Masters Thesis Information Showcase
Spring Semester-2026
Year 2026

	Department: Biomedical Engineering Programme: Masters in Engineering Specialization: Biomedical Engineering
1	**Title of the Thesis** Temporal Dynamics of EEG Microstates Induced by Binaural Beats
2	**Abstract** (min 300 to 500 words) EEG microstates are transient, quasi-stable configurations of scalp electrical activity that reflect rapidly shifting large-scale brain states. Despite growing interest in binaural beat stimulation as a non-invasive neuromodulation approach, its differential effects on EEG microstate temporal dynamics and signal complexity across frequency bands remain poorly characterized. This study investigated how alpha, beta, and gamma binaural beats modulate microstate parameters and non-linear EEG complexity in healthy adults. Sixty healthy adults were randomly allocated to three groups of twenty, each exposed to a distinct frequency band: alpha (8–12 Hz), beta (13–30 Hz), or gamma (30–50 Hz). Resting-state EEG was recorded before and after fifteen minutes of stimulation using a 14-channel Emotiv EPOC headset. Microstate segmentation was performed via Global Field Power-based k-means clustering, yielding four canonical classes. Parameters assessed included duration, occurrence, occurrence rate, fractional coverage, and transition probabilities. Higuchi Fractal Dimension was computed as a non-linear complexity measure. Statistical comparisons employed one-tailed paired t-tests at $p < 0.05$. Alpha stimulation produced increased occurrence and occurrence rate of microstate C alongside reduced duration across multiple microstates, reflecting heightened temporal flexibility of the salience network, with signal complexity increasing across frontal, temporal, and occipital regions. Beta stimulation induced the most widespread modulation, with global reductions in microstate duration across all four canonical classes, increased occurrence metrics, and broadly elevated signal complexity consistent with heightened neural alertness. Gamma stimulation produced a markedly contrasting profile: microstate C was consistently suppressed while microstates A and B demonstrated increased temporal stability, and signal complexity decreased exclusively at bilateral temporal electrodes, reflecting localized acoustic entrainment rather than widespread cortical modulation. The findings confirm that binaural beat stimulation exerts frequency-specific, dissociable effects on resting-state brain dynamics. Alpha beats enhance salience-network flexibility, beta beats drive widespread neural alertness and throughput, and gamma beats stabilize primary sensory networks through localized entrainment. These results support the combined use of microstate analysis and non-linear complexity measures as a framework for characterizing auditory neuromodulation and provide a neurophysiological basis for frequency-targeted applications of binaural beat stimulation.
3	**Impact on SDG# 3"** (min 500 words) (Please mention the impact of the relevant attained SDG) This research directly advances UN Sustainable Development Goal 3 (Good Health and Well-being) by establishing a validated, non-invasive auditory neuromodulation framework to treat neurological dysfunctions and optimize mental states. By investigating the exact effects of alpha, beta, and gamma binaural beats (BB) on large-scale brain networks, this study

	provides a crucial neurophysiological blueprint for targeted, affordable, and risk-free therapies. The study reveals that different frequencies of binaural beats drive distinct changes in the brain's canonical EEG microstates, also called as the “atoms of thought”, offering unique clinical pathways. Alpha Beats (8–12 Hz) can be used for alleviation of stress and anxiety as it selectively increases the occurrence and occurrence rate of Microstate C, which directly reflects the flexibility of the salience network. This flexibility is critical for helping individuals switch smoothly between stressful external stimuli and relaxed internal states, presenting a direct therapeutic option for anxiety and emotional arousal disorders. Beta Beats (13–30 Hz) can be utilized for modulating attention and fatigue as exposure to beta binaural beats induce a global reduction in microstate duration and widespread elevation of signal complexity across the cortex. This signature shifts the brain into a state of heightened neural alertness, establishing an effective protocol for treating cognitive fatigue, concentration deficits, and executive function issues common in conditions like Attention-Deficit/Hyperactivity Disorder (ADHD). Gamma Beats (30–50 Hz) can be leveraged for sensory regulation as gamma frequency binaural beats uniquely stabilize primary sensory networks through localized temporal lobe synchronization. This targeted entrainment provides therapeutic utility for individuals experiencing sensory processing anomalies or memory binding fragmentation. Conventional neuromodulation techniques present major structural barriers to achieving global health equity under SDG 3. Systems like Deep Brain Stimulation (DBS) require costly surgical implants and carry high physical risks. Frameworks like Transcranial Magnetic Stimulation (TMS) or Transcranial Direct Current Stimulation (tDCS) demand specialized institutional hardware and expert operators. In stark contrast, binaural beats offer a purely acoustic form of neurostimulation that runs indirectly through standard headphones. By demonstrating that consumer-grade hardware (like the 14-channel Emotiv EPOC headset utilized in the protocol) can successfully record and trace these microstate shifts, this thesis proves that advanced neural therapies can be deployed cheaply. This low-barrier methodology supports community-wide, preventative mental health care outside specialized hospitals, perfectly matching the goals of global health access. A historical hurdle in mental healthcare has been the reliance on subjective patient questionnaires to measure well-being. This research solves that problem by pairing microstate temporal dynamics with the Higuchi Fractal Dimension (HFD). HFD serves as a mathematically precise, non-linear index of biological signal complexity. Tracking changes in space-filling microstate configurations gives doctors clear, numeric biomarkers of a patient's neurophysiological state. Instead of guessing whether an auditory therapy is working, healthcare providers can track changes in real-time microstate cycles. This mathematical clarity prevents drug over-prescription and allows for highly optimized clinical monitoring. Because acoustic brainwave entrainment works with the brain's natural synchronization systems rather than overriding them electrically, it is inherently safe. The system functions as a flexible feedback loop that gently adjusts neural networks. This offers a safe alternative or supportive tool alongside traditional pharmaceuticals, lowering the risk of chemical dependencies or unwanted medical side effects. Ultimately, by turning a simple sound illusion into an exact science, this thesis maps out a practical path toward safe, highly effective, and widely accessible neurological care for everyone.
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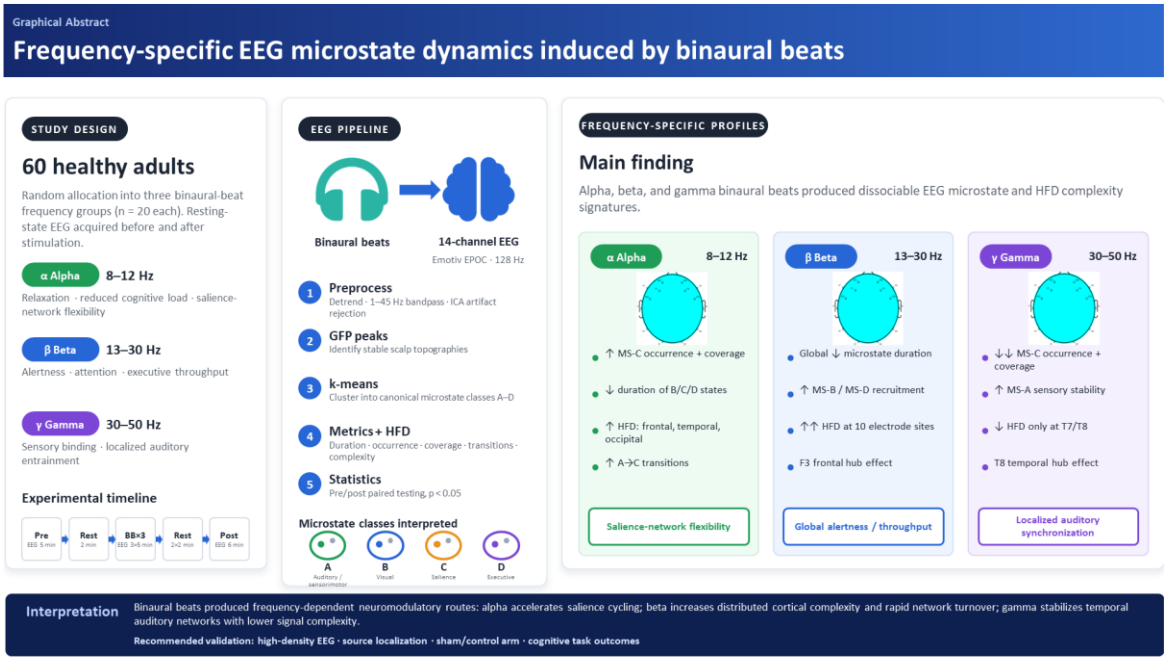
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6	**Graphical Abstract**