

# Prefrontal Laterality Modulation Through Targeted Auditory Beat Stimulation During Multimodal Cognitive Tasks under Photometric Conditions

## Abstract

This study investigates how auditory beat stimulation modulates prefrontal hemispheric asymmetry and autonomic nervous system activity during cognitively demanding tasks under two different photometric conditions. Participants (N=30 – 40) will perform verbal-logical (left hemisphere dominant) and visual-spatial (right hemisphere dominant) tasks under two auditory conditions: 10Hz binaural beats ( $440\pm 10\text{Hz}$ ) and 40Hz binaural beats ( $440\pm 40\text{Hz}$ ), each paired in two groups based on photometric condition (i.e. Red with 10Hz & 40Hz auditory conditions; Blue with 10Hz & 40Hz auditory conditions). Red light therapy has been shown to enhance cognitive function by improving mitochondrial activity, increasing ATP production, and enhancing regional cerebral blood flow, which may benefit tasks requiring attention and memory[a][b][c]. Additionally, red light has been linked to improved executive function and memory in patients with traumatic brain injuries[b][d]. Blue light exposure is known to enhance alertness and improve performance on cognitive tasks, particularly those requiring attention and working memory. It increases activation in brain regions associated with executive functions, such as the dorsolateral and ventrolateral prefrontal cortex. Prefrontal beta-gamma asymmetry indices (ASI) will be calculated from 4-channel EEG recordings, while autonomic activity will be monitored through heart rate variability (RMSSD) and electrodermal phasic responses. This study aims to elucidate how the combination of auditory stimulation and photometric conditions influences cognitive task performance and physiological responses.

## Abstract References

- **Red Light Effects:** Red light therapy enhances cognitive function by improving mitochondrial activity, increasing ATP production, and enhancing regional cerebral blood flow, benefiting tasks requiring attention and memory[a][b][c]. It also improves executive function and memory in patients with traumatic brain injuries[b][d].
- **Blue Light Effects:** Alertness and Cognitive Performance, Working Memory [h]; Reaction Time and Attention[i],

- **Auditory Stimulation:** The study examines the effects of 10Hz and 40Hz binaural beats on hemispheric asymmetry and autonomic activity.
- **Physiological Measures:** EEG and autonomic measures (RMSSD, EDA) are used to assess physiological responses during tasks[e][f].
- **Cognitive Modulation:** Auditory beat stimulation can modulate cognitive processes and mood states[g].

## Keywords:

Binaural Beats, Alpha Wave Stimulation, Gamma Wave Stimulation, Auditory Stimuli, Photometric Conditions, Brain Lateralization, Physiological Responses, Cognitive Monitoring, Multisensory, Multidomain

# Section 1: Cognitive Task Design [1][3]

## 1.1 Dual-Modality Challenge (10+10 mins)

### A. Verbal-Semantic Processing (Left Hemisphere Engagement)

- **Auditory Text Analysis** (10 mins)

**Task Description:** Participants will listen to text passages via earphone Buds (70 dB SPL) and identify semantic inconsistencies. The task requires participants to determine if a statement is logically and semantically correct. Based on statement, participants will choose correction option on the screen and state out loud the statement.

**Instructions to Participants:** You will hear a series of sentences. Your task is to listen carefully and identify whether each sentence makes sense or if there is a semantic inconsistency (i.e., something that doesn't logically fit). If you find an inconsistency, please choose correction option on the screen based on what correction should be made.

### B. Visuospatial Manipulation (Right Hemisphere Engagement)

- **Pattern Recognition and Optical Illusion Task** (10 mins)
  - Identify hidden patterns or objects within complex image puzzles
  - Tasks involve recognizing patterns, counting objects, or detecting hidden images
  - Performance metric: Rotation angle vs response time slope

**Task Description:** Participants will view a series of optical illusions images on PC screen. In each illusion, it may exist hidden patterns, no. of objects, or images. Tasks would be to find out and identify these patterns.

**Instructions to Participants:** You will be shown a series of optical illusions puzzle. Your task is to identify any hidden patterns, objects, or images within each puzzle. For example, you may need to count the number of certain objects, detect a hidden image, or spot a pattern in a cluttered design. Please respond within 1 min.

## Section 2: Auditory Stimulation Protocol [1][2][3]

### 2.1 Beat Generation Parameters

Condition	Specification	Neurological Basis[1][3]
10Hz Binaural Beats	440Hz ±10Hz (L/R phase offset)	Right prefrontal beta enhancement[1]
40Hz Binaural Beats	440Hz carrier, 40Hz AM depth 80%	Left temporal gamma entrainment[2][3]

### 2.2 Stimulus Delivery Protocol

- **Galaxy Buds Pro Earphones**
  - Binaural beats: Phase-locked delivery (0° left, 180° right initialization)
  - Inter-stimulus interval: 1500ms ±300ms jitter

## Section 3: Multimodal Data Acquisition Framework

### 3.1 Neurophysiological Synchronization

- **Muse S EEG Preprocessing**
  - Asymmetry Index (ASI) calculation: (Right AF8 - Left AF7) / (AF7 + AF8)
  - Frequency bands: Alpha (8–12Hz), Gamma (30–45Hz)[3]
  - Artifact rejection: ±75µV threshold with moving window SD
- **Empatica EmbracePlus Metrics**
  - Phasic EDA: 0.05-1.5Hz bandpass (cvxEDA decomposition)
  - HRV Analysis: RMSSD in 128s windows (matched to task epochs)

## 3.2 Experimental Timeline

Phase	Duration	Auditory Condition	Task Component
Acclimation Time	5 Mins	None	General Survey
Baseline Recording	5 mins	None	Resting eyes-open
Condition 1	10 mins	10Hz Binaural	Verbal-Semantic
Washout	4 mins	10Hz Binaural + 1min Silence	Experiment Survey
Condition 2	10 mins	40Hz Binaural	Visuospatial
Washout	3 mins	40Hz Binaural	Experiment Survey

### Group A:

Condition\_1 ( $C_1$ ) = RedLED ( $L_1$ ), 10Hz ( $A_1$ ), Task1,2 ( $T_{1,2}$ )  
Condition\_2 ( $C_2$ ) = RedLED ( $L_1$ ), 40Hz ( $A_2$ ), Task1,2 ( $T_{1,2}$ )

### Group B:

Condition\_1 ( $C_1$ ) = BlueLED ( $L_2$ ), 10Hz( $A_1$ ), Task1,2 ( $T_{1,2}$ )  
Condition\_2 ( $C_2$ ) = BlueLED( $L_2$ ), 40Hz( $A_2$ ), Task1,2 ( $T_{1,2}$ )

## Section 4: Control Protocol (Per [3] Methodological Standards)

### 4.1 Environmental Controls

- **Acoustic Isolation**
  - Double-walled Nextroom lab
  - Galaxy Buds passive isolation: 23dB SNR
- **Environmental Constants**
  - Ambient light:Four LED panels + Two Red lights
  - Ambient light: Four LED panels + Two Blue lights
  - Temperature: Normal conditions  $\sim 22\pm 1.0^{\circ}\text{C}$  (HVAC-controlled)

## Section 5: Technical Validation for 10Hz Binaural and

# 40Hz Binaural Effects

- The technical validation of binaural effects involves neuroscientific, psychoacoustic, and EEG-based evidence supporting the influence of these frequencies on brain activity.

## 5.1 10Hz Binaural Effects (Alpha Wave Stimulation)

### Neuroscientific Basis

- **Right Prefrontal Beta Modulation:**
  - Studies show 10Hz binaural beats influence right temporal lobe activity, enhancing relaxation and mild cognitive shifts.
- **EEG Alpha Power Increase:**
  - Increased alpha synchronization correlates with meditation, stress reduction, and improved mood.

### Psychoacoustic Considerations

- **Interaural Time Difference (ITD) Validation:**
  - Phase offset ( $0^\circ$  vs  $180^\circ$ ) ensures proper brainwave entrainment by maintaining the 10Hz difference between left and right auditory pathways.

### Experimental Design Validation

- **Entrainment Duration:**
  - 10-minute exposure to 10Hz beats aligns with literature on theta-to-alpha wave transition, which is linked to relaxation and attentional shifts.
- **Artifact Control:**
  - ISI jittering (introducing slight variations in stimulus timing) prevents rhythmic expectation effects, ensuring natural brain entrainment.

## 5.2 40Hz Binaural Effects (Gamma Wave Stimulation)

### Neuroscientific Basis

- **Cognitive Enhancement and Memory Processing:**
  - 40Hz stimulation has been linked to increased gamma activity, associated with working memory, cognitive function, and neural synchronization.
- **Neural Oscillation Support in Alzheimer's Research:**

- Studies suggest 40Hz entrainment may enhance synaptic plasticity and reduce beta-amyloid accumulation, relevant for neurodegenerative disease research.

## Psychoacoustic Considerations

- **Interaural Amplitude Modulation (AM) Depth Validation:**
  - 80% AM depth effectively triggers auditory steady-state responses (ASSR), supporting cognitive enhancement protocols.

## Experimental Design Validation

- **Hemispheric Asymmetry Consideration:**
  - Right-ear dominant delivery exploits left-hemisphere auditory processing benefits, known for language and logical reasoning functions.
- **Gamma Entrainment Protocol:**
  - 10-minute exposure aligns with cortical phase synchronization timeframes used in focus and attention studies.

## 5.3 Task Synchronization

- 10-min blocks allow sufficient entrainment time per [1] theta wave observations
- ISI jitter prevents rhythmic expectation artifacts [3]

## 5.4 Asymmetry Index (ASI)

Asymmetry Index is used to measure differences in brain activity between the left and right hemispheres, and commonly used to quantify hemispheric dominance, validated against [3] laterality index methods. We will be utilizing Muse S sensor capabilities [1] to match beta/gamma focus.

$$ASI = \frac{(P_{Right} - P_{Left})}{(P_{Right} + P_{Left})}$$

where :  $P_{Right}$  = Power(or amplitude) of brain activity in the right hemisphere  
 $P_{Left}$  = Power(or amplitude) of brain activity in the left hemisphere

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