean gamma was 7.38% with music versus 8.96% without (Δ = −1.58 pp; Cohen's d = −0.31). In the Sudoku Study, the corresponding values were 4.50% versus 7.26% (Δ = −2.76 pp; d = −0.89). The effect was directionally consistent across all ten EDM participants (see Figure 2a), and across three of four Sudoku participants.

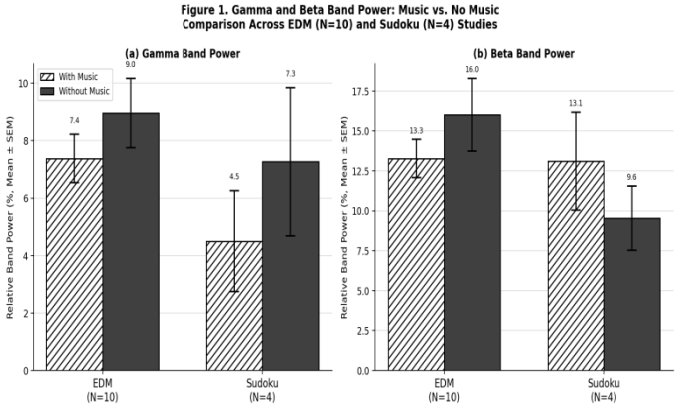

Figure 1. Cross-study comparison of gamma (a) and beta (b) band power: Music vs. No Music conditions in the EDM Study (N=10) and Sudoku Study (N=4). Error bars = ±1 SEM. Format optimised for black-and-white reproduction.

Gamma oscillations in the PFC are generated through reciprocal interactions between pyramidal neurons and parvalbumin-positive inhibitory interneurons, and support the rapid, synchronised binding of distributed feature representations into coherent perceptual and cognitive objects. (Fries *et al.,* 2007) The consistent suppression of gamma across both task types suggests that background music, regardless of the nature of the concurrent cognitive task, may competitively engage the cortical resources underlying high-frequency synchronised processing.

Table 1. Side-by-Side Comparison: EDM Study and Sudoku Study

Feature	Study 1: EDM + Word Recall	Study 2: Hip-Hop + Sudoku
Music genre	Electronic Dance Music (EDM)	Hip-hop
Cognitive task	Word list memorisation (12 words)	Sudoku puzzle solving
Task domain	Verbal / episodic memory	Spatial / executive reasoning
Sample size	N = 10 (6F, 4M)	N = 4 (4F)
Age group	Students (age not recorded)	High-school students (age not recorded)
Design	Within-subjects; music order: no music first	Within-subjects; order not specified
EEG device	BrainLink Lite EEG Headband	BrainLink Lite EEG Headband
Bands measured	Gamma, Beta, Alpha, Theta, Delta	Gamma, Beta (primary)
Outcome 1 (behaviour)	Word recall score (0–12)	Not measured (time only)
Gamma direction	Music < No Music (7.38 vs 8.96%)	Music < No Music (4.50 vs 7.26%)
Beta direction	Music < No Music (13.28 vs 16.01%)	Music > No Music (13.11 vs 9.55%)
Delta direction	Music > No Music (44.81 vs 40.14%)	Not measured
Gamma Cohen's d	−0.31	−0.89
Beta Cohen's d	−0.34	+0.55
Gamma p-value	0.355	0.172
Beta p-value	0.309	0.349
Recall/score effect	+0.60 words (d = 0.36, p = 0.279)	Not applicable
Statistical power	Low (N=10, pilot)	Very low (N=4, pilot)

EDM = electronic dance music; pp = percentage points; d = Cohen's d.

Table 2. EEG Band Power Summary: Both Studies, Music vs. No Music Condition

Band	EDM Music	EDM No Music	Sudoku Music	Sudoku No Music	Direction consensus
Gamma (%)	7.38 ± 0.84	8.96 ± 1.21	4.50 ± 1.75	7.26 ± 2.57	Music < No Music (both)
Beta (%)	13.28 ± 1.19	16.01 ± 2.28	13.11 ± 3.07	9.55 ± 2.01	Divergent
Alpha (%)	13.54 ± 1.63	14.21 ± 1.79	Not measured	—	Music < No Music (EDM)
Theta (%)	21.00 ± 1.67	20.68 ± 1.73	Not measured	—	Negligible (EDM)
Delta (%)	44.81 ± 3.93	40.14 ± 5.49	Not measured	—	Music > No Music (EDM)

Values = relative % of total spectral power, Mean ± SEM. 'Divergent' = opposite direction in the two studies.

One mechanistic interpretation is that the auditory cortex, when processing music, generates its own gamma activity particularly in response to rapid tonal and rhythmic transitions that partially desynchronises or competes with PFC gamma during task performance. (Nagatani *et al.,* 2023) A complementary interpretation is that music occupies cross-modal attentional resources that would otherwise contribute to prefrontal gamma synchronisation during encoding or problem-solving. (Womelsdorf & Fries, 2007) The larger effect size in the Sudoku Study (d = −0.89 vs. −0.31) may reflect the greater sensitivity of the spatial problem-solving task to higher-order prefrontal binding demands, making it more susceptible to gamma disruption or may simply reflect the small sample inflating effect size estimates.

Beta Power: Task-Type Moderation of Executive Attentional Responses

In contrast to the convergent gamma finding, beta power diverged between studies in a theoretically informative way (Figure 1b). In the EDM Study, music was associated with lower beta power (13.28% vs. 16.01%; d = −0.34), while in the Sudoku Study music was associated with higher beta power (13.11% vs. 9.55%; d = +0.55). Figure 2 presents the direction of change for all bands in both studies, making this divergence visually clear.

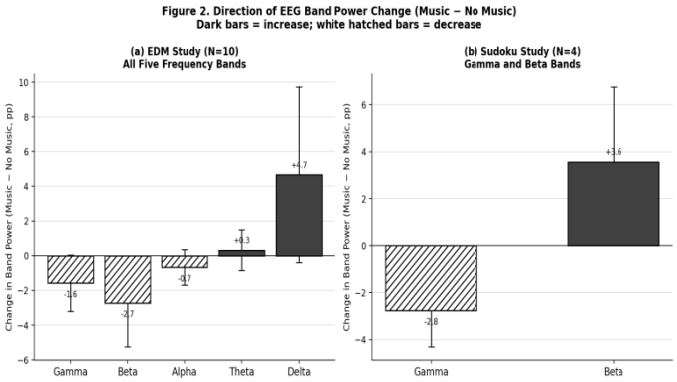

Figure 2. Direction of EEG band power change (Music − No Music, percentage points) across both studies. (a) EDM Study all five frequency bands. (b) Sudoku Study gamma and beta bands. Dark bars = increase with music; white hatched bars = decrease with music. Error bars = ±1 SEM.

This dissociation is consistent with distinct roles of beta-mediated executive control in the two task types. In the EDM Study, the verbal memorisation task requires active maintenance of word sequences in the phonological loop a working memory process strongly indexed by prefrontal beta. (Engel & Fries, 2010) Music may impair this maintenance process either through phonological interference with the word sequences (Irrelevant Sound Effect (Jones & Macken, 1993)) or through a 'beta suppression during cognitive update' mechanism, whereby the concurrent auditory processing demands force repeated reconfiguration of the working memory network. (Engel & Fries, 2010) Either mechanism would predict lower beta during music for a verbal memory task, consistent with the observed direction. In the Sudoku Study, by contrast, the spatial problem-solving task has minimal phonological working memory demands, eliminating the primary competition between music and task on phonological resources. In this context, the rhythmically structured, tempo-consistent character of hip-hop may function as an arousal-enhancing stimulus that optimises the PFC's executive attentional state, increasing beta-mediated top-down control rather than disrupting it. (Schellenberg, 2005; Thaut *et al.,* 2014) This interpretation aligns with the Arousal and Mood Hypothesis: for tasks that do not compete with music on a shared cognitive resource, music may elevate beta-indexed executive readiness. The beta divergence also illustrates why meta-analyses of music's effects on cognition so frequently find null or heterogeneous results (Kämpfe *et al.,* 2011): the direction of beta change depends fundamentally on the match or mismatch between the music's auditory demands and the task's cognitive resource requirements.

Delta Power: EDM-Specific Findings

The EDM Study additionally measured alpha, theta, and delta bands, providing a richer oscillatory picture unavailable from the Sudoku Study. Figure 3 presents the full five-band profile for the EDM Study.

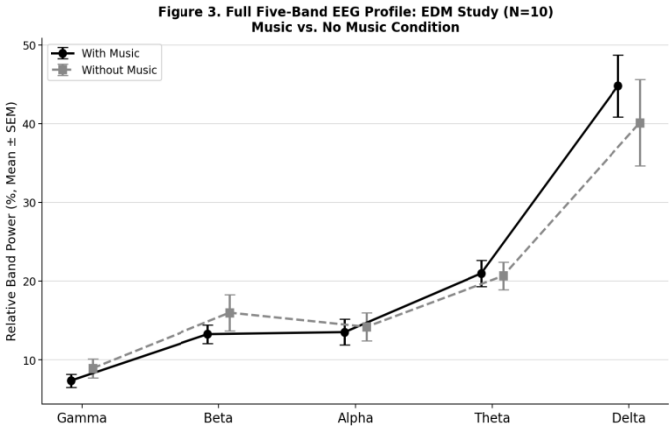

Figure 3. Full five-band EEG profile: EDM Study (N=10), Music vs. No Music condition. Error bars = ±1 SEM.

Delta power was directionally higher in the music condition (44.81% vs. 40.14%; d = +0.29), consistent with the findings of a related Stroop study in the same laboratory (Shaw, 2026c) where delta power was the dominant neural signature of cognitive interference. Delta oscillations in the waking PFC have been associated with active suppression of competing response tendencies and motivational-inhibitory processing. (Harmony, 2013; Knyazev, 2007) In the context of music during memorisation, the delta increase may reflect the cognitive effort required to filter the auditory stream and maintain focus on the word sequences against ongoing auditory distraction. Alpha and theta power showed only negligible differences (Δ = −0.67 pp and +0.32 pp respectively), suggesting that resting attentional gating and hippocampal-prefrontal encoding communication were not substantially altered by EDM at the group level. These near-zero effects are consistent with EDM's moderate-intensity, lyric-free character, which may provide background arousal without strongly engaging the attentional filtering or memory encoding systems.

Effect Sizes Across Studies

Figure 4 provides an overview of effect sizes (Cohen's d) for all measured band comparisons in both studies, and Figure 5 presents these as a heatmap for visual synthesis.

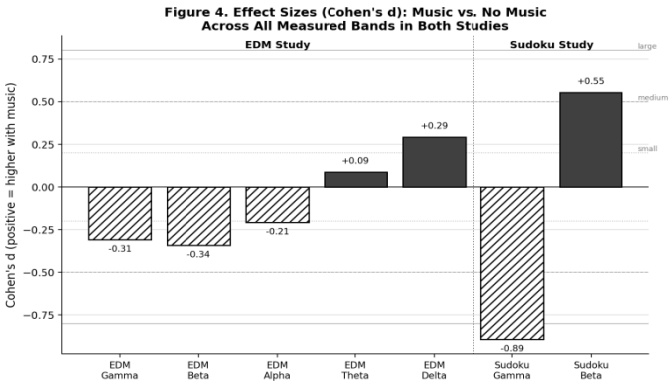

Figure 4. Cohen's d effect sizes for all band comparisons across both studies. Positive d = higher with music; negative d = lower with music. Grey reference lines indicate small (0.2), medium (0.5), and large (0.8) effect size thresholds. Dashed vertical line separates the two studies.

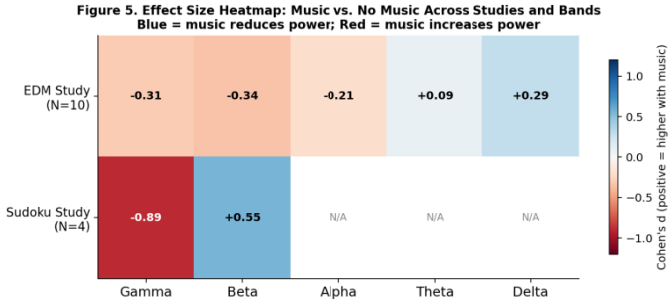

Figure 5. Effect size heatmap (Cohen's d) across studies and frequency bands. Blue = music reduces power; red = music increases power. N/A = band not measured in Sudoku Study.

Effect sizes were generally small in the EDM Study (all |d| < 0.40), consistent with a mild influence of EDM on prefrontal oscillations during verbal memorisation. In the Sudoku Study, effect sizes were larger in magnitude particularly for gamma (d = −0.89) and beta (d = +0.55) though these estimates should be treated cautiously given the very small sample (N = 4) which inflates observed effect sizes. The pattern of larger effects in the Sudoku Study is also consistent with a ceiling effect in the EDM Study's delta band, where delta already dominates the power spectrum (~45% of total power with music), potentially compressing the measurable variance in other bands.

INTEGRATED THEORETICAL INTERPRETATION

A Two-System Model of Music–Cognition Interaction

Drawing together the cross-study patterns, we propose a two-system interpretive framework for understanding how background music modulates prefrontal oscillatory activity during cognitive tasks. The first system higher-order perceptual binding (indexed by gamma) appears to be universally suppressed by music, regardless of task type. The second system executive working memory maintenance and attentional control (indexed by beta) is task-type dependent: suppressed by music when the task competes with music on phonological working memory resources (verbal tasks), but potentially enhanced when no such resource competition exists (spatial tasks). This framework reconciles the conflicting predictions of the Arousal and Mood Hypothesis and the Irrelevant Sound Effect by assigning them to different oscillatory and cognitive subsystems. The Irrelevant Sound Effect operates primarily on the phonological working memory system, reducing beta-mediated maintenance during verbal tasks. The Arousal and Mood mechanism operates on the broader executive alertness system, enhancing beta-mediated attentional readiness during tasks with no phonological resource competition. Meanwhile, gamma suppression may reflect a third, task-independent mechanism: the competitive engagement of auditory processing resources that reduces the availability of high-frequency synchronised networks for prefrontal cognitive binding.

Implications for EEG Research

Both studies used BrainLink EEG devices for data collection. This methodological choice has important implications for interpreting the findings and for the broader agenda of accessible neuroscience research in educational settings. (Maskeliunas *et al.,* 2016) The relative band power output of these devices is sensitive to the overall spectral distribution and can be influenced by movement artefacts, skin impedance, and environmental electromagnetic noise. The single frontal electrode placement captures a mixture of frontal lobe activity without the spatial resolution to localise effects to specific PFC subregions. Nevertheless, the cross-study convergence in gamma direction, and the theoretically coherent beta divergence, suggests that such EEG headbands can detect oscillatory signatures that are meaningful and interpretable when used with appropriate methodological caution, adequate rest periods, and within-subjects designs that control for individual differences in baseline oscillatory profiles. These findings add to a growing literature demonstrating the utility of EEG for educational and applied neuroscience research. (Maskeliunas *et al.,* 2016)

FUTURE DIRECTIONS

These pilot studies point to several specific and testable hypotheses for future investigation. The convergent gamma suppression hypothesis that background music reduces prefrontal gamma power regardless of task type should be tested in a single adequately powered study (estimated N ≥ 25–30 per cell) using counterbalanced music/silence conditions, matched verbal and spatial task blocks, and multi-channel EEG with source analysis. The beta task-moderation hypothesis that music increases beta during spatial tasks but decreases it during verbal tasks requires a factorial design crossing music (present/absent) with task type (verbal/spatial) within the same participants. Such a design would also enable direct testing of the interaction between music genre (EDM, hip-hop, classical, lyrical) and task type, which the current data cannot address. EEG headband methodology can be retained for larger-scale deployment in schools and study environments, provided that: the device is upgraded to a multi-channel system (e.g. Emotiv EPOC or OpenBCI); rest baselines are recorded and used to normalise absolute band power; and validated artefact detection algorithms are applied. Combining EEG with concurrent behavioural measures (response accuracy, reaction time, recall scores) in both task types will also be essential for establishing the functional significance of the oscillatory changes described here.

CONCLUSION

This comparative analysis of two pilot EEG studies from the same laboratory provides preliminary evidence that the

relationship between background music and prefrontal neural oscillations is both nuanced and theoretically coherent. The convergent suppression of gamma power across a verbal memorisation task (EDM; N = 10) and a spatial problem-solving task (Sudoku; N = 4) suggests that music universally engages auditory processing resources in ways that reduce higher-order prefrontal perceptual binding efficiency. The divergent direction of beta power reduced with music during verbal memorisation but increased with music during spatial reasoning is consistent with a task-type moderating framework in which music impairs phonological working memory maintenance on verbal tasks while enhancing executive attentional alertness on spatial tasks where no such resource competition exists. These findings, while preliminary and underpowered, offer a mechanistic bridge between the Irrelevant Sound Effect and the Arousal and Mood Hypothesis that has practical implications for how we design music-accompanied learning environments. Students memorising verbal material may benefit from silence; those engaged in spatial reasoning or problem-solving may benefit from background music. Validating and extending these findings in adequately powered, multi-task, multi-genre studies using higher-density EEG systems represents an important and tractable agenda for educational and cognitive neuroscience.

Author Contributions

N.S.: Conceptualization, Data Curation (original studies), Formal Analysis, Writing – Original Draft and Project Administration.

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Data Availability Statement

Raw data from the two original studies are available from the corresponding author upon reasonable request.

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Conflict of Interest

The author declares no conflict of interest.

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