Mapping Cognitive Control: EEG Signals Modulating Real-Time Music Composition

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***Abstract* — This thesis explores the use of real-time electroencephalogram (EEG) signals to control Virtual Studio Technology (VST) parameters within a Digital Audio Workstation (DAW), using NeuroBell's portable Luna EEG Amplifier. Four stimulus environments were designed to engage each of the brain's primary lobes (frontal, parietal, temporal, occipital), targeting neural oscillatory patterns. EEG signals were processed in real time, extracting theta, alpha, and beta features per lobe, mapped to MIDI Control Change messages, and routed into Reaper for modulation of a wavetable synthesiser. Results showed stable EEG-to-MIDI translation and real-time modulation, though perceptual feedback varied. This demonstrates a viable, low-cost brain–music interface with potential creative and technological applications.**

***Keywords* — EEG, Python, Brain–Computer Music Interface (BCMI), DAW, VST, MIDI mapping, real-time signal processing, music technology.**

Abbreviations

SSVEP	–	Steady-State Visually Evoked Potentials
NICU	–	Neonatal Intensive Care Unit
MIDI	–	Musical Instrument Digital Interface
EDF	–	European Data Format
FFT	–	Fast Fourier Transform

I. Introduction

Many studies have investigated the effect of music on the brain; however, there is an emerging field using brain activity to control music instead. Specific sections of the brain are responsible for various sensory processing functions. This could be harnessed and analysed using electroencephalogram (EEG) technology in a musical context.

Previous studies have shown that certain parts of the brain are responsible for auditory processing of music and that this electrical activity can be reprocessed back into the song being heard [1] Certain parts of the brain can be attributed to processing specific musical elements, activating many of the same regions that speech does [2]. Emotional state can also be used via EEG data to trigger and control musical transformations [3]

This study investigates using brain activity to control VST parameters within a DAW, providing an interactive musical experience using real-time activity from four brain regions. EEG technology was used to record brain activity from the scalp and feed it directly into a DAW via a USB connection. The hypothesis is that sensory-specific lobes can distinctly influence VST control and musical expression.

II. Background & Design

A. Background & Theoretical Framework

EEG measures electrical activity across the scalp via standardised 10–20 electrode placement, with each site corresponding to underlying brain regions [4].

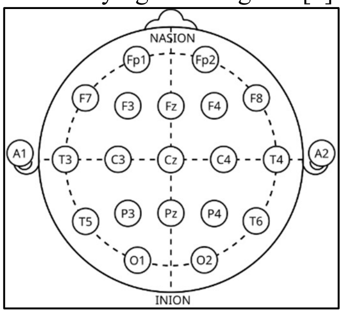

Fig. 1 - Electrode locations of the 10-20 system for EEG recording

For the oscillatory patterns, alpha waves (8–12 Hz) are linked to visual and attentional processing, theta waves (4–8 Hz) to memory, and beta waves (13–30 Hz) are linked to cognitive activity as well as motor planning (especially in the frontal lobe).

B. EEG in Music Technology

Music perception engages distributed brain networks, and EEGs have been used for real-time musical control in systems such as the Encephalophone [5], ICCMR's EEG-driven musical style switching [6], and accessibility-focused brain–computer music interfaces (BCMIs) [7]. These systems demonstrate that low-channel EEG can meaningfully drive synthesis parameters.

C. Technology Overview

The NeuroBell Luna EEG Amplifier, developed for neonatal seizure monitoring, streams 8-channel EEG either wirelessly or via USB [8]. Its portable design and electrode layout (Pz, Cz, F3, F4, C3, C4, T3, T4, O1, O2) allowed for mapping of activity across lobes to DAW parameters.

D. Experimental Framework

This study's framework involves four stimulus environments. The finalised stimulus tasks performed can be seen below in 0This discusses the primary lobe and region being targeted for each task, the stimulus carried out, the target EEG frequency band invoked and mapped to MIDI control in Reaper, and a summary of the rationale behind the choice.

TABLE I. FINALISED STIMULUS TASKS

Brain Region	Stimulus Task	Target Band	Scientific Basis
Occipital Lobe (Visual Cortex)	9 Hz flicker stimulus	Alpha (8–12 Hz)	SSVEP show alpha-band resonance in the visual cortex when the flicker frequency aligns with the occipital alpha rhythm [9].
Temporal Lobe (Auditory/ Medial Temporal)	Mental recall of a pre-learned number list	Theta (4–7 Hz)	Theta rhythms emerge during memory retrieval; increased theta power is linked to hippocampal and temporal processing [10][11].
Parietal Lobe (Sensorimotor Cortex)	Mental rotation of a 3D object	Alpha (8–12 Hz)	Spatial tasks like mental rotation engage the superior parietal lobule and reduce parietal alpha rhythms [12].
Frontal Lobe (Prefrontal Cortex)	Imagined hand movement	Theta (4–7 Hz), Beta (13–30 Hz)	Frontal-midline theta increases with working memory. Motor imagery should induce beta desynchronisation (beta decrease), signalling motor engagement followed by a beta rise when it is ended[13][14].

E. *Final System*

For clarity of the system structure, Fig. 2 shows a block flow diagram of the final desired setup. The following section will discuss how it was implemented.

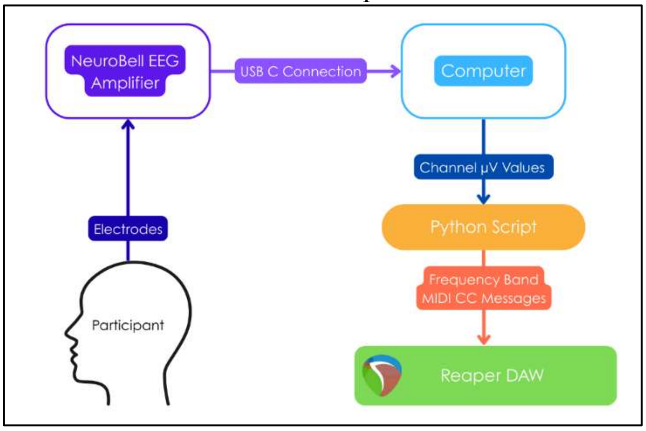

Fig. 2 - Block Flow Diagram of Entire System

III. IMPLEMENTATION

A prototype EEG-to-MIDI system was initially built using sample EDF datasets to simulate a live feed of EEG data, verify the structure and perform initial experiments. This Python script was then adapted for live use with NeuroBell's Luna EEG Amplifier. Live streaming replaced offline file input, with USB serial communication configured at 115200 baud and 250 Hz sampling. Data packets containing eight microvolt channels were parsed, validated, and stored per lobe.

A 4th-order Butterworth bandpass filter (1.6–40 Hz) removed low-frequency drift and electrical power supply artefacts. Each lobe's valid channels were averaged, mean-removed, and transformed via FFT to extract theta (4–7 Hz), alpha (8–12 Hz), and beta (13–30 Hz) amplitudes. These were linearly scaled into 0–127 MIDI Control Change (CC) values and assigned fixed CC numbers for DAW mapping.

Four independent lobe streams (12 CC messages per second) were routed to Reaper's Helgobox ReaLearn plugin, mapped to parameters in the Vital wavetable synthesiser. Bach preludes provided a standardised musical base, with CC values modulating LFO smoothing, delay, and stereo width. Fig. 3 shows this setup.

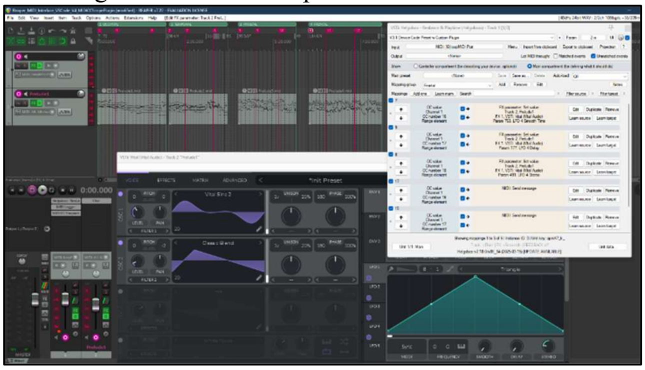

Fig. 3 - Reaper Session with ReaLearn, Vital, and Preludes

The final system consisted of the Luna device, Python processing, MIDI mapping, and Reaper-based modulation in a fully integrated, lobe-specific control chain, as per Fig. 2.

IV. TESTING & RESULTS

External trials were conducted in a quiet lecture theatre to minimise noise and distractions. Participants wore the Luna EEG device, with electrode contact optimised using conductive gel. Four lobe-specific tasks, each approximately 1 minute long, were completed in sequence, with inactive lobes disabled in software to isolate control.

Objective data was captured as CSV logs of raw EEG and feature-extracted values. Custom scripts plotted feature trends against calibration periods (0s-30s, 90s-120s) and stimulus (30s-90s) markers. An example of this can be seen below in Fig. 4.

Fig. 4 - Feature Comparison across Lobes with Event Markers

Subjective data was gathered via Likert-scale and open-ended questionnaires after each task.

Results showed an inconsistent perception of modulation. Memory recall tasks (temporal lobe) produced the most frequent reports of subtle timbral change. Parietal and frontal tasks yielded minimal perceived effects, with some participants noting that cognitive effort reduced attention to the music.

The 1 Hz system update rate was sufficient for slow timbral changes but limited for fast, rhythm-linked effects. Findings indicated functional lobe-specific mapping, but with variable perceptual impact.

V. Discussion

The project achieved stable, real-time EEG-to-MIDI translation using low-cost hardware. Technical performance was reliable, with band-specific amplitude mapping preserved across four lobe streams. However, user influence over music was only partially validated.

The temporal lobe memory recall task aligned best with the literature, producing theta increases and subjective reports of change, though statistical correlation was inconclusive. Parietal alpha suppression during spatial tasks and frontal beta changes during motor imagery were less evident both in data and perception. Mapping subtle spectral shifts to nuanced effects (e.g., stereo width) may have reduced perceived control.

VI. Future Work

Several refinements could improve the system's scientific validity and creative scope.

For signal processing, implementing relative power normalisation (e.g., expressing each band as a percentage of total 4–30 Hz power) would enhance comparability across participants and sessions. Ratios such as alpha/beta could yield more stable mappings, while spectral windowing and log-power calculations would improve FFT resolution.

For stimulus validation, increasing the EEG data rate would better synchronise neural changes with musical modulation. Live timestamped event logging and statistical analysis could confirm alignment between EEG patterns and intended tasks, while longer trials and larger participant pools would increase reliability.

In mapping strategies, exploring FM or granular synthesis, assigning EEG features to more perceptually obvious parameters, or modulating pre-recorded playback could create clearer before/after comparisons.

These enhancements could make the system more precise, responsive, and versatile for both research and artistic performance.

VII. Conclusion

This study investigated whether EEG signals from distinct brain lobes could be mapped in real time to control VST parameters within a DAW. A portable EEG device (NeuroBell Luna) was successfully integrated with a Python-based processing pipeline and Reaper, achieving stable, lobe-specific MIDI control.

While the system met its technical objective, enabling continuous neural modulation of synthesiser parameters, perceptual results were mixed.

Key contributions include demonstrating that low-channel, consumer-grade EEG hardware can support functional BCMIs. Future work will refine signal processing, expand mapping strategies, validate stimulus–response correlations, and explore cross-disciplinary applications.

The findings support EEG-driven modulation as a creative tool, with promise for inclusive performance, adaptive composition, and responsive sound design.

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