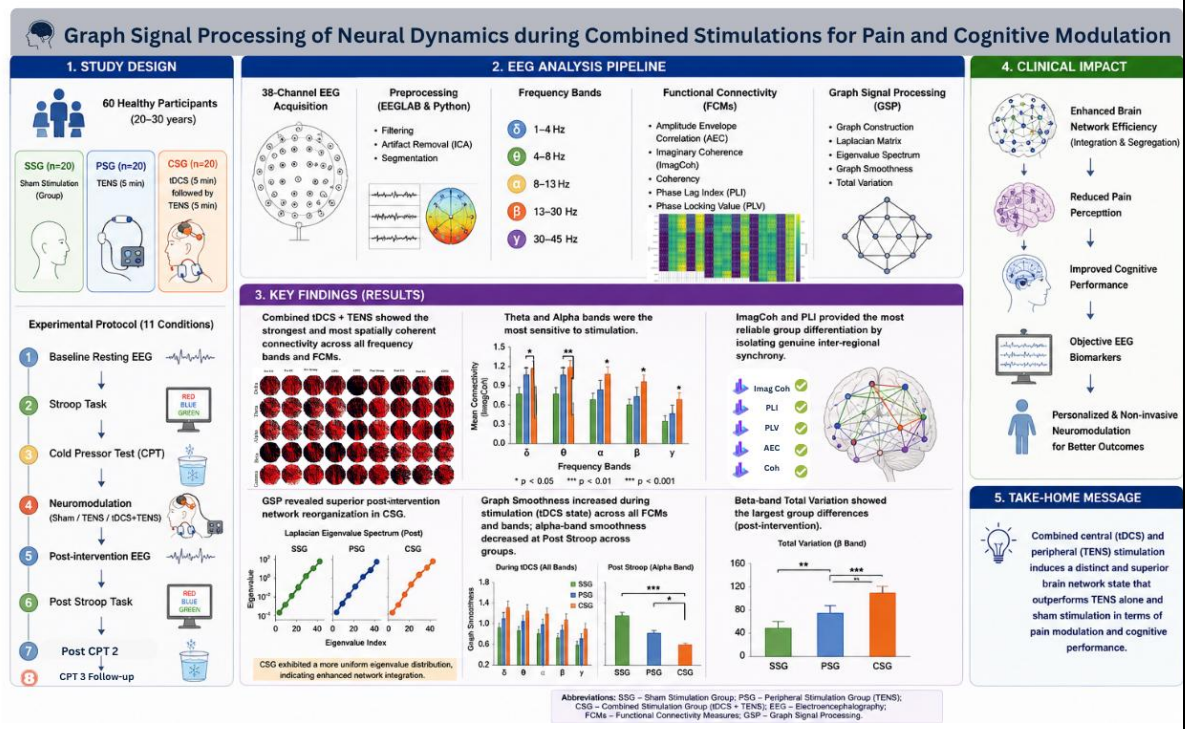
Masters Thesis Information Showcase
Spring Semester-2026
Year 2026

Department: Biomedical Engineering
Programme: Weekend
Specialization: M.Engg. Biomedical Engineering

1	**Title of the Thesis** Graph Signal Processing of Neural Dynamics during Combined Stimulations for Pain and Cognitive Modulation
2	**Abstract** (min 300 to 500 words) **Background:** Chronic pain is associated with widespread alterations in functional brain connectivity and frequently coexists with cognitive dysfunction, highlighting the need for objective neurophysiological biomarkers and effective non-pharmacological interventions. Although transcutaneous electrical nerve stimulation (TENS) and transcranial direct current stimulation (tDCS) have independently demonstrated efficacy in pain modulation and cognitive enhancement, the neural mechanisms underlying their combined application remain poorly understood. This study investigated the effects of combined central and peripheral neuromodulation on functional brain networks using electroencephalography (EEG)-based functional connectivity and graph signal processing (GSP). **Methods:** EEG recordings from 60 healthy adults (20–30 years) were analyzed following a controlled experimental protocol. Participants were randomly allocated to 3 equal groups (n = 20): a Sham Stimulation Group (SSG) receiving no active stimulation, a Peripheral Stimulation Group (PSG) receiving TENS, and a Combined Stimulation Group (CSG) receiving sequential cathodal tDCS followed by TENS. The experimental paradigm consisted of pre EEG acquisition in eyes open and closed states, Stroop task, Cold Pressor Test (CPT1), neuromodulation, and post-intervention EEG, post Stroop and CPT2 followed by CPT3 in follow-up assessments to evaluate changes in cognitive performance and pain perception. Behavioral outcomes included Visual Analogue Scale (VAS), pain threshold, and Stroop task performance. 38 channels EEG were preprocessed and analyzed across delta, theta, alpha, beta, and gamma frequency bands. Functional connectivity (FC) was quantified using Amplitude Envelope Correlation (AEC), Imaginary Coherence (ImagCoh), Coherency, Phase Lag Index (PLI), and Phase Locking Value (PLV). GSP was subsequently employed to characterize network topology through Smoothness, and Total Variation. **Results:** Combined neuromodulation produced the greatest behavioral and neurophysiological improvements compared with sham and peripheral stimulation alone. The CSG demonstrated significantly ($p<0.05$) enhanced pain tolerance, reduced pain perception, and improved cognitive performance following stimulation. FC analysis revealed stronger and more spatially coherent cortical interactions in the CSG across all frequency bands, with theta and alpha oscillations exhibiting the highest sensitivity to neuromodulation. Among the connectivity measures, ImagCoh and PLI most effectively

	differentiated ($p<0.05$) stimulation-induced network reorganization by minimizing volume conduction effects. GSP analysis further demonstrated pronounced post-intervention alterations in brain network topology within the CSG, characterized by a more uniform Laplacian eigenvalue distribution, significantly ($p<0.05$) increased smoothness and prominent ($p<0.05$) total variation changes compared with the PSG and SSG. **Conclusions:** These findings demonstrate the synergistic benefits of combined central and peripheral neuromodulation, laying the groundwork for personalized, non-pharmacological strategies to enhance brain network function and cognitive resilience.
3	**Impact on SDG#___"** (min 500 words) (Please mention the impact of the relevant attained SDG) **<u>Impact on SDG #3: Good Health and Well-being</u>** This research contributes to Sustainable Development Goal (SDG) #3: Good Health and Well-being by advancing non-invasive, technology-driven approaches for pain management and cognitive enhancement. Through the combined application of Transcutaneous Electrical Nerve Stimulation (TENS) and transcranial Direct Current Stimulation (tDCS), along with EEG-based functional connectivity and Graph Signal Processing (GSP), the study provides objective evidence of brain network reorganization associated with neuromodulation. The proposed framework supports the development of personalized, evidence-based neurorehabilitation strategies that can improve patient outcomes, reduce dependence on pharmacological treatments, and enhance overall quality of life. **<u>Impact on SDG #4: Quality Education</u>** This research supports Sustainable Development Goal (SDG) #4: Quality Education by strengthening interdisciplinary education and research in biomedical engineering, neuroscience, and computational signal processing. The proposed EEG-GSP framework serves as a valuable resource for students and researchers by providing a reproducible methodology for analyzing functional brain networks and evaluating neuromodulation. By promoting advanced scientific knowledge, research innovation, and evidence-based learning, this work contributes to building skilled professionals capable of addressing future healthcare challenges through technology-driven solutions.
4	**Scholar Name** (along with contact details) **Scholar name:** Nayab Mubashir **Email:** nm.nayab@gmail.com
5	**Supervisor & Co-supervisor Name** (along with contact details) **Supervisor name:** Prof. Dr. Muhammad Abul Hasan

	Email: abulhasan@cloud.neduet.edu.pk **Co-supervisor name:** Dr. Muhammad Danish Mujib **Email:** danishmujib@neduet.edu.pk
6	**Graphical Abstract**