Project Notes:

Project Title: Investigating the Relationship Between Alpha, Beta, and Gamma Neurofeedback and Cognitive Performance to Predict Training Outcomes

Name: Rddhima Bora

Note Well: There are NO SHORT-cuts to reading journal articles and taking notes from them. Comprehension is paramount. You will most likely need to read it several times, so set aside enough time in your schedule.

Knowledge Gaps:

This list provides a brief overview of the major knowledge gaps for this project, how they were resolved and where to find the information.

Knowledge Gap	Resolved By	Information is located	Date resolved
How is brain activity collected?	Google search	https://bcn.iums.ac.ir/article-1-608-en.pdf	8/30/2025
What kind of software is used to analyze EEG data?	Discussion with Dr. C and peer	With Dr. C	12/5/2025
How is real-time feedback given during NFT?	Google search	https://pmc.ncbi.nlm.nih.gov/articles/PMC4892319/	12/7/2025
How do eyes open vs. closed make a difference in NFT outcomes?	Google search	https://www.nature.com/articles/s41598-021-99235-7	12/8/2025

Literature Search Parameters:

These searches were performed between (Start Date of reading) and XX/XX/2019.
List of keywords and databases used during this project.

Database/search engine	Keywords	Summary of search
WPI Library	Audio Neurofeedback	Found article #4
WPI Library	"self regulation" AND "neurofeedback training" AND "EEG"	Found article #11

Tags:

Tag Name	
#neurofeedback	#EEG
#predictors	#learning ability
#alphaband	#betaband
#selfregulation	

Article #0 Notes: Template

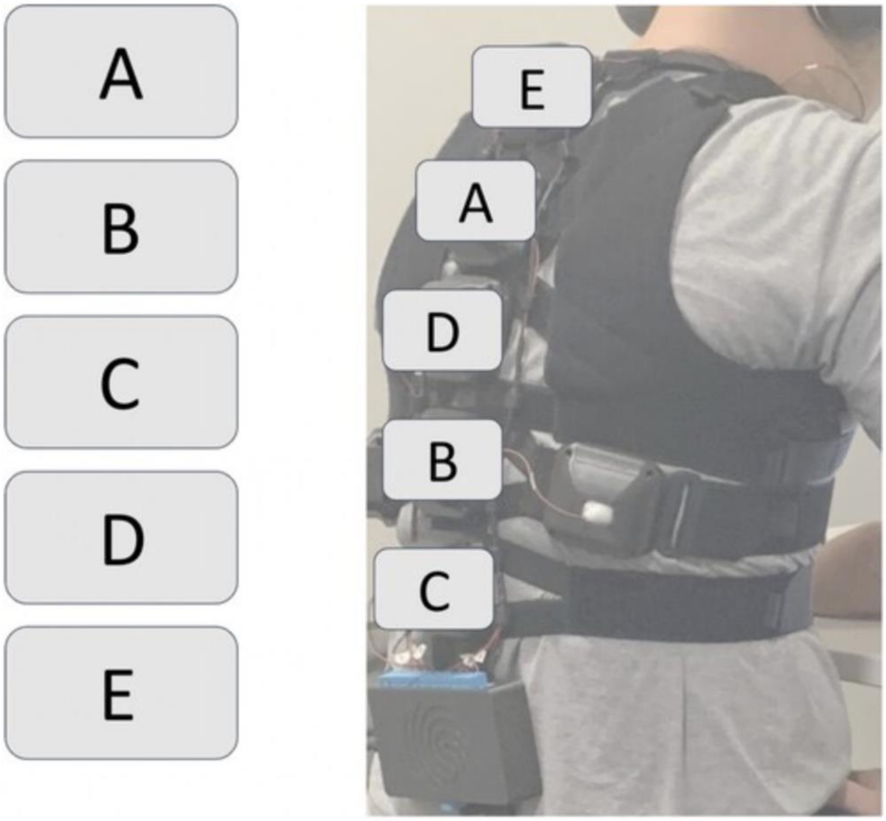
Article notes should be on separate sheets

KEEP THIS BLANK AND USE AS A TEMPLATE

Source Title	
Source citation (APA Format)	
Original URL	
Source type	
Keywords	
#Tags	
Summary of key points + notes (include methodology)	
Research Question/Problem/ Need	
Important Figures	
VOCAB: (w/definition)	
Cited references to follow up on	
Follow up Questions	

Article #1 Notes: Evaluation of audio-tactile congruences for a wearable musical interface

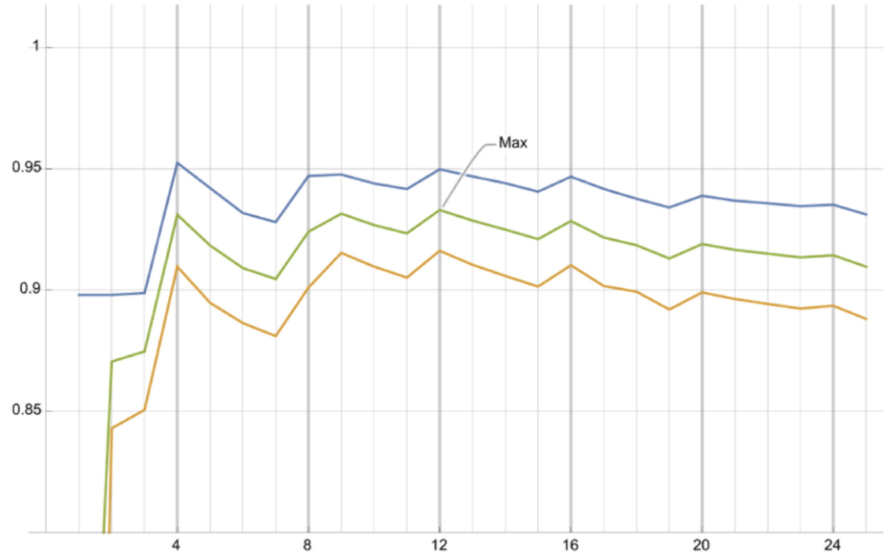
Source Title	Evaluation of audio-tactile congruences for a wearable musical interface
Source citation (APA Format)	Aker, S. C., Richards, C., Marozeau, J., Faux, D., & Misdariis, N. (2025). Evaluation of audio-tactile congruences for a wearable musical interface. *Journal of New Music Research*, 1–17. https://doi.org/10.1080/09298215.2025.2540440
Original URL	https://www.tandfonline.com/doi/full/10.1080/09298215.2025.2540440
Source type	Journal Article
Keywords	Tactile, Auditory, Stimuli, Correspondence, Musical enhancement
#Tags	
Summary of key points + notes (include methodology)	The study evaluates 21 participants wearing a tactile device and how they rated a sequence of audio stimuli (a few simple melodies). Researchers studied the correspondence between the device's tactile stimuli and the auditory stimuli. Results showed that timing and intensity of the tactile stimuli were strong suggestions of musical enhancement.
Research Question/Problem/ Need	How do individual differences (like musical backgrounds, tactile sensitivity, etc.) affect the participant's response to exposure of different audio-tactile stimuli? What impact would varying auditory stimuli have on the detected effectiveness of tactile stimuli? Different genres of music, complexity, tempo, etc. Can long-term exposure to audio-tactile stimuli give way to seeing new types of predictors for tactile musical enhancers?

Important Figures	
VOCAB: (w/definition)	• Neurofeedback: A technique that provides real-time feedback of brain activity (e.g. via EEG) to enable self-regulation of neural states. • Ambient Intelligence: Environments embedded with sensors, computing, and responsiveness to human presence and context. • Humanized Computing: Design of systems that adapt to human behaviors, preferences, or emotions. • Electroencephalography (EEG): Recording of electrical brain activity via electrodes on the scalp. • Band Power: The magnitude of EEG signal energy within a specific frequency band (e.g. alpha, beta). • Brain–Computer Interface (BCI): System enabling direct communication or control using brain activity signals. • Real-Time Feedback: Instantaneous feedback delivered to users based on their brain signals, used in training or adaptation. • Adaptive Algorithm: A method that adjusts its behavior or parameters based on input data or changing conditions. • Signal Processing: Techniques to filter, transform, and analyze raw neural signals to extract meaningful metrics. • Machine Learning Model: An algorithm that learns patterns from data to make predictions or decisions. • Feature Extraction: The process of selecting or computing relevant metrics (e.g. band powers, connectivity) from raw brain signals.

	• User-Centered Design: Designing systems with a focus on usability, user experience, and human needs. • Latency / Delay: The time lag between recording neural activity and producing feedback or system response. • Artifact Rejection / Correction: Techniques to remove noise (blinks, muscle movement) from EEG data. • Cognitive Load / Cognitive Demand: The mental effort required to perform a task, often reflected in EEG changes. • Personalization / Individualization: Tailoring system settings or protocols (e.g. target frequency bands) to each user.

Article #2 Notes: Modelling of Musical Perception using Spectral Knowledge Representation

Source Title	Modelling of Musical Perception using Spectral Knowledge Representation
Source citation (APA Format)	Homer, S. T., Harley, N., & Wiggins, G. A. (2024). Modelling of Musical Perception using Spectral Knowledge Representation. *Journal of Cognition*, *7*(1). https://doi.org/10.5334/joc.356
Original URL	https://journalofcognition.org/articles/10.5334/joc.356
Source type	Scientific publication
Keywords	Music perception, spectral analysis, key affinity, key distance, resonance, cognitive modelling, knowledge representation, Hilbert space, neural dynamics
#Tags	
Summary of key points + notes (include methodology)	The article introduces spectral knowledge representation, a novel approach for AI and cognitive modeling focused on the brain's oscillatory behavior. It says that resonances, which are literal representations of waves, describe the dynamics of neural assemblies processing perceived input. Resonances are mathematical structures like damped oscillators, suitable for modeling neural dynamics because they naturally arise from linearized dynamical systems near a stationary point, offering a physiologically plausible primitive. When applied to music perception, this model captures pitch and chord/key distances, aligning with empirical data from Krumhansl and Kessler. This model proposes that there is an underlying mechanism for music perception, which unifies key and chord differences and offers a computationally less demanding alternative to other dynamical models. This mechanism can also help form the base representation for the broader Information Dynamics of Thinking cognitive architecture.
Research Question/Problem/ Need	The need is to find a more biologically-inspired or neurally plausible way to represent perceptual and cognitive knowledge, especially in the domain of music perception.

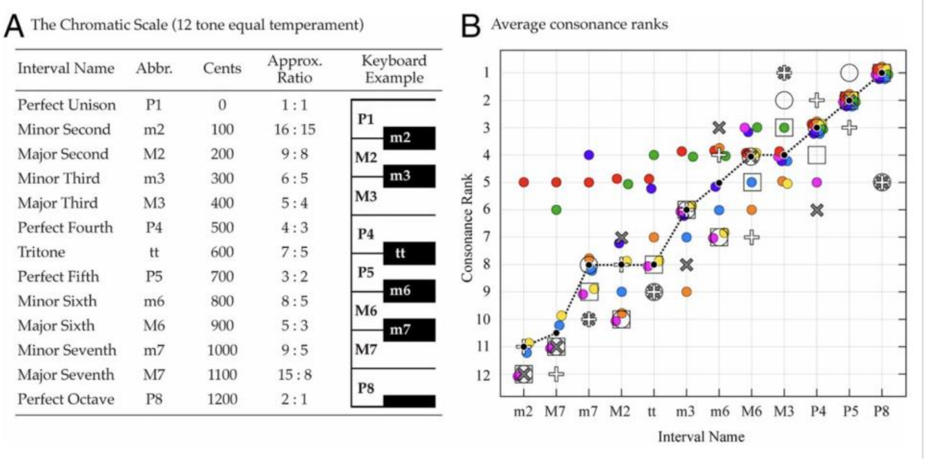
Important Figures	
VOCAB: (w/definition)	• Spectral Knowledge Representation: A modeling approach that uses literal wave / oscillatory representations to encode perceptual and cognitive information. • Oscillatory Neural Assemblies: Groups of neurons that produce rhythmic (wave-like) electrical activity, often associated with representing sensory or cognitive content. • Harmonic Distance: A measure of how “far apart” two pitches, chords, or keys are in musical space (often in perceived similarity). • Key Affinity / Key Distance: The perceived closeness or distance between musical keys (tonal centers). • Resonance: The phenomenon by which neural assemblies oscillate more strongly in response to input frequencies that match or harmonize with their natural (preferred) frequencies. • Hilbert Space: A mathematical space used in signal analysis and wave functions; essentially a vector space where waveforms can be represented and manipulated. • Toroidal Model: A geometric/topological model (a torus-like structure) that represents musical pitch and key relationships in a continuous, curved space. • Neural Dynamics: How the activity of neural populations evolves over time, especially with respect to oscillations, interactions, and transitions. • Cognitive Architecture: A theoretical model of how cognitive processes are organized, including how perception, prediction, memory, and representation interact. • Information Dynamics of Thinking (IDyOT): The larger framework within which spectral knowledge representation sits, proposing cognitive operations like segmentation, categorization, prediction, and abstraction.

Cited references to follow up on	• Krumhansl & Kessler’s work • Models my Milne et al. • IDyOT cognitive architecture
Follow up Questions	• How well does the spectral knowledge model generalize beyond harmonic music (e.g., to non-Western music, atonal, microtonal)? • Can this model account for temporal dynamics in music (rhythm, meter) as well as spectral (pitch, harmony)? • How might one test or validate this model empirically using neural data (e.g. EEG, MEG, intracranial recordings)? • What are the limitations or trade-offs of using literal wave representations for complex musical structure (e.g. complexity, computational cost)? • How might this spectral representation interface with other cognitive modules (e.g. memory, prediction, attention) in a full cognitive architecture?

Article #3 Notes: A biological rationale for musical consonance

Source Title	A biological rationale for musical consonance
Source citation (APA Format)	D.L. Bowling, & D. Purves. (2015). A biological rationale for musical consonance, *Proc. Natl. Acad. Sci. U.S.A*. 112 (36) 11155-11160, https://doi.org/10.1073/pnas.1505768112
Original URL	https://www.pnas.org/doi/10.1073/pnas.1505768112
Source type	Scientific journal
Keywords	Consonance, biology, music, audition, vocalization
#Tags	
Summary of key points + notes (include methodology)	The article examines musical consonance, considering mathematical, physical, and biological interpretations, and concludes that a biological rationale provides the most reasonable explanation. Consonance has been attributed to the mathematical simplicity of small integer ratios, though this theory struggled to explain why simplicity is pleasing. The scientific revolution shifted focus to physical explanations, most notably Hermann von Helmholtz's roughness theory, which proposed that consonance comes from the absence of "jarring" amplitude fluctuations caused by sound wave interference. The article also discusses an evolved attraction to the harmonic series that characterizes human vocalizations, arguing that our auditory system is uniquely tuned to process these biologically important social sound signals with special efficiency. This perspective suggests that the more voice-like a tone combination is, the more appealing it becomes, with research showing that popular musical intervals are statistically emphasized in vocal spectra and that preferred scales conform to uniform harmonic series. This biological framework relates to the topic of modeling musical perception by moving the focus from abstract mathematical principles or purely physical interactions to the evolutionary and biological aspects of human auditory processing.
Research Question/Problem/ Need	Why do certain combinations of tones sound pleasant, while others don't?

Important Figures



The Chromatic Scale (12 tone equal temperament)

Interval Name	Abbr.	Cents	Approx. Ratio
Perfect Unison	P1	0	1 : 1
Minor Second	m2	100	16 : 15
Major Second	M2	200	9 : 8
Minor Third	m3	300	6 : 5
Major Third	M3	400	5 : 4
Perfect Fourth	P4	500	4 : 3
Tritone	tt	600	7 : 5
Perfect Fifth	P5	700	3 : 2
Minor Sixth	m6	800	8 : 5
Major Sixth	M6	900	5 : 3
Minor Seventh	m7	1000	9 : 5
Major Seventh	M7	1100	15 : 8
Perfect Octave	P8	1200	2 : 1

Keyboard Example

VOCAB: (w/definition)

- Consonance: Perceptual pleasantness or stability of a combination of tones (e.g., octave, fifth).
-
- Dissonance: Perceptual roughness, tension, or instability in a tone combination (e.g., minor second).
-
- Harmonic series (overtones/partials): Frequencies that are integer multiples of a fundamental frequency; produce the timbre of voiced sounds.
- Harmonicity: Degree to which a sound's spectral components align with an ideal harmonic series (high harmonicity → often more consonant).
- Auditory roughness / beating: Rapid amplitude fluctuations from close spectral components interacting; associated with perceived dissonance.
- Critical band: The frequency bandwidth within which two tones interact strongly on the basilar membrane (important for roughness calculations).
- Spectral coincidence / overlap: The extent to which harmonics of two tones align (coincident harmonics usually increase perceived consonance).
- Equal temperament: The modern tuning system that divides the octave into 12 equal logarithmic steps (used to define the chromatic intervals shown in the paper).
- Dyad / triad / tetrad: Two-note, three-note, and four-note chords, respectively (used in the paper's stimulus sets).
- Voiced speech spectrum: The spectral energy patterns produced by human voiced sounds; the paper shows certain musical intervals are statistically prominent in voiced speech.

Cited references to follow up on

- Plomp & Levelt – tonal consonance and critical bandwidth
- Kameoka & Kuriyagawa – consonance theory
- Bowling – the nature of musical consonance

Follow up Questions

- Does the vocal-similarity hypothesis predict consonance preferences in

	cultures with very different vocal/music exposure (e.g., the Tsimane')? - What neural mechanisms would implement a "vocal-recognition" advantage — are there specific auditory cortical patterns that map between vocal spectra and consonance perception? - What are the implications for instrument design, composition, or music therapy if vocal-similarity drives consonance perception?

Article #4 Notes: Neuroscientists explore the intersection of music and memory

Source Title	Neuroscientists explore the intersection of music and memory
Source citation (APA Format)	Georgia Institute of Technology. (2024). Neuroscientists explore the intersection of music and memory. *ScienceDaily*. https://www.sciencedaily.com/releases/2024/08/240828224256.htm
Original URL	https://research.gatech.edu/feature/music-and-memory
Source type	Journal article
Keywords	Music, episodic memory, memory recollection, false memory, emotion, fMRI, amygdala
#Tags	
Summary of key points + notes (include methodology)	Neuroscientists at Georgia Institute of Technology led by Yiren Ren, a Ph.D. student, are exploring the significant intersection of music and memory, suggesting possible therapeutic applications for mental health. Their research, explained in two papers, looks at how music impacts both the formation of new memories and the emotional quality of existing ones. One study showed that familiar, more predictable music can increase concentration and learning by helping the brain make a framework for new information, while unfamiliar or irregular music can cause disruption. The second study discussed that music with stronger emotional notes can change the quality of existing memories, including ones connected with difficult experiences. In the study, participants who were reminded of tough memories while listening to film soundtracks added new emotions that matched the music, and this addition seemed long-lasting. This research indicates the flexibility of memory in response to music

	and that it has the ability to help individuals shift emotional tones attached to certain memories.
Research Question/Problem/ Need	How does music influence learning and memory?
VOCAB: (w/definition)	• Encoding: The process of forming a new memory (learning) by transforming sensory input into a storable neural code. • Recollection / Recall: The act of retrieving previously stored memories. • Affective / Emotional Tone: The emotional quality (positive, negative, neutral) associated with a memory. • Music Schema / Musical Structure: The organized, predictable patterns in melody, harmony, rhythm, which listeners internalize (schemas). • Familiar Music: Music known previously by the listener (melodies, rhythms) that aligns with their musical expectations. • Irregular / Atonal Music: Music that violates typical structure, melody, or harmonic expectations (less predictable). • Modulation: In this context, the influence or change induced (e.g. music modifying emotional tone of memory). • Scaffold (cognitive scaffold): Support structure in cognition into which new information can be integrated; here, structured music serving as a scaffold for learning. • fMRI (functional Magnetic Resonance Imaging): Brain imaging method that detects changes in blood flow to infer neural activity. • Amygdala: A brain region crucial in processing emotions, especially fear or negative affect, often implicated in emotional memory.
Cited references to follow up on	• doi.org/10.3758/s13415-024-01200-0
Follow up Questions	• Does the modulation of emotional tone by music during recollection generalize to clinical populations (e.g. PTSD, depression)? • Does the emotional shift in memory remain beyond a day or a couple of weeks? • How individual differences (e.g. musical training, age, baseline mood) moderate effects?

Article #5 Notes: Assessing the Effectiveness of Audio-Visual vs. Visual Neurofeedback for Attention Enhancement: A Pilot Study with Neurological, Behavioural, and Neuropsychological Measures

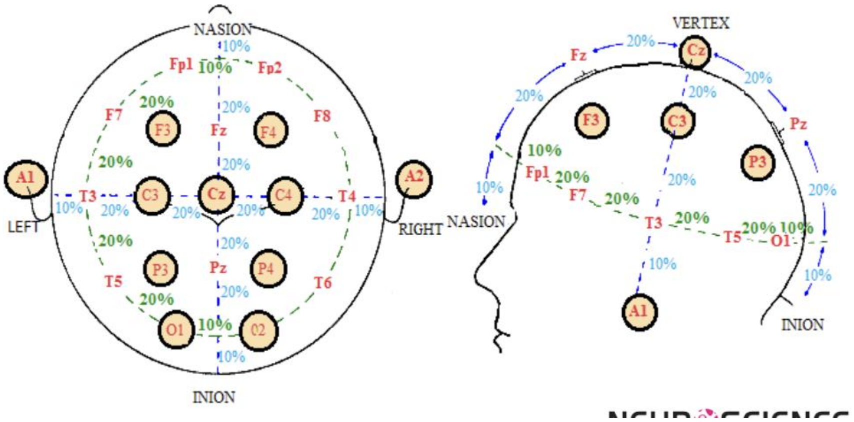
Source Title	Assessing the Effectiveness of Audio-Visual vs. Visual Neurofeedback for Attention Enhancement: A Pilot Study with Neurological, Behavioural, and Neuropsychological Measures
Source citation (APA Format)	Ejaz, O., Hasan, M.A., Raees, F. *et al.* (2025). Assessing the Effectiveness of Audio-Visual vs. Visual Neurofeedback for Attention Enhancement: A Pilot Study with Neurological, Behavioural, and Neuropsychological Measures. *Brain Topogr* **38**, 7. https://doi-org.ezpv7-web-p-u01.wpi.edu/10.1007/s10548-024-01076-w
Original URL	https://doi.org/10.1007/s10548-024-01076-w
Source type	Journal article
Keywords	Neurofeedback, Audiovisual stimulus, attention, EEG, MAAS, Stroop
#Tags	
Summary of key points + notes (include methodology)	The article investigates whether combining audio and visual feedback in neurofeedback training can more effectively improve attention compared to visual-only feedback. Neurofeedback is a technique that trains individuals to regulate their brain activity using real-time EEG signals, and this study aimed to determine whether adding an auditory component could enhance the process. Researchers divided 21 healthy participants into two groups: one receiving audiovisual feedback (G1) and the other visual-only feedback (G2). Both groups completed six neurofeedback sessions on alternating days. The neurofeedback targeted beta-band activity at the frontocentral EEG site FC5, a region associated with attention and cognitive control. Participants' progress was measured through EEG recordings, behavioural tasks (such as the Stroop test), and self-reported mindfulness scores. Results showed that the audiovisual group demonstrated a significant increase in global beta activity over the training period compared to the visual-only group. Further EEG analysis revealed that this group also exhibited improvements in more detailed neural dynamics: dwell time (how long the brain maintained a high-beta state), fractional occupancy (the

	proportion of time spent in that state), and transition probability (the likelihood of switching into that state) all increased significantly. These findings suggest stronger and more sustained engagement of attentional neural networks in participants who received audiovisual cues. Behaviorally, the audiovisual group outperformed the visual-only group on the Stroop task, showing both higher accuracy and faster reaction times, indicating enhanced attentional control and cognitive processing speed. Additionally, their mindfulness scores (MAAS-15) improved, suggesting that the benefits of training extended to broader aspects of cognitive awareness. The researchers concluded that multisensory (audio-visual) feedback can make neurofeedback training more effective and engaging, potentially leading to faster learning and stronger attention-related outcomes. However, they emphasized that consistent practice over multiple sessions remains essential to achieve lasting neural and behavioural changes. Overall, the study highlights how integrating multiple sensory modalities into neurofeedback may improve both neural efficiency and cognitive performance.
Research Question/Problem/ Need	Does combining auditory and visual feedback lead to greater improvements in attention and related brain activity compared to visual feedback alone?
VOCAB: (w/definition)	• Neurofeedback (NF): A brain-training technique that provides real-time feedback on brain activity to help individuals learn to regulate it. • Electroencephalography (EEG): A method for recording the brain’s electrical activity using sensors placed on the scalp. • Beta Activity / Beta Band: A range of brainwave frequencies (13–30 Hz) associated with focus, alertness, and active thinking. • Frontocentral Region (FC5): A specific EEG electrode site near the front-left area of the head, linked to attention and cognitive control. • Audio-Visual Feedback: Feedback that combines both sound and visual cues to show how well a person is controlling their brain activity. • Visual Feedback: Feedback presented only through visuals, such as graphs, animations, or color changes. • Global Beta Power: The overall level of beta-wave activity across the brain. • EEG State Dynamics: The patterns and timing of how brain activity changes over time. • Dwell Time: The average amount of time the brain stays in a particular EEG state. • Fractional Occupancy: The percentage of total time the brain spends in a specific EEG state. • Transition Probability: The likelihood that the brain will shift from

	one EEG state to another. - Stroop Task: A psychological test that measures attention and cognitive control by requiring participants to name the color of a word rather than the word itself. - MAAS-15 (Mindful Attention Awareness Scale): A questionnaire that measures how mindful and aware a person is of the present moment. - Pilot Study: A small, preliminary version of a study designed to test methods and gather initial results before a larger experiment. - T-test: A statistical test used to compare the averages of two groups to see if they differ significantly. - P-value: A measure of statistical significance; values below 0.05 indicate that results are unlikely to be due to chance.

Article #6 Notes: Neurofeedback: A Comprehensive Review on System Design, Methodology and Clinical Applications

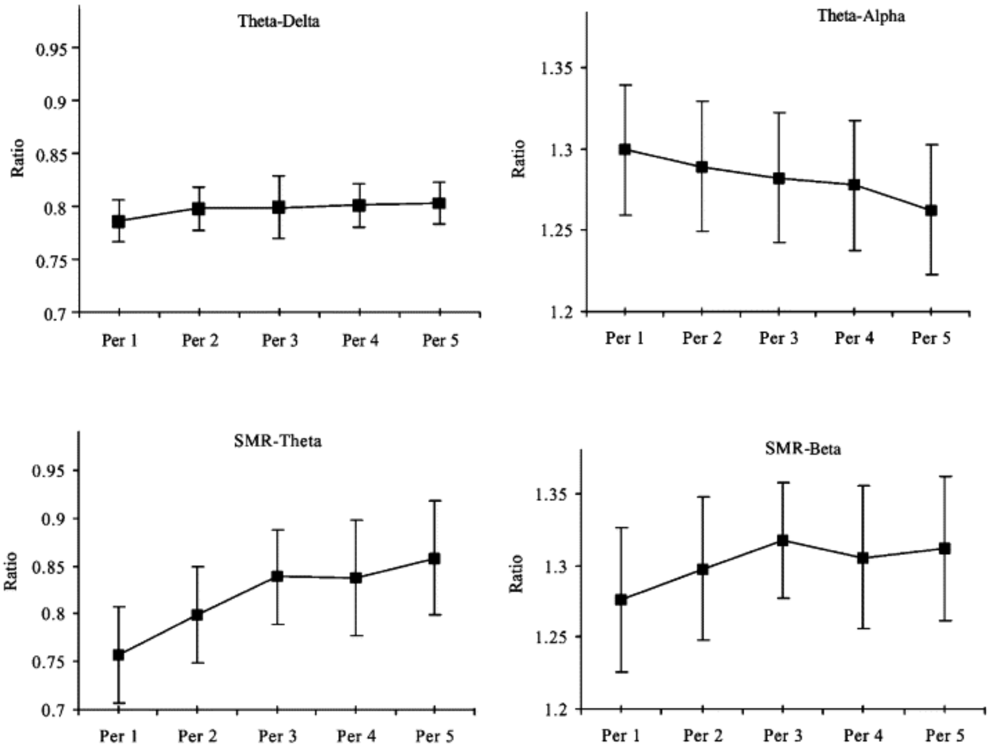
Source Title	Neurofeedback: A Comprehensive Review on System Design, Methodology and Clinical Applications
Source citation (APA Format)	Marzbani, H., Marateb, H. R., & Mansourian, M. (2016). Neurofeedback: A Comprehensive Review on System Design, Methodology and Clinical Applications. *Basic and clinical neuroscienc*e, 7(2), 143–158. https://doi.org/10.15412/J.BCN.03070208
Original URL	https://pmc.ncbi.nlm.nih.gov/articles/PMC4892319/
Source type	Journal article
Keywords	Brain diseases, Brain waves, Complementary therapies, Electroencephalography, Neurofeedback
#Tags	
Summary of key points + notes (include methodology)	The article provides a detailed overview of how neurofeedback works, how systems are designed, and where it is applied. Neurofeedback is explained as a noninvasive brain-training method that uses real-time EEG feedback to help individuals learn to control their brain activity. The authors describe different EEG frequency bands—delta, theta, alpha, beta, and gamma—and explain how each is targeted in various training protocols to improve mental states such as focus, relaxation, or creativity. Methodologically, the review outlines how neurofeedback systems are built using electrodes (following the 10–20 EEG placement system), amplifiers, signal processing software, and feedback interfaces that can be visual, auditory, or both. The paper discusses several types of neurofeedback, including frequency/power-based training, slow cortical potentials (SCP), hemoencephalographic feedback (HEG), LORETA-based training, and real-time fMRI neurofeedback, noting that each method targets different neural mechanisms. Clinically, neurofeedback has been used to treat ADHD, anxiety, depression, epilepsy, autism, and insomnia, and has also been applied to performance enhancement in athletes and professionals. However, the authors highlight key challenges: neurofeedback can be time-consuming, costly, and its results vary between individuals. The field also suffers from methodological

	inconsistencies, such as differing electrode placements and feedback designs, which make it difficult to compare results across studies.
Research Question/Problem/ Need	How are neurofeedback systems designed and applied across clinical and cognitive domains? What methodological factors influence their effectiveness?
Important Figures	
VOCAB: (w/definition)	- Frequency Bands: Categories of brainwave activity measured in hertz (Hz), including delta, theta, alpha, beta, and gamma. - Delta Waves (0.5–4 Hz): Associated with deep sleep and restorative processes. - Theta Waves (4–8 Hz): Linked to drowsiness, relaxation, and creativity. - Alpha Waves (8–12 Hz): Related to calm focus and relaxed alertness. - Beta Waves (13–30 Hz): Associated with active thinking, concentration, and attention. - Gamma Waves (>30 Hz): Linked to higher-level cognition, memory, and information integration. - Electrode Placement (10–20 System): Standardized positions on the scalp for EEG measurement. - Montage: The configuration of EEG electrodes, either unipolar (referenced to a single point) or bipolar (between two points). - SCP (Slow Cortical Potentials) Neurofeedback: A type of neurofeedback targeting slow voltage shifts in the brain to improve self-regulation. - HEG (Hemoencephalographic Feedback): Neurofeedback using blood flow or oxygenation measures to guide training. - LORETA Neurofeedback: 3D neurofeedback that targets deeper brain regions based on source localization of EEG signals. - Real-Time fMRI Neurofeedback: Uses brain imaging to provide feedback about regional brain activity in real time. - Alpha/Theta Training: Neurofeedback protocol aimed at balancing alpha and theta waves, often used for stress reduction and relaxation.

	• SMR (Sensorimotor Rhythm): Beta-range brainwaves (around 12–15 Hz) used in neurofeedback to enhance focus and reduce hyperactivity. • Pilot Study: A small-scale preliminary study used to test the feasibility and methodology of research.
Cited references to follow up on	• Patil et al. (2023) • Vernon et al. (2005) • Weber et al. (2020) • Wider et al. (2024) • Dehghani et al. (2020) • Dehghani et al. (2022) • https://www.sciencedirect.com/science/article/pii/S0167876002000910
Follow up Questions	• How do different electrode montages (unipolar vs. bipolar) affect neurofeedback outcomes? • Which EEG frequency bands are most effective for improving attention, and does this vary by age or condition? • How does the type of feedback (visual, auditory, or combined) influence learning speed and retention? • Are there optimal session lengths or training schedules for maximizing neurofeedback effectiveness? • How consistent are neurofeedback effects across disorders such as ADHD, anxiety, and depression? • What factors predict individual variability in neurofeedback outcomes? • Can neurofeedback be effectively combined with other therapies (e.g., CBT, medication)? • How durable are the effects of neurofeedback—do benefits persist months or years after training? • What standardized protocols could be developed to reduce variability in neurofeedback studies? • How can emerging technologies (LORETA, real-time fMRI, connectivity-based NF) improve training precision? • What ethical considerations arise when applying neurofeedback for cognitive or performance enhancement in healthy individuals? • How can large-scale, controlled trials be designed to provide stronger evidence for neurofeedback efficacy?

Article #7 Notes: The effect of training distinct neurofeedback protocols on aspects of cognitive performance

Source Title	The effect of training distinct neurofeedback protocols on aspects of cognitive performance
Source citation (APA Format)	Vernon, D., Egner T., Cooper N., Compton T., Neilands C., Sheri A., Gruzelier J. (2003). The effect of training distinct neurofeedback protocols on aspects of cognitive performance, International Journal of Psychophysiology, 47(1), 75-85, https://doi.org/10.1016/S0167-8760(02)00091-0.
Original URL	https://doi.org/10.1016/S0167-8760(02)00091-0
Source type	Journal article
Keywords	Neurofeedback; Cognitive performance; Sensorimotor rhythm
#Tags	
Summary of key points + notes (include methodology)	The article examines how different types of neurofeedback (NF) training influence brainwave activity and cognitive performance. The researchers aimed to determine whether training specific EEG frequency bands, particularly the sensorimotor rhythm (SMR; 12–15 Hz), could lead to measurable improvements in attention, reaction time, and executive function. Their findings showed that participants who trained with the SMR protocol successfully increased SMR activity after eight training sessions, demonstrating that neurofeedback can selectively enhance targeted brainwave frequencies. This neural improvement was accompanied by better performance on cognitive tasks, particularly in measures of attention and reaction speed, suggesting a link between SMR regulation and cognitive control. The methodology involved dividing participants into groups, each trained using different neurofeedback protocols. Over eight sessions, participants received real-time EEG feedback to learn how to modulate specific frequency bands. The SMR group focused on increasing power in the 12–15 Hz range, while comparison groups trained other frequency ranges. Cognitive performance was assessed before and after training using standardized reaction-time and attention-based tasks. EEG recordings were analyzed to confirm whether participants had successfully modulated their target brainwave activity. The results indicated that only the SMR-trained group showed both a significant rise in SMR power and corresponding cognitive gains. Overall, the study provides evidence that neurofeedback training can produce frequency-specific changes in brain activity that transfer to improvements in

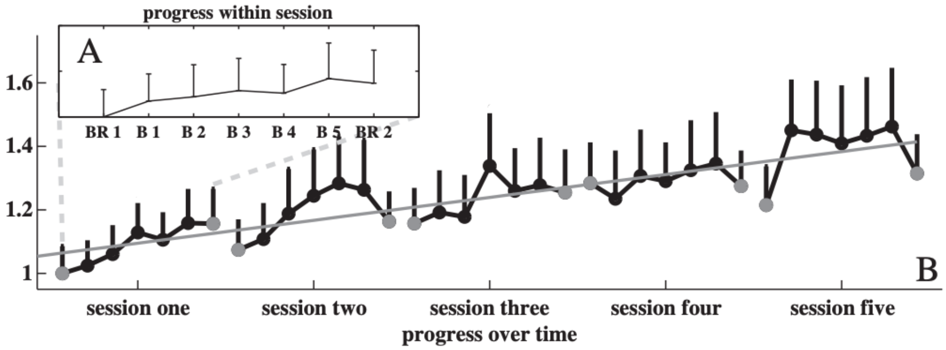
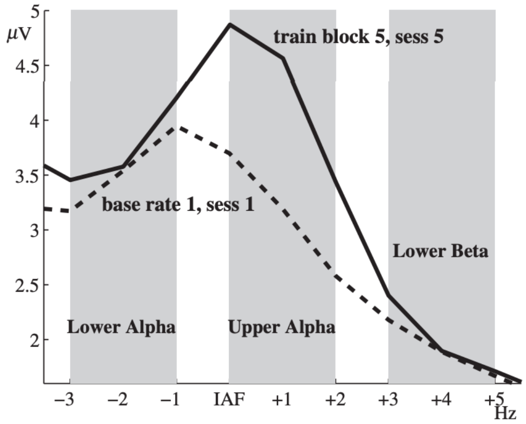
	certain aspects of cognition. However, the authors note that the relatively short training duration and small sample size limit the generalizability of the findings. They recommend further research with more sessions and larger participant groups to better understand how different neurofeedback protocols affect cognitive performance and neural plasticity.
Research Question/Problem/ Need	Do different neurofeedback training protocols, particularly those targeting the sensorimotor rhythm (SMR), lead to specific changes in brainwave activity and corresponding improvements in cognitive functioning?
Important Figures	
VOCAB: (w/definition)	• Neuroregulation: The process of training the brain to change its activity patterns through feedback and reinforcement. • Cognitive Performance: The efficiency and accuracy with which mental processes such as attention, memory, and problem-solving are carried out. • Sensorimotor Rhythm (SMR): A brainwave frequency range (about 12–15 Hz) recorded over the sensorimotor cortex; linked to calm, focused alertness and reduced motor activity. • Frequency Band: A specific range of EEG wave frequencies (measured in hertz) associated with different mental and neural states. • Amplitude: The strength or power of a brainwave signal within a particular frequency band. • Power Spectral Density (PSD): A measure of how power (signal strength) is distributed across different frequencies in EEG data. • Baseline Measurement: Initial data recorded before an intervention or training, used as a reference for later comparisons.

	• Feedback Loop: The process in which brain activity is measured and immediately displayed to the participant, allowing them to adjust and improve regulation in real time. • Artifact Rejection: The removal of unwanted electrical noise from EEG signals, such as muscle movement or blinking. • Protocol Specificity: The concept that different neurofeedback training protocols (e.g., SMR vs theta) may lead to distinct neurophysiological and behavioral effects. • Transfer Effects: Improvements in performance on tasks outside of the training itself, showing generalization of learned brain regulation skills. • Attention Network: A collection of brain regions responsible for controlling focus, alertness, and the allocation of cognitive resources. • Executive Function: Higher-level cognitive processes involved in goal-directed behavior, such as planning, inhibition, and working memory. • Reinforcement Mechanism: The reward or feedback provided during neurofeedback to encourage the participant to maintain desired brain activity. • Between-Group Comparison: A statistical method used to determine differences in outcomes between separate experimental groups.
Cited references to follow up on	• Gruzelier, J. (2006). • Vernon, D. J. (2005). Can neurofeedback training enhance performance? • Kober, S. E., et al. (2015). An SMR neurofeedback training study — Investigates the effects of SMR neurofeedback training (12–15 Hz) on cognition.
Follow up Questions	• How long do the cognitive and EEG changes from SMR neurofeedback training last after the sessions end? • Would a longer training period (more than eight sessions) lead to stronger or more consistent cognitive improvements? • How does SMR training compare to other neurofeedback protocols (e.g., theta/beta or alpha/theta) in improving attention and memory? • Are there differences in how individuals respond to neurofeedback based on age, baseline EEG patterns, or cognitive ability? • Can combining neurofeedback with behavioral or cognitive training enhance results more than neurofeedback alone? • What neural mechanisms link SMR enhancement to improvements in reaction time and executive functioning? • How do placebo effects or expectations influence neurofeedback outcomes? • Would using more advanced imaging techniques (like fMRI or LORETA EEG) provide deeper insights into how neurofeedback changes brain networks? • How specific are the effects of neurofeedback—do they generalize to unrelated cognitive tasks or remain task-specific? • What are the ethical and practical implications of using neurofeedback for

	performance enhancement rather than clinical treatment?

Article #8 Notes: Neurofeedback training of the upper alpha frequency band in EEG improves cognitive performance

Source Title	Neurofeedback training of the upper alpha frequency band in EEG improves cognitive performance
Source citation (APA Format)	Zoefel, B., Huster, A. J., & Herrmann, C. S. (2011). Neurofeedback training of the upper alpha frequency band in EEG improves cognitive performance, *NeuroImage*, 54(2), 1427-1431, https://doi.org/10.1016/j.neuroimage.2010.08.078.
Original URL	https://www.sciencedirect.com/science/article/pii/S105381191001181X?via%3Dihub
Source type	Journal article
Keywords	Neurofeedback, EEG, upper alpha, trainability, cognitive performance, mental rotation
#Tags	
Summary of key points + notes (include methodology)	The study investigates whether individuals can learn to increase their upper alpha EEG activity through neurofeedback training and whether this change translates into cognitive improvement. The researchers hypothesized that training participants to self-regulate their upper alpha rhythm—an individualized frequency range associated with memory and attention—would enhance performance on mental and memory tasks. Participants underwent several neurofeedback sessions where they received real-time visual feedback of their brain activity and were encouraged to raise their upper alpha power. EEG data were recorded and analyzed to determine whether alpha power increased over time, and participants completed cognitive tests before and after training to assess behavioral effects. Results showed that most participants successfully increased their upper alpha amplitude across sessions, and those who did demonstrated improvements in cognitive performance, particularly in tasks involving mental rotation and short-term memory. The findings suggest that individualized neurofeedback in the upper alpha band can strengthen cognitive function by promoting better self-regulation of brain activity.
Research Question/Problem/ Need	Can individuals learn to self-regulate their upper alpha EEG activity through neurofeedback, and does this regulation lead to measurable improvements in cognitive performance?

Important Figures	 
VOCAB: (w/definition)	- Upper Alpha Band: The higher sub-range of the alpha frequency band (often ~10–12 Hz or subject-specific), associated with cognitive idling or top-down inhibitory control. - Spectral Power / Band Power: The magnitude of EEG signal energy in a given frequency band (e.g. upper alpha) over time. - Artifact Correction / Artifact Rejection: Methods to remove or reduce noise in EEG (e.g. from eye movements, muscle activity) before spectral analysis. - Baseline EEG / Resting State: EEG measurement taken before any training or manipulation, used to calibrate or compare later changes. - Transfer Effect: Improvement in cognitive tasks (not directly trained) following neurofeedback training, implying generalization of learned regulation. - Sham Feedback: A control condition in neurofeedback where the feedback given is not contingent on the subject’s actual brain activity (used to control for placebo). - Within-Subject Design: An experimental design in which the same participants are measured repeatedly (e.g. before, during, after training). - Correlation / Regression Analysis: Statistical methods to examine whether change in EEG measure (upper alpha power) predicts change in behavioral performance. - Spectral Analysis / FFT (Fast Fourier Transform): Algorithm to convert time-domain EEG signals into frequency-domain components (used to

	compute band powers). - Operant Conditioning: In this context, the learning principle that participants are rewarded (via feedback) when their brain activity moves toward a target (increasing upper alpha).
Cited references to follow up on	- Klimesch, W. - EEG alpha & theta oscillations reflecting cognitive and memory performance - Egner et al. - effect of training neurofeedback protocols - Hanslmayr et al. - oscillatory power decreases and long-term memory
Follow up Questions	- Can combining upper alpha neurofeedback with other cognitive training or stimulation enhance effects? - How stable is an individual's "upper alpha band" over time? Could the definition shift and affect training efficacy?

Article #9 Notes: EEG Biofeedback of low beta band components: frequency-specific effects on variables of attention and event-related brain potentials

Source Title	EEG Biofeedback of low beta band components: frequency-specific effects on variables of attention and event-related brain potentials
Source citation (APA Format)	Egner, T, Gruzelier, J.H. (2004). EEG Biofeedback of low beta band components: frequency-specific effects of variables of attention and event-related brain potentials, Clinical Neurophysiology, 115(1), 131-139, https://doi.org/10.1016/S1388-2457(03)00353-5.
Original URL	https://www.sciencedirect.com/science/article/pii/S1388245703003535?via%3Dihub

Source type	Journal article
Keywords	EEG biofeedback, neurofeedback, beta1 activity, sensorimotor rhythm, attention, P300
#Tags	
Summary of key points + notes (include methodology)	Egner (2004) conducted a study to investigate the effects of neurofeedback training on the low beta frequency band in healthy individuals. Participants underwent EEG biofeedback sessions aimed at increasing their low beta power. The study utilized a within-subject design, where each participant served as their own control, ensuring that observed effects were attributable to neurofeedback intervention. Cognitive performance was assessed using tasks that measure attention and memory. Results indicated that participants who successfully increased their low beta activity showed significant improvements in cognitive performance, suggesting that targeted neurofeedback can modulate brain activity and enhance specific cognitive functions.
Research Question/Problem/ Need	Can neurofeedback training targeting the low beta (β1) frequency band enhance cognitive performance in healthy individuals?
VOCAB: (w/definition)	• EEG Biofeedback (Neurofeedback): A technique that trains individuals to alter their brainwave activity through real-time feedback. • Low Beta Band (β1): A frequency range in EEG (13–18 Hz) associated with active thinking and problem-solving. • SMR (Sensorimotor Rhythm): A type of brainwave activity (12–15 Hz) linked to relaxed alertness and motor control. • Cognitive Performance: The ability to perform tasks that require attention, memory, and problem-solving skills. • Within-Subject Design: An experimental design where the same participants are exposed to all conditions, allowing for direct comparison of effects. • Protocol-Specific Effects: Outcomes that are directly related to the specific neurofeedback training protocol used.
Cited references to follow up on	• Hammond, D. C. - neurofeedback with anxiety and affective disorders
Follow up Questions	• How does low beta neurofeedback training affect individuals with cognitive impairments or neurological disorders? • Do the cognitive enhancements observed persist over time without continued neurofeedback training?

Article #10 Notes: Double-Blind Single-Session Neurofeedback Training in Upper-Alpha for Cognitive Enhancement of Healthy Subjects

Source Title	Double-Blind Single-Session Neurofeedback Training in Upper-Alpha for Cognitive Enhancement of Healthy Subjects
Source citation (APA Format)	Escolano, C., Olivan, B., Lopez-del-Hoyo, Y., Garcia-Campayo J., and Minguez, J. (2019). Double-blind single-session neurofeedback training in upper-alpha for cognitive enhancement of healthy subjects, *2012 Annual International Conference of the IEEE Engineering in Medicine and Biology Society*, 4643-4647, https://doi.org/10.1109/EMBC.2012.6347002.
Original URL	https://ieeexplore.ieee.org/document/6347002/authors#authors
Source type	Journal article
Keywords	Noise measurement, Training, Electroencephalography, Psychology, Oscillators, Neurofeedback, Batteries
#Tags	
Summary of key points + notes (include methodology)	The study “Double-Blind Single-Session Neurofeedback Training in Upper-Alpha for Cognitive Enhancement of Healthy Subjects” by Escolano et al. (2012) examines whether a single session of upper-alpha neurofeedback training can enhance cognitive performance in healthy individuals. The researchers used a double-blind, sham-controlled design to ensure that any observed effects were due to true neurofeedback rather than placebo influences. Nineteen participants were divided into two groups: one received real-time EEG feedback based on their own upper-alpha (UA) activity—an individualized frequency band linked to attention and working memory—while the control group received sham feedback unrelated to their brain activity. Training occurred over a single 25-minute session, divided into five 5-minute trials, where participants attempted to increase their upper-alpha power at parieto-occipital sites (P3, Pz, P4, O1, O2). Before and after training, participants completed a series of **cognitive and psychological tests**—including mental rotation, PASAT, RAVLT, Stroop, and TMT—to assess changes in attention, memory, and executive function. The results showed that only the real neurofeedback group achieved a significant **increase in upper-alpha power** and greater **alpha desynchronization** during cognitive tasks, suggesting enhanced neural engagement. Behaviorally, this

	group also demonstrated **improvements in working memory and mental rotation performance**, though not all changes reached statistical significance. These findings indicate that even a single session of individualized upper-alpha neurofeedback can induce measurable neurophysiological changes and modest cognitive benefits. However, the authors note that more robust and lasting effects likely require multiple training sessions and larger participant samples. Overall, the study provides preliminary evidence that upper-alpha neurofeedback can serve as a short-term method for cognitive enhancement in healthy adults.
Research Question/Problem/ Need	Can a session of individualized upper-alpha neurofeedback training enhance alpha power and improve cognitive performance in healthy individuals?
Important Figures	
VOCAB: (w/definition)	• Alpha Modulation: The process of intentionally increasing or decreasing alpha brainwave activity through training or task engagement. • Cognitive Enhancement: The improvement of mental functions such as memory, attention, or problem-solving through interventions like neurofeedback or brain stimulation. • EEG Channel: A single electrode or recording site used to measure brain activity from a specific scalp location (e.g., Pz, O1, O2). • Spectral Analysis: A method for decomposing EEG signals into their frequency components to identify power levels within different bands (like alpha or beta). • Power Ratio: The proportion of EEG power within a specific frequency band relative to total EEG power, used to assess how strongly a band dominates brain activity. • Feedback Signal: The real-time visual or auditory indicator (such as a moving bar or colored square) that reflects the participant's brain activity level. • Artifact Removal: The process of cleaning EEG data by filtering out noise from eye movements, blinks, or muscle tension that can distort measurements. • Event-Related Potential (ERP): Time-locked EEG responses to a specific event or stimulus, reflecting neural processing stages. • Cognitive Workload: The mental effort required to perform a task, often linked to changes in EEG patterns (e.g., alpha suppression during high effort). • Placebo Response: Behavioral or physiological changes that result from participants' expectations rather than the actual neurofeedback manipulation. • Task Engagement: The degree of active participation and mental focus a person maintains during a cognitive activity or feedback session.

	• Neuroplasticity: The brain’s ability to reorganize itself by forming new neural connections, which can underlie learning effects from neurofeedback training. • Electrode Montage: The configuration or layout of EEG electrodes across the scalp, chosen to target specific brain regions. • Latency: The time delay between the presentation of a stimulus and the corresponding neural or behavioral response. • Psychophysiology: The study of how physiological processes (like brain or heart activity) relate to psychological phenomena (like cognition or emotion).
Cited references to follow up on	• Klimesch, W. (1999). EEG alpha and theta oscillations reflect cognitive and memory performance. Brain Research Reviews. • Hanslmayr et al. (2005). Increasing individual upper alpha power by neurofeedback improves cognitive performance. Applied Psychophysiology & Biofeedback.
Follow up Questions	• Would multiple sessions of upper-alpha neurofeedback yield stronger or longer-lasting cognitive improvements? • How does individual variability in baseline alpha activity affect neurofeedback learning success? • Can optimizing feedback type (visual, auditory, haptic) improve training effectiveness?

Article #11 Notes: Predictors of neurofeedback training outcome: A systematic review

Source Title	Predictors of neurofeedback training outcome: A systematic review
Source citation (APA Format)	Weber, L. A., Ethofer, T., & Ehlis, A.-C. (2020). Predictors of neurofeedback training outcome: A systematic review. *NeuroImage: Clinical*, *27*, 102301. https://doi.org/10.1016/j.nicl.2020.102301
Original URL	https://www.sciencedirect.com/science/article/pii/S2213158220301388?via%3Dihub
Source type	Journal Article
Keywords	Neurofeedback; EEG; Predictors; Brain structure; Brain-computer interface; fMRI; Review; Psychological factors; Neuroanatomical parameters
#Tags	
Summary of key points + notes (include methodology)	• There are large differences in NFT for individuals ○ NFT has high variability across different individuals ○ Around 30-50% of participants are “non-responders” • Early EEG changes can predict long-term outcomes ○ Performance during the first few NFT sessions can be some of the strongest predictors of final outcomes • Alpha is the strongest predictive evidence. ○ Specifically upper-alpha power and modulation ability predict memory and attention improvements • Beta and gamma predictors is also emerging, but less established ○ Potential research gap? • One-size does not fit all for NFT, so adaptive protocols based on early EEG responses is recommended.
Research Question/Problem/ Need	Which neurophysiological and behavioral factors predict successful neurofeedback learning and outcomes?
Important Figures	N/A
VOCAB: (w/definition)	• Responder / Non-responder: Individuals who show significant improvement vs. little or no improvement from NFT. • Baseline EEG: Brain activity recorded before training begins. • Trainability: A person’s ability to successfully modulate brain activity through NFT. • Learning Curve: The trajectory of EEG modulation improvement across sessions. • Biomarker: A measurable biological signal used to predict outcomes.

	• Resting-State EEG: Brain activity measured when a participant is not performing a task.
Cited references to follow up on	• Wan, F., Nan, W., Vai, M.I., Rosa, A., 2014. Resting alpha activity predicts learning ability in alpha neurofeedback. https://doi.org/10.3389/fnhum.2014.005 • https://www.frontiersin.org/journals/human-neuroscience/articles/10.3389/fnhum.2013.00695/full ○ https://www.frontiersin.org/journals/human-neuroscience/articles/10.3389/fnhum.2013.00453/full
Follow up Questions	• Can early-session beta and gamma EEG changes predict NFT outcomes as similar to alpha? • How many NFT sessions can be used to reliably classify responders and non-responders? • Are the predictive markers the same across healthy and clinical subjects?

Article #12 Notes: Resting alpha activity predicts learning ability in alpha neurofeedback

Source Title	Resting alpha activity predicts learning ability in alpha neurofeedback
Source citation (APA Format)	
Original URL	Wan, F., Nan, W., Vai, M.I., Rosa, A., (2014). Resting alpha activity predicts learning ability in alpha neurofeedback. *Front. Hum. Neurosci*. 8, 500. https://doi.org/10.3389/ fnhum.2014.00500.
Source type	Journal Article
Keywords	Neurofeedback, prediction, learning ability, alpha band, resting baseline
#Tags	
Summary of key points + notes (include methodology)	• Participants: 25 healthy adults • EEG Recording: ○ Resting EEG collected with eyes open and eyes closed ○ Training targets each subject's individual alpha frequency band • Training Setup: ○ 3D objects (sphere + cube) provided real-time feedback. • Participants tried to increase relative alpha amplitude. • Learning Indices (3 types): ○ Change from Session 1 to Session 20 (L1) ○ Within-day improvements (L2) ○ Overall learning slope across all sessions (L3) • Study aimed to investigate if resting alpha activity measured before training was related to the learning ability in alpha NFT and if it could be used as a predictor.
Research Question/Problem/ Need	Can a person's resting alpha activity predict their ability to learn and improve during alpha neurofeedback training?

Important Figures

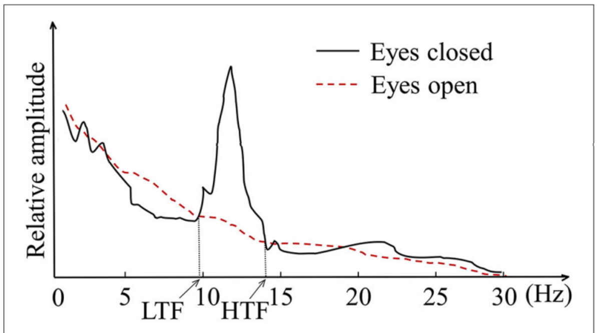


FIGURE 1 | The illustration of individual alpha frequency band.

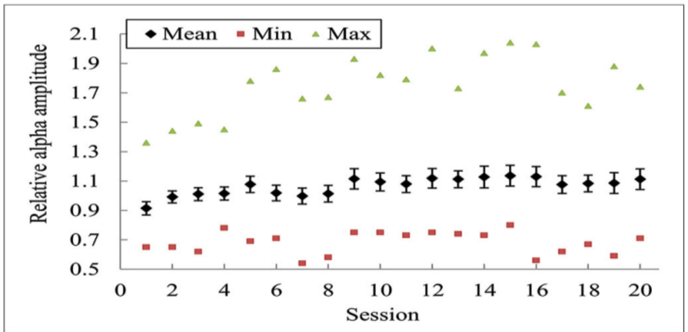


FIGURE 3 | The mean (± its standard error) of alpha amplitude across all subjects as well as the minimum and maximum values in each training session. The bars indicate the standard error of the mean.

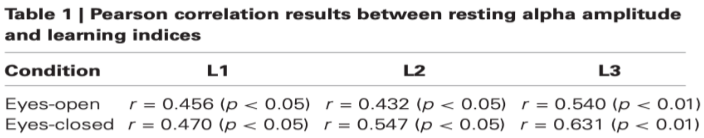


Table 1 | Pearson correlation results between resting alpha amplitude and learning indices

Condition	L1	L2	L3
Eyes-open	$r = 0.456$ ($p < 0.05$)	$r = 0.432$ ($p < 0.05$)	$r = 0.540$ ($p < 0.01$)
Eyes-closed	$r = 0.470$ ($p < 0.05$)	$r = 0.547$ ($p < 0.05$)	$r = 0.631$ ($p < 0.01$)

VOCAB: (w/definition)

N/A

Cited references to follow up on

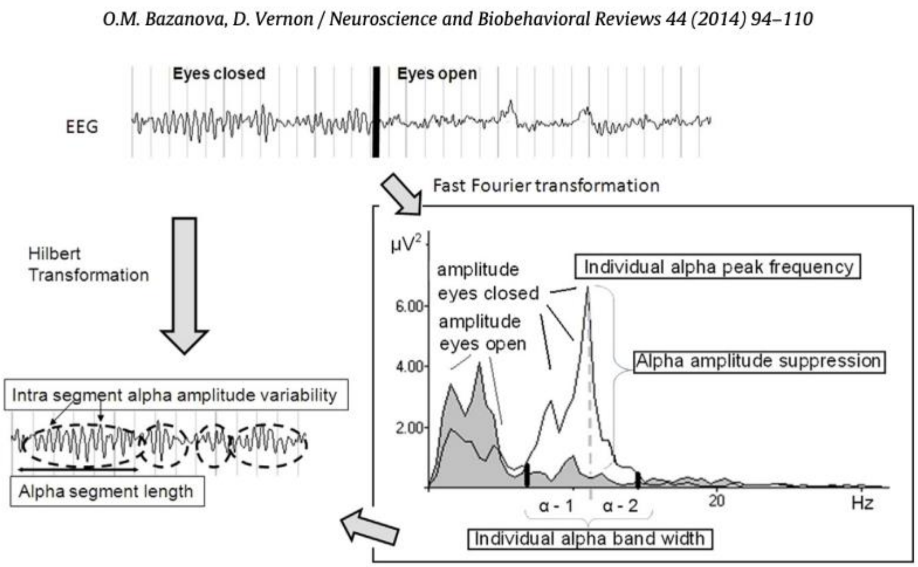
https://www.sciencedirect.com/science/article/abs/pii/S0149763413002248
https://doi.org/10.1016/j.neuroimage.2010.03.022
https://karger.com/nps/article-abstract/63/1/43/233401/Is-Alpha-Wave-Neurofeedback-Effective-with?redirectedFrom=fulltext
https://www.sciencedirect.com/science/article/abs/pii/S0149763413001279

Follow up Questions

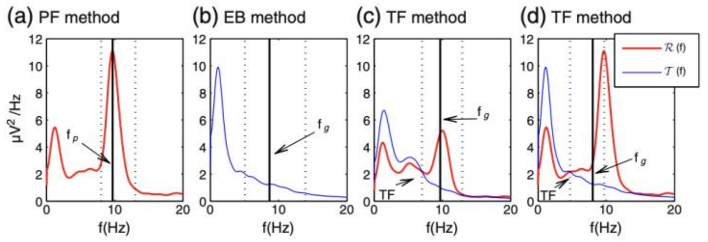
- How stable are resting alpha predictors over time, and would repeated baseline EEG measurements improve prediction accuracy?
- Would combining baseline alpha power with early-session learning slopes provide a stronger predictor of neurofeedback success than just baseline measures?
- How early in training can reliable predictions be made, and is one session sufficient or are multiple early sessions required?

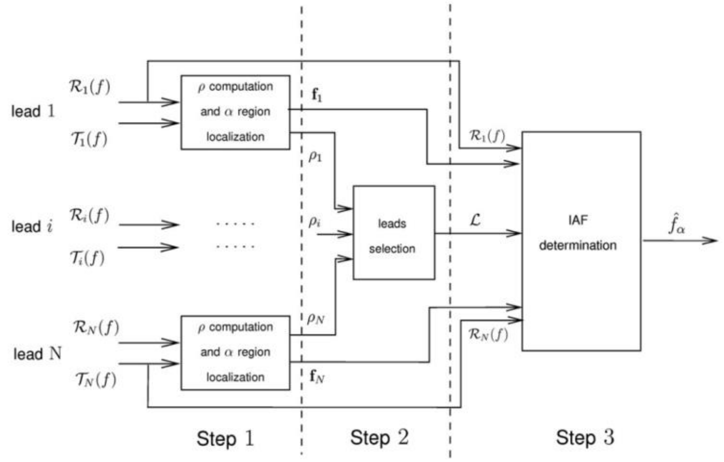
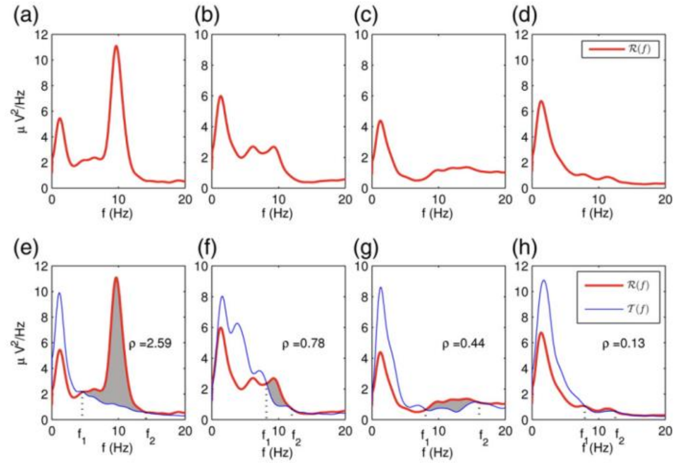
Article #13 Notes: EEG-neurofeedback for optimising performance. I: A review of cognitive and affective outcome in healthy participants

Source Title	EEG-neurofeedback for optimising performance. I: A review of cognitive and affective outcome in healthy participants
Source citation (APA Format)	Gruzelier, J. H. (2014). EEG-neurofeedback for optimising performance. I: A review of cognitive and affective outcome in healthy participants. *Neuroscience & Biobehavioral Reviews*, *44*, 124–141. https://doi.org/10.1016/j.neubiorev.2013.09.015
Original URL	https://doi.org/10.1016/j.neubiorev.2013.09.015
Source type	Journal Article
Keywords	Neurofeedback, EEG, Cognition, Affect, Validity, Optimal performance, Elderly
#Tags	
Summary of key points + notes (include methodology)	• Review paper synthesizing research on neural oscillations (alpha, beta, gamma) and their role in cognition • Focuses on how brain rhythms coordinate information processing across neural networks • Emphasizes that cognitive performance depends on interactions between frequency bands, not isolated rhythms • Alpha oscillations regulate inhibition and attentional gating • Beta oscillations support top-down control, task maintenance, and cognitive stability • Gamma oscillations enable local neural communication and feature binding • Introduces cross-frequency coupling (e.g., alpha phase influencing gamma amplitude) as a key mechanism • Did not collect actual data in this article, but synthesized findings from EEG studies, MEG studies, and intracortical recordings
Research Question/Problem/ Need	How do neural oscillations across different frequency bands support cognitive processing?

Important Figures	 O.M. Bazanova, D. Vernon / Neuroscience and Biobehavioral Reviews 44 (2014) 94–110 Individual EEG alpha activity indices. Individual alpha band width can be determined across the frequency range in which the amplitude is suppressed in response to eyes opening.
VOCAB: (w/definition)	• Intracranial: Within the skull, referring to processes inside the cranium • Intracortical: Within the cortex, refers to activities situated within the cerebral cortex • Cross-frequency coupling: Interaction between different oscillatory frequencies • Top-down processing: Goal-driven cognitive control from higher brain regions • Bottom-up processing: Sensory-driven information flow
Cited references to follow up on	https://doi.org/10.1016/j.neuroimage.2011.12.001
Follow up Questions	• Can early oscillatory changes predict long-term cognitive improvement? • Are certain individuals more responsive to oscillation-based training? • How does cross-frequency coupling change during neurofeedback? • Can neurofeedback target oscillatory interactions rather than single bands? • Do different frequency bands predict different cognitive outcomes?

Article #14 Notes: A novel method for the determination of the EEG individual alpha frequency

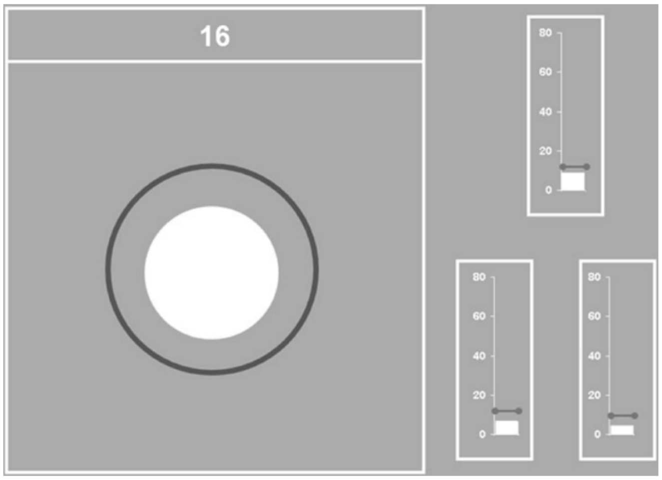
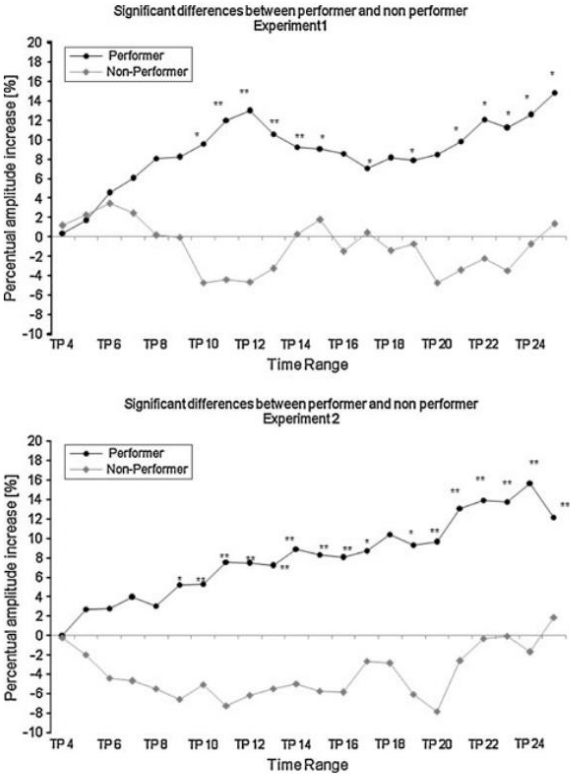
Source Title	A novel method for the determination of the EEG individual alpha frequency
Source citation (APA Format)	Goljahani, A., D'Avanzo, C., Schiff, S., Amodio, P., Bisiacchi, P., & Sparacino, G. (2012). A novel method for the determination of the EEG individual alpha frequency. *NeuroImage*, *60*(1), 774–786. https://doi.org/10.1016/j.neuroimage.2011.12.001
Original URL	https://www.sciencedirect.com/science/article/pii/S105381191101398X
Source type	Journal Article
Keywords	Alpha reactivity, Inter-individual variability, Leads selection, Peak frequency, Transition frequency, Spectrum
#Tags	
Summary of key points + notes (include methodology)	• Uses a method called Channel Reactivity-Based (CRB) to determine individual alpha frequency (IAF). • CRB focuses on task-related alpha activity rather than resting spectral peaks • Compared resting vs. task spectra to identify alpha desynchronization regions ○ • Computed a reactivity index to quantify the responsiveness of alpha • Calculated Channel Alpha Frequencies (CAFs) and the median was derived as the IAF.
Research Question/Problem/ Need	How can individual alpha frequency be reliably determined without relying on visible spectral peaks, while capturing task-relevant neural dynamics?
Important Figures	A. Goljahani et al. / NeuroImage 60 (2012) 774–786 775  **Fig. 1.** Representative cases of resting (red) and test (blue) EEG spectra. Panel (a) illustrates an example of peak frequency (PF) f_p determination by the PF method. In the picture, two vertical dotted black lines delimit the (8, 13) Hz alpha range and the vertical solid line is drawn in correspondence with f_p. Panel (b) shows an example of gravity frequency f_g determined by the extended band (EB) method for a representative test spectrum that is quite flat in the alpha range. In the picture, a vertical solid line is drawn in correspondence with f_g and the interval on which it was computed (the extended alpha band) is delimited by two vertical dotted lines. Panels (c) and (d) show two examples of gravity frequencies f_g determined by the transition frequency (TF) method. The panels depict two representative cases of superimposed resting and test spectra with the relative TFs. For both images, vertical dotted lines delimit the interval from TF toTF + 5 Hz and the vertical solid line is drawn in correspondence with f_g.

	 **Fig. 2.** Block diagram illustrating the three steps of the CRB method. $\mathcal{R}_i(f)$ and $\mathcal{T}_i(f)$ are the resting and test spectrum, respectively, for the *i*-th lead; $\mathbf{f}_i = (f_1, f_2)$, where f_1 and f_2 are the boundaries of the responsiveness interval for the *i*-th lead; ρ_i is the reactivity index relative to $\mathbf{f}_i$; $\mathscr{L}$ is the set of leads selected by the CRB method and $\hat{f}_\alpha$ is the individual alpha frequency (IAF, determined as the median of the CAFs relative to the leads in $\mathscr{L}$).  **Fig. 3.** Panels (a)–(d): four representative cases of resting EEG spectra (red). Panels (e)–(h): the same as (a)–(d) with superimposed test EEG spectra (blue) and responsiveness regions shaded in grey. The ρ values were computed using the area of the shaded region [numerator of Eq. (1)] and the frequency interval (f_1, f_2) [denominator of Eq. (1)].
VOCAB: (w/definition)	- Alpha reactivity: Reduction, or desynchronization of alpha power during cognitive tasks - CAF: alpha frequency computed per EEG channel - Reactivity index: measure of alpha responsiveness (quantitative) - Peak frequency (PF): frequency of maximum power in alpha band during rest - Extended band (EB): alpha frequency calculated with a visually defined band (usually from a graph) - Transition frequency (TF): frequency where theta synchronization shifts into alpha desynchronization
Cited references to follow up on	
Follow up Questions	- Can CRB improve personalization of NFT frequency targets? - How stable is CRB-derived IAF over sessions?

	• Can this method be extended to individual beta or gamma frequency calculation?

Article #15 Notes: Predicting Successful Learning of SMR Neurofeedback in Healthy Participants: Methodological Considerations

Source Title	Predicting Successful Learning of SMR Neurofeedback in Healthy Participants: Methodological Considerations
Source citation (APA Format)	Weber, E., Köberl, A., Frank, S., & Doppelmayr, M. (2011). Predicting Successful Learning of SMR Neurofeedback in Healthy Participants: Methodological Considerations. *Applied Psychophysiology and Biofeedback*, *36*(1), 37–45. https://doi.org/10.1007/s10484-010-9142-x
Original URL	https://link.springer.com/article/10.1007/s10484-010-9142-x
Source type	Journal Article
Keywords	Neurofeedback, SMR, predicting performance
#Tags	
Summary of key points + notes (include methodology)	• Major challenge in NF research is the high number of training sessions required, and the presence of non-responders. • Focuses on sensorimotor rhythm (SMR, 12-15 Hz) NF in healthy participants • Conducted 25 SMR NF sessions with 13 participants, and 30 sessions with 14 participants • Participants received visual feedback that represented SMR amplitude and instructed to use mental strategies to increase it. • Performers and non-performers were classified based on: • ≥ 8% increase in SMR by the end of training • + learning trend across sessions • Found that performance at TP 11 (11 sessions) could reliably predict final learning outcomes • A formula that subtracted individual variability from amplitude increase correctly classified most participants
Research Question/Problem/ Need	Can early neurofeedback performance be used to predict whether an individual will successfully learn to modulate SMR EEG activity?

Important Figures	**Fig. 1** The graphic in figure represents the feedback display viewed by the participants. The *white circular area* in the middle of the screen, which indicates the amplitude of the SMR (12–15 Hz) frequency band, is surrounded by a *gray* “threshold circle”. The three *bars* on the right-hand side of the screen represent the amplitudes of the three inhibitory bands (3–5, 22–30, and 45–60 Hz). A counter is displayed at the *top* of the screen; every time a participant increased and maintained the size of the *white circle* to an area larger than the threshold circle for more than 250 ms, a point was added to the counter   Significant differences between performer and non performer Experiment1 Significant differences between performer and non performer Experiment2 **Fig. 2** The percent amplitude increase for TP 4–TP 25 for the participants of experiments 1 (*upper panel*) and 2 (*lower panel*). Significant differences between the performers and non-performers, as determined with Mann–Whitney *U* tests, are indicated with one or two asterisks for the 5 or 1% level of significance, respectively
VOCAB: (w/definition)	- Sensorimotor rhythm (SMR): EEG frequency band between 12-15 Hz, associated with motor inhibition and attention regulation - Time period (TP): Median EEG amplitude calculated across 3 consecutive training days

	- Event-related synchronization (ERS): increase in EEG power relative to baseline
Cited references to follow up on	Egner, T., & Gruzelier, J. H. (2004). EEG Biofeedback of low beta band components: Frequency-specific effects on variables of attention and event-related brain potential. *Clinical Neurophysiology, 115*(1), 131–139.
Follow up Questions	- Can this prediction model be applied to other frequency bands (alpha, beta, gamma)? - Would similar predictors exist for cognitive performance, and not just EEG modulation? - Could prediction happen earlier than 11 sessions with better signal processing? - How could this model generalize to clinical populations?

Article #16 Notes: EEG Biofeedback of low beta band components: frequency-specific effects on variables of attention and event-related brain potentials

Source Title	EEG Biofeedback of low beta band components: frequency-specific effects on variables of attention and event-related brain potentials
Source citation (APA Format)	Egner, T., & Gruzelier, J. H. (2004). EEG Biofeedback of low beta band components: Frequency-specific effects on variables of attention and event-related brain potential. *Clinical Neurophysiology, 115*(1), 131–139. https://doi.org/10.1016/S1388-2457(03)00353-5
Original URL	https://www.sciencedirect.com/science/article/pii/S1388245703003535
Source type	Journal Article
Keywords	EEG biofeedback; Neurofeedback; Beta1 activity; Sensorimotor rhythm; Attention; P300
#Tags	
Summary of key points + notes (include methodology)	• Compares SMR training (12-15 Hz) vs beta1 training (15-18 Hz) vs control • Shows distinct cognitive outcomes depending on frequency band trained • Beta1 training increases arousal and response speed, seen in faster reaction times and higher P300 amplitudes • Randomized 3 groups from 25 participants into SMR NFT, beta1 NFT, and non-NFT control groups • Gave 10 weekly NFT sessions for around 15 min each • Behavioral measures: Test of Variables of Attention (TOVA), and divided auditory attention task
Research Question/Problem/ Need	Does training specific EEG frequency bands (SMR vs beta1) produce distinct and predictable effects on attention and neural processing?

Important Figures

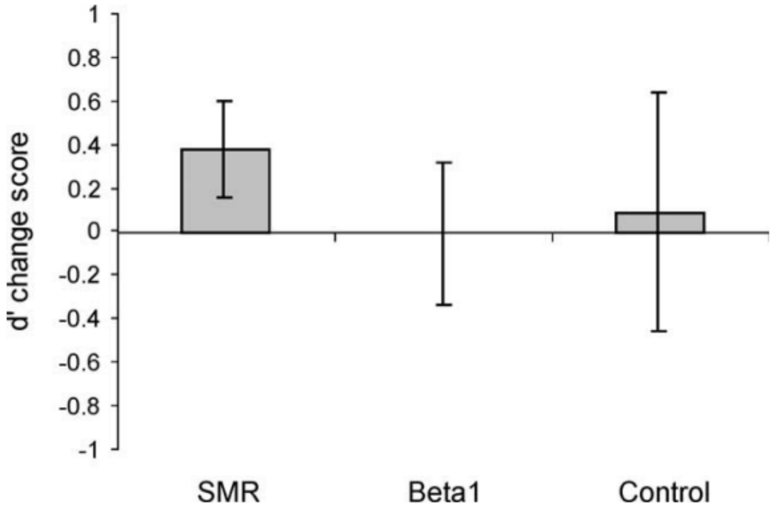


Fig. 1. Post-training changes on mean d′ scores (± SEM) on the TOVA task for the SMR, beta1, and control groups.

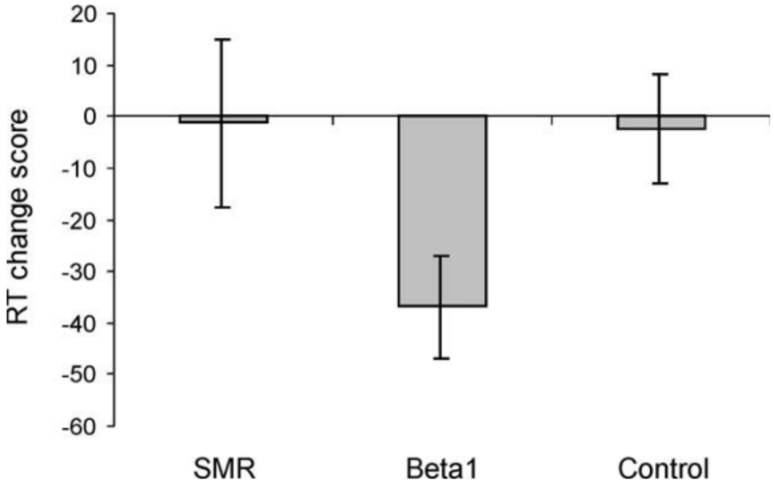


Fig. 2. Post-training changes (in ms) on mean reaction times (± SEM) on the TOVA task for the SMR, beta1, and control groups.

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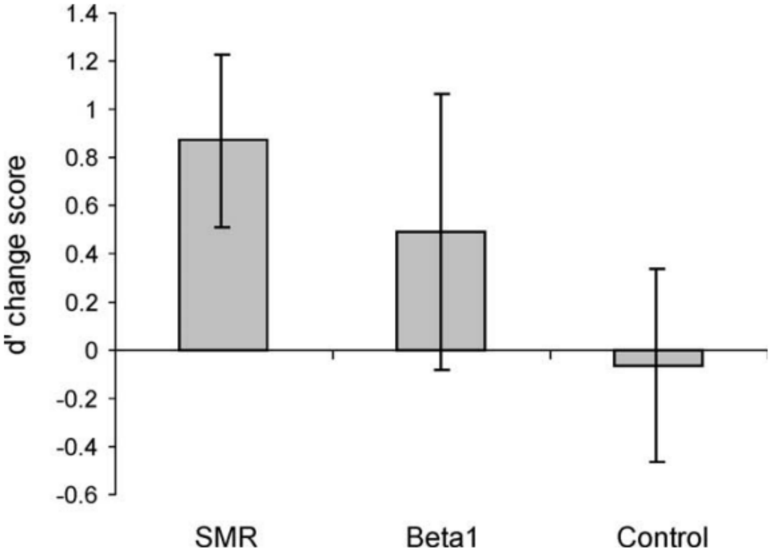

Fig. 3. Post-training changes on mean d′ scores (± SEM) on the divided attention task for the SMR, beta1, and control groups.

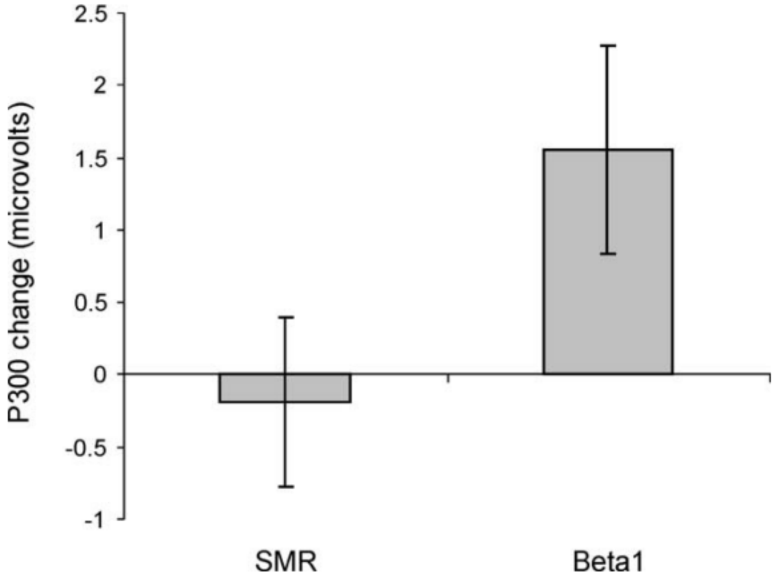

Fig. 5. Post-training changes on mean oddball target P300 amplitudes (± SEM) averaged for frontal, central, and parietal electrodes for the SMR and beta1 groups.

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VOCAB: (w/definition)

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- Beta1: 15-18 Hz EEG band associated with alertness and arousal
- P300: An Event-Related Potential component reflecting stimulus evaluation and attentional resource allocation
- Reaction Time Variability (RTV): Measure of consistency in attentional performance

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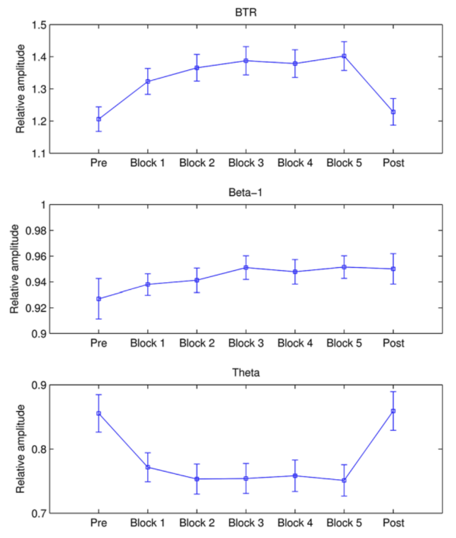
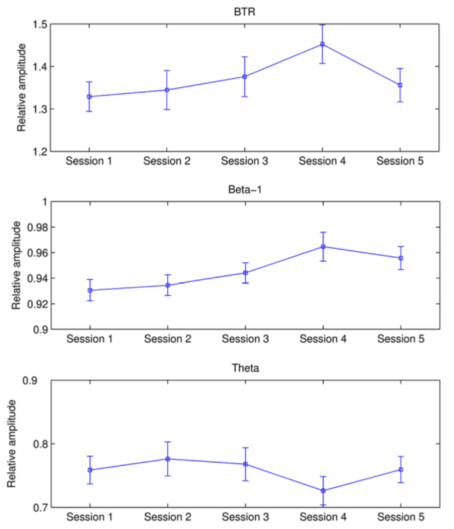
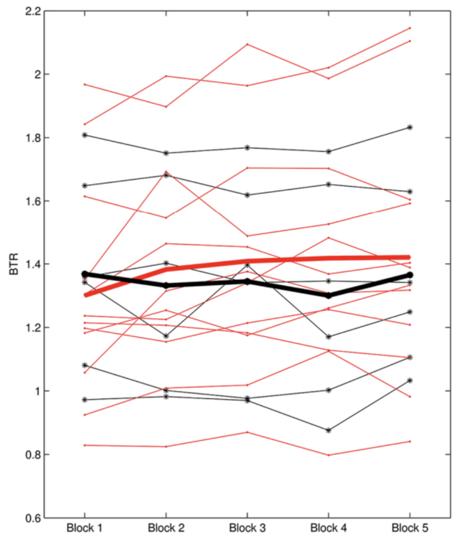
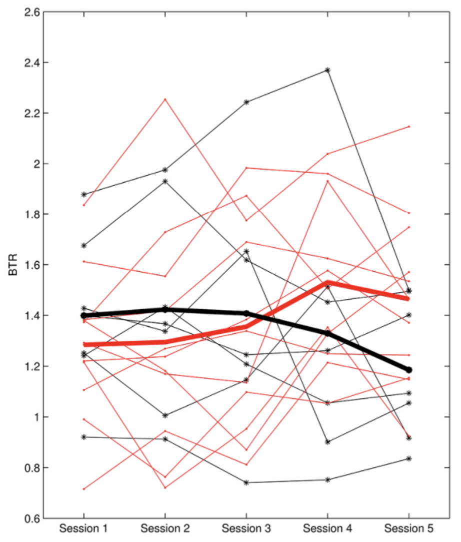
	• Oddball task: paradigm used to elicit P300 by presenting infrequent target stimuli.
Cited references to follow up on	Egner, T., & Gruzelier, J. H. (2004). EEG Biofeedback of low beta band components: Frequency-specific effects on variables of attention and event-related brain potentials. *Clinical Neurophysiology, 115*(1), 131–139. Lubar JO, Lubar JF. (1984). Electroencephalographic biofeedback of SMR and beta for treatment of attention deficit disorders in a clinical setting. *Biofeedback Self Regul 9*:1–23.
Follow up Questions	• Can early-session learning rates in SMR or beta1 predict long-term cognitive gains? • How do SMR and beta1 compare to upper alpha training in terms of cognitive outcomes? • Could gamma-band training show similarly distinct electrophysiological signatures? • How might machine learning improve prediction of responders vs. non-responders?

Article #17 Notes: Resting and Initial Beta Amplitudes Predict Learning Ability in Beta/Theta Ratio Neurofeedback Training in Healthy Young Adults

Source Title	Resting and Initial Beta Amplitudes Predict Learning Ability in Beta/Theta Ratio Neurofeedback Training in Healthy Young Adults
Source citation (APA Format)	Nan, W., Wan, F., Vai, M. I., & Da Rosa, A. C. (2015). Resting and Initial Beta Amplitudes Predict Learning Ability in Beta/Theta Ratio Neurofeedback Training in Healthy Young Adults. *Frontiers in Human Neuroscience*, *9*. https://doi.org/10.3389/fnhum.2015.00677
Original URL	https://www.frontiersin.org/journals/human-neuroscience/articles/10.3389/fnhum.2015.00677/full
Source type	Journal Article
Keywords	Neurofeedback training, beta/theta ratio, self-regulation, prediction, learning indices
#Tags	
Summary of key points + notes (include methodology)	• Study looks at whether early EEG features in beta/theta ratio (BTR) NFT can predict learning success • Eighteen healthy young adults completed **five consecutive days** of BTR NF training. • Training targeted **up-regulation of beta-1 (15–18 Hz) relative to theta (4–7 Hz)** using a bipolar montage under O1 and O2. • EEG amplitude (not power) was used to reduce skew and improve statistical validity. • Learning was assessed using: ○ **L1**: within-session learning (short-term changes). ○ **L2**: across-session learning (long-term linear slope). • Results showed: ○ Significant **within-session increases in BTR**, mainly driven by theta decreases. ○ Significant **across-session increases in BTR**, driven primarily by beta-1 increases. • **Low beta resting amplitude** and **beta-1 amplitude during the first training block** significantly predicted across-session learning ability (L2). • A linear discriminant analysis achieved **~88% classification accuracy** for learners vs. non-learners using early EEG features.
Research Question/Problem/ Need	Can early EEG measurements reliably predict long-term NF learning ability?

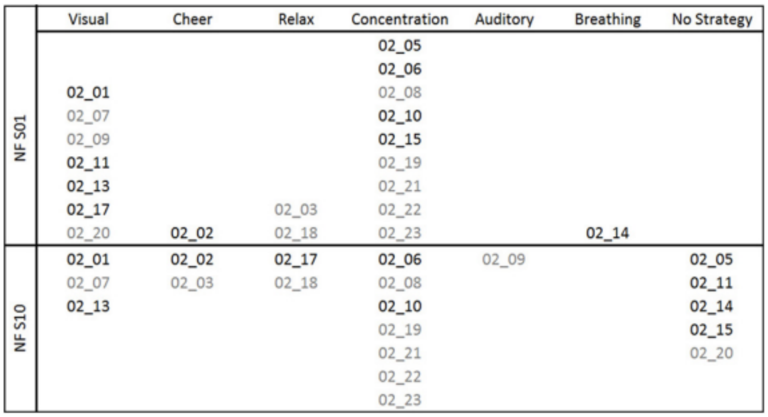
Important Figures	 **FIGURE 1 | Mean BTR, beta-1, and theta in each period.** The error bars depict standard error of the mean (SEM).  **FIGURE 2 | Mean BTR, beta-1, and theta in each session.** The error bars indicate SEM.  **FIGURE 3 | BTR within sessions of learner_L1 and non-learner_L1.** Thin red lines with dot represent BTR of each learner; thick red line represents the mean BTR across all learners; thin black lines with star show each non-learner; thick black line represents the mean across non-learners.  **FIGURE 4 | BTR across sessions of learner_L2 and non-learner_L2.** Thin red lines with dot represent BTR of each learner; thick red line depicts the mean BTR across all learners; thin black lines with star show each non-learner; thick black line shows the mean across non-learners.
VOCAB: (w/definition)	• Beta/theta ratio (BTR): ratio of beta1 amplitude to theta amplitude, often linked to attention and arousal • Linear discriminant analysis (LDA): statistical method used to classify participants into groups based on predictive features • Training independence: idea that NF effects should be specific to the frequency band rather than global EEG changes
Cited references to follow up on	Hammond, D. C. (2005). Neurofeedback to improve physical balance, incontinence, and swallowing. J. *Neurother. 9,* 27–36. doi:

	10.1300/J184v09n01_03
Follow up Questions	• Would similar predictors emerge for other NF protocols (e.g., alpha or gamma training)? • Can early EEG predictors be combined with behavioral or psychological measures to improve prediction accuracy? • How do neural predictors relate to actual cognitive or behavioral improvements, not just EEG learning?

Article #18 Notes: Learning to modulate one's own brain activity: the effect of spontaneous mental strategies

Source Title	Learning to modulate one's own brain activity: the effect of spontaneous mental strategies
Source citation (APA Format)	Kober, S. E., Witte, M., Ninaus, M., Neuper, C., & Wood, G. (2013). Learning to modulate one's own brain activity: The effect of spontaneous mental strategies. *Frontiers in Human Neuroscience*, *7*. https://doi.org/10.3389/fnhum.2013.00695
Original URL	https://www.frontiersin.org/journals/human-neuroscience/articles/10.3389/fnhum.2013.00695/full
Source type	Journal Article
Keywords	Neurofeedback, mental strategies, sensorimotor rhythm, gamma, EEG, implicit learning
#Tags	
Summary of key points + notes (include methodology)	• Investigates how spontaneous mental strategies affect NFT learning • Focuses on why a lot of individuals fail to learn NF control • Compares SMR NFT vs gamma NFT • Key finding: ○ SMR training improves most when participants stop using explicit mental strategies ○ Effect does not generalize to gamma NFT • Implicit learning mechanisms are critical for successful SMR NF.
Research Question/Problem/ Need	How do spontaneous mental strategies influence NF learning outcomes?

Important Figures



	Visual	Cheer	Relax	Concentration	Auditory	Breathing	No Strategy
NF S01				02_05			
				02_06			
	02_01			02_08			
	02_07			02_10			
	02_09			02_15			
	02_11			02_19			
	02_13			02_21			
	02_17		02_03	02_22			
	02_20	02_02	02_18	02_23		02_14	
NF S10	02_01	02_02	02_17	02_06	02_09		02_05
	02_07	02_03	02_18	02_08			02_11
	02_13			02_10			02_14
				02_19			02_15
				02_21			02_20
				02_22			
				02_23			

FIGURE 1 | Mental strategies used during the first (NF S01) and the last (NF S10) NF training session, presented separately for each participant of the SMR (subject code in black font color) and Gamma group (subject code in gray font color).

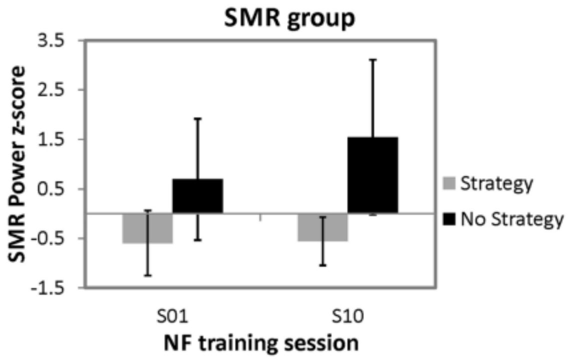


FIGURE 2 | Means and standard deviations of *z*-transformed SMR power (12–15 Hz) values during the first and tenth NF training session, presented separately for participants reporting to use a specific mental strategy in the tenth NF session (strategy group) and participants reporting no specific mental strategy in the tenth NF session (no strategy group).

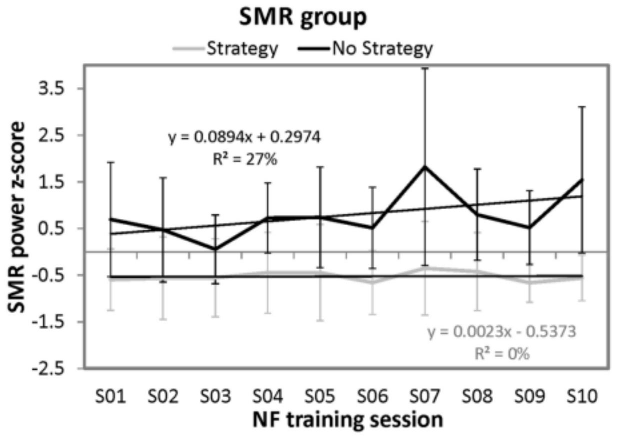


FIGURE 3 | Means and standard deviations of *z*-transformed SMR (12–15 Hz) power (NF performance) over the ten NF training sessions, presented separately for participants reporting to use a specific mental strategy in the tenth NF session (strategy group) and participants reporting no specific mental strategy in the tenth NF session (no strategy group) of the SMR group and the results of the regression analyses.

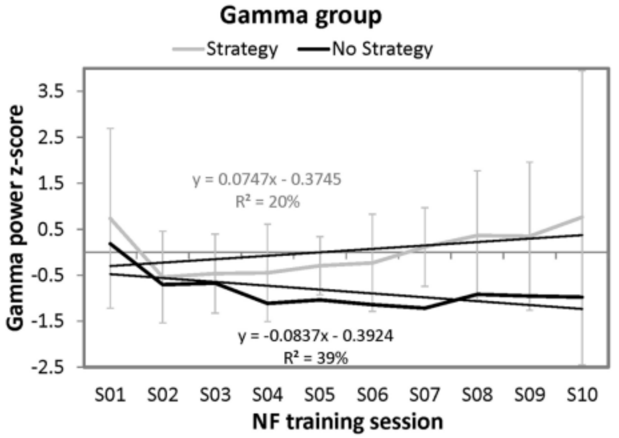


FIGURE 4 | Means and standard deviations of *z*-transformed Gamma (40–43 Hz) power (NF performance) over the ten NF training sessions, presented separately for participants reporting to use a specific mental strategy in the tenth NF session (strategy group) and participants reporting no specific mental strategy in the tenth NF session (no strategy group) of the Gamma group and the results of the regression analyses. Note that only standard deviations for the strategy group are plotted since only one participant was present in the no strategy group.

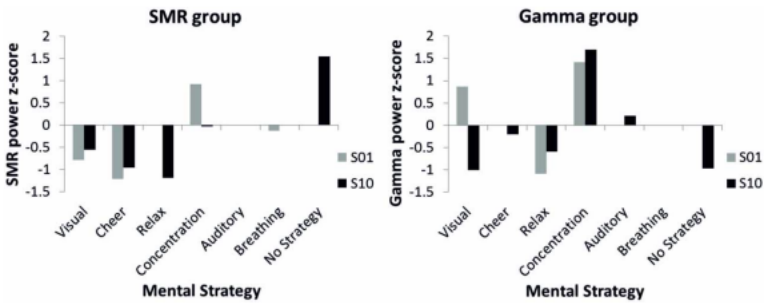
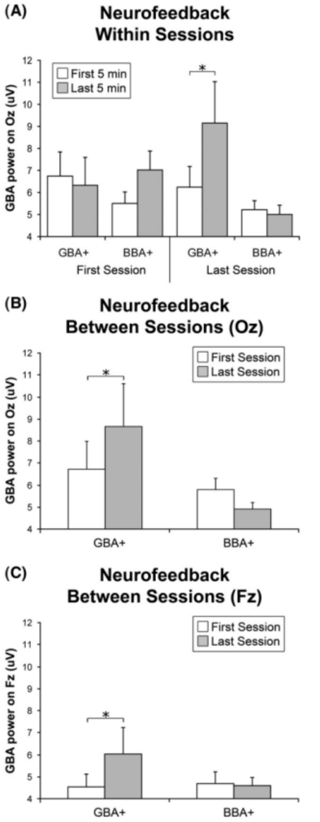


FIGURE 5 | *Z*-transformed SMR power for the SMR group (left panel) and *z*-transformed Gamma power for the Gamma group (right panel) during first (gray bars) and tenth (black bars) NF training session, presented separately for different mental strategies used to control one's own EEG signal. Note that no error bars are plotted since only single participants were present in several categories.

VOCAB: (w/definition)	• Gamma band: 40-43 Hz, associates with attention, integration • Implicit learning: Learning that occurs without conscious strategy • Complex demodulation: Signal-processing method to extract frequency-specific power • Dual-process theory: learning model involving both explicit (conscious) and implicit processes
Cited references to follow up on	• Angelakis et al., 2007 – Alpha neurofeedback and cognition https://doi.org/10.1080/13854040600744839 • Nan et al., 2012 – Individual alpha NF and memory https://doi.org/10.1016/j.ijpsycho.2012.07.182 • Blankertz et al., 2010 – Predictors of SMR-BCI performance https://doi.org/10.1016/j.neuroimage.2010.03.022 • Hammer et al., 2012 – Psychological predictors of NF performance https://doi.org/10.1016/j.biopsycho.2011.09.006 • Keizer et al., 2010a/b – Gamma neurofeedback and cognition https://doi.org/10.1016/j.neuroimage.2009.11.023
Follow up Questions	• Are implicit learning markers detectable within the first few sessions? • Do adolescents or younger participants show the same strategy-to-implicit transition? • Can explicit strategies be phased out systematically to improve outcomes? • Why does Gamma NF not benefit from implicit strategy disengagement? • How do baseline EEG traits interact with strategy use? • Can machine learning classify “implicit learners” early in training?

Article #19 Notes: Enhancing cognitive control through neurofeedback: A role of gamma-band activity in managing episodic retrieval

Source Title	Enhancing cognitive control through neurofeedback: A role of gamma-band activity in managing episodic retrieval
Source citation (APA Format)	Keizer, A. W., Verment, R. S., & Hommel, B. (2010). Enhancing cognitive control through neurofeedback: A role of gamma-band activity in managing episodic retrieval. *NeuroImage*, *49*(4), 3404–3413. https://doi.org/10.1016/j.neuroimage.2009.11.023
Original URL	https://www.sciencedirect.com/science/article/pii/S1053811909012075?via%3Dihub
Source type	Journal Article
Keywords	N/A
#Tags	Neurofeedback, gamma, EEG, cognitive control
Summary of key points + notes (include methodology)	• Investigates whether NFT can manipulate neural syncrony and improve cognition • Compares gamma-band NF vs beta-band NFT • Demonstrates that gamma NFT increases local gamma power and frontal-occipital gamma coherence ○ Beta NFT primarily increases long-range beta coherence, and not local beta power • Supports the idea that early neuroal changes during NFT reflect trainability and functional relevance • Conducted double-blind, multisession NFT with randomly assigned gamma and beta groups with 17 healthy adults. • Analyzed EEG power and coherence changes within and across sessions • Compared pre/post behavior
Research Question/Problem/ Need	Does experimentally enhancing neural synchrony in specific frequency bands through neurofeedback causally influence cognitive control and memory processes?

Important Figures	 (A) Neurofeedback Within Sessions (B) Neurofeedback Between Sessions (Oz) (C) Neurofeedback Between Sessions (Fz) **Fig. 3.** The neurofeedback training led to an increase of occipital GBA in the GBA+ group compared to the BBA+ group within the last session (first 5 min versus last 5 min) compared with the first session (A). Across sessions (first session versus last session), the neurofeedback training resulted in an increase of occipital (B) and frontal (C) GBA in the GBA+ group compared to the BBA+ group. Error bars represent standard errors, asterisks indicate significance level of $p < .05$.

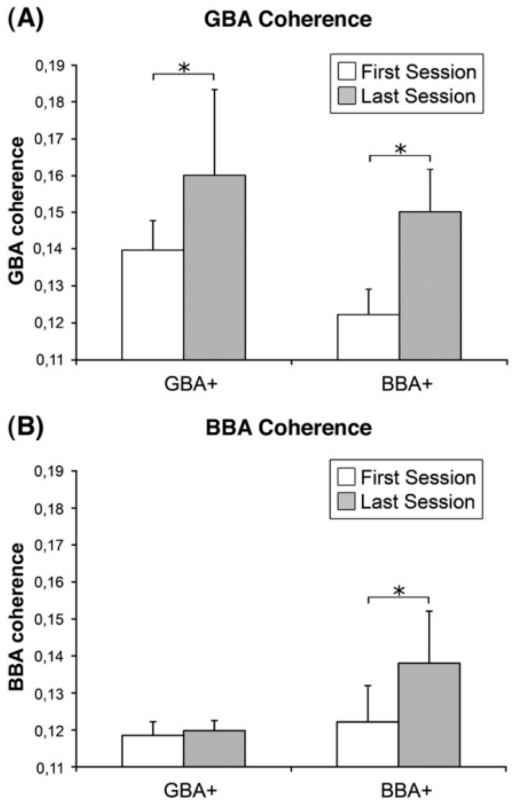
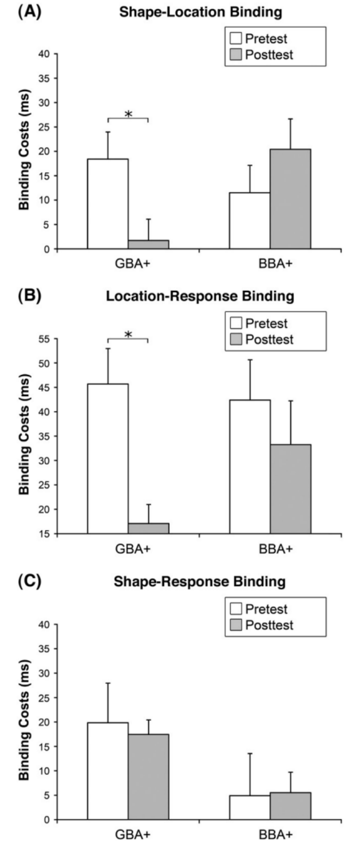


Fig. 4. Across sessions, the neurofeedback training resulted in a significant increase in GBA coherence in both groups (A) and a significant increase of BBA-coherence in the BBA+ group (B). Error bars represent standard errors, asterisks indicate significance level of $p<.05$.

	 **Fig. 5.** Reaction time data of the binding task. The neurofeedback training resulted in a decrease of binding costs between shape and location (A) and between location and response (B), but not between shape and response (C). Error bars represent standard errors, asterisk indicates significance level of $p < .05$.
VOCAB: (w/definition)	• Neural synchrony: Coordinated timing of neural firings across neurons or brain regions • Gamma-band activity (GBA) • Coherence: measure of functional connectivity between EEG signals at different brain sites • Recollection: conscious retrieval of contextual details about a memory • Cognitive control: ability to regulate attention, memory retrieval, and behavior
Cited references to follow up on	• Vernon et al. (2003) – Neurofeedback and cognitive performance https://doi.org/10.1016/S0167-8760(02)00228-0 • Jensen et al. (2007) – Gamma oscillations in attention and memory • https://doi.org/10.1016/j.tins.2007.05.001 • Engel & Singer (2001) – Temporal binding and awareness https://doi.org/10.1016/S1364-6613(00)01568-0 • Burgess & Ali (2002) – Gamma connectivity and recollection https://doi.org/10.1016/S0167-8760(02)00167-5 • Gruber et al. (2008) – Gamma vs theta in memory https://doi.org/10.1162/jocn.2008.20058 • Klimesch (1999) – EEG oscillations and memory https://doi.org/10.1016/S0165-0173(98)00056-3

	• Varela et al. (2001) – Large-scale brain integration https://doi.org/10.1038/35067550 • Keizer, A.W., Verschoor, M., Verment, R.S., Hommel, B., in press. Enhancing gamma band power (36–44 Hz with neurofeedback improves feature-binding flexibility and intelligence. Int. J. Psychophysiol.
Follow up Questions	• Can early-session gamma or beta changes predict who will benefit most from NFT? • Would combining gamma and beta training sequentially enhance both recollection and familiarity? • Are there individual baseline EEG markers that determine which frequency band is optimal for a person?

Article #20 Notes: The effect of gamma enhancing neurofeedback on the control of feature bindings and intelligence measures

Source Title	The effect of gamma enhancing neurofeedback on the control of feature bindings and intelligence measures
Source citation (APA Format)	Keizer, A. W., Verschoor, M., Verment, R. S., & Hommel, B. (2010). The effect of gamma enhancing neurofeedback on the control of feature bindings and intelligence measures. *International Journal of Psychophysiology*, *75*(1), 25–32. https://doi.org/10.1016/j.ijpsycho.2009.10.011
Original URL	https://www.sciencedirect.com/science/article/pii/S0167876009002682?via%3Dihub
Source type	Journal Article
Keywords	Gamma, Neurofeedback, Binding, Feature integration, Intelligence
#Tags	
Summary of key points + notes (include methodology)	• Neural synchronization in the gamma frequency band (≈30–60 Hz) has been theorized to underlie visual feature binding and fluid intelligence. • Study aimed to provide causal evidence by directly manipulating gamma activity using NFT • Participants were trained over 8 sessions to either increase gamma power (gamma-up group) or suppress gamma power relative to beta power (control group) • Found that participants successfully learned to increase gamma-band power via NF • Increased gamma power led to reduced visual binding costs, makes better control over feature bindings • Suggests a shared neural mechanism linking gamma activity and binding control
Research Question/Problem/ Need	Does experimentally increasing gamma-band neural synchronization causally influence feature binding performance and intelligence-related measures?

Important Figures

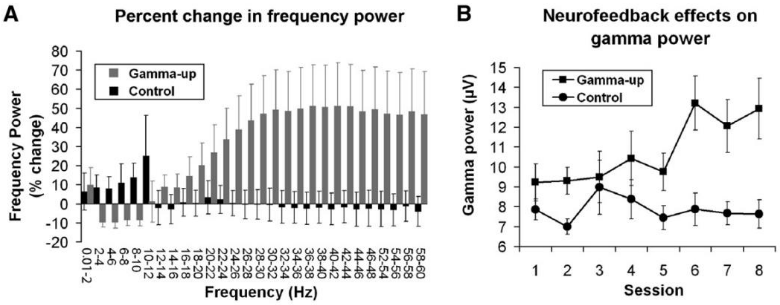


Fig. 2. The effects of neurofeedback on the power in frequency bands in the Gamma-up group and the Control group. The graph indicates the percent change in power between 0.01 and 60 Hz, divided in bins of 2 Hz (A). The increase of gamma band power (30–60 Hz) over the course of 8 neurofeedback sessions (B). Error bars depict standard error of the mean.

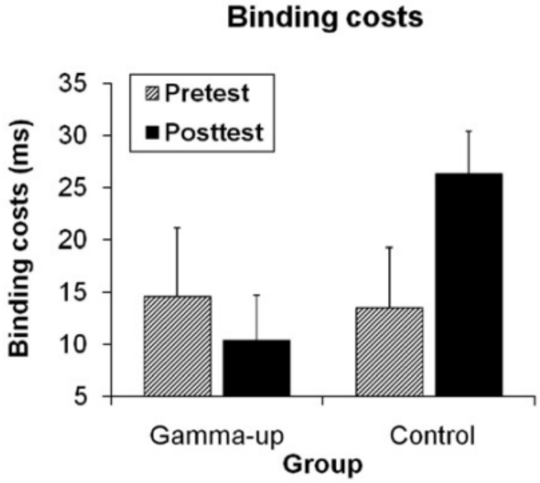


Fig. 3. The neurofeedback training resulted in a decrease of binding costs in the Gamma-up group and an increase of binding costs in the Control group (for the first half of the trials). Error bars depict standard error of the mean.

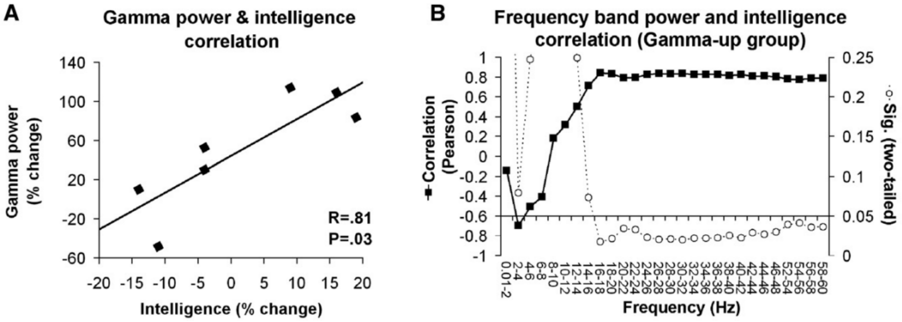
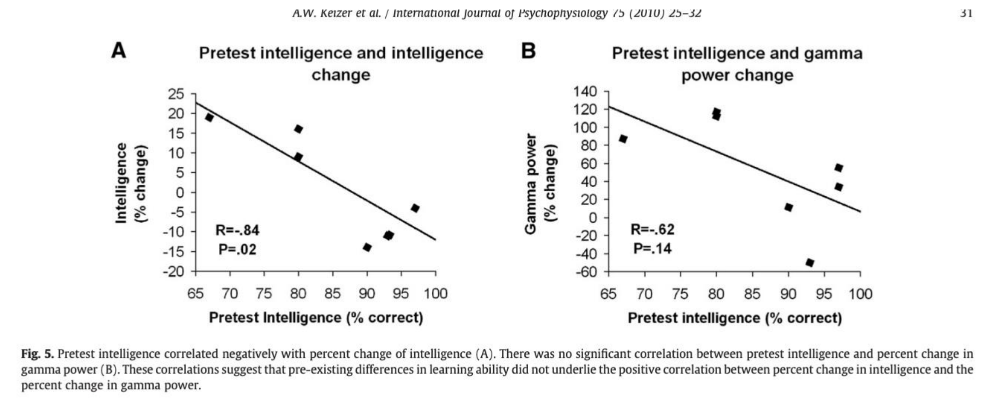
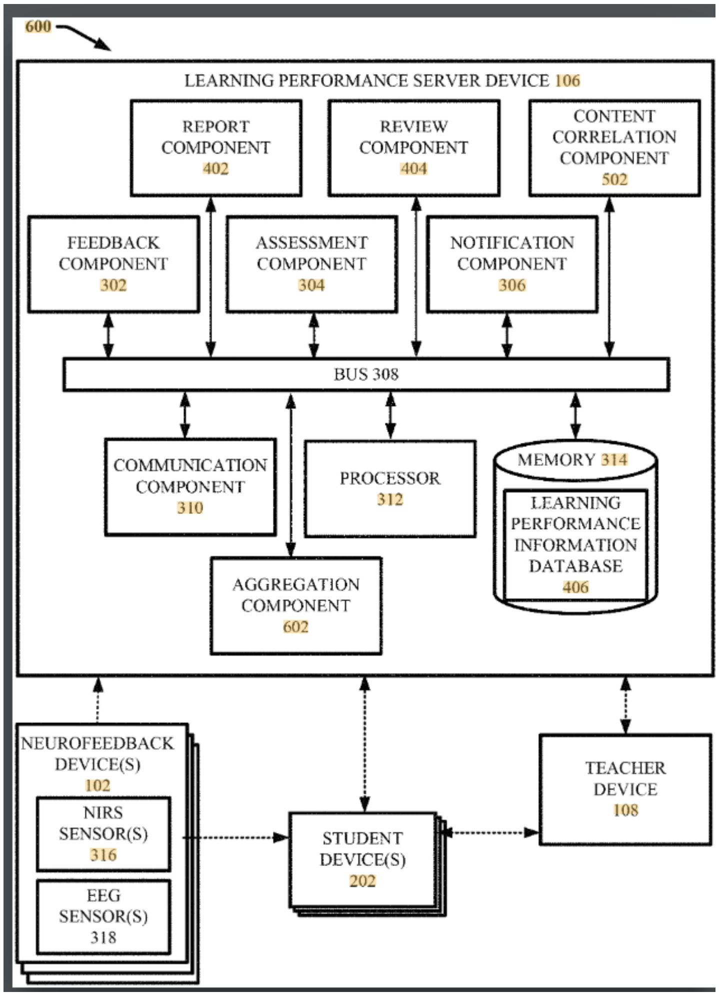


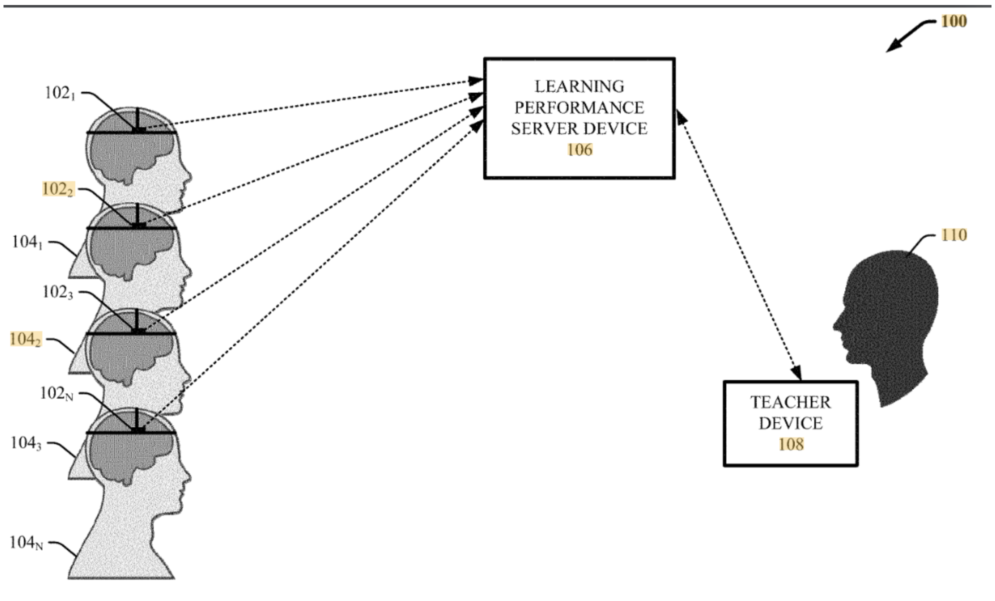
Fig. 4. There was a significant positive correlation between the percent change in gamma power (30–60 Hz) and the percent change in intelligence for the Gamma-up group (A). Figure 4B shows the correlation between the percent change in power between 0.01 and 60 Hz, divided in bins of 2 Hz with the percent change in intelligence. This graph shows that the positive correlation was present between 16 and 60 Hz, thus including both the gamma band (30–60 Hz) and the high-beta band (16–20 Hz). Error bars depict standard error of the mean.

	 A.W. Keizer et al. / International Journal of Psychophysiology 75 (2010) 25–32 31 **Fig. 5.** Pretest intelligence correlated negatively with percent change of intelligence (A). There was no significant correlation between pretest intelligence and percent change in gamma power (B). These correlations suggest that pre-existing differences in learning ability did not underlie the positive correlation between percent change in intelligence and the percent change in gamma power.
VOCAB: (w/definition)	• Feature binding: process where the brain integrates separate features into a coherent concept • Binding costs: performance impairments that occur when previously bound features are partially repeated • Event file: temporary cognitive representation that integrates stimulus features and responses • Fluid intelligence: ability to reason and solve novel provlems independent of learned knowledge • ANCOVA: statistical method controlling for baseline differences while comparing group effects
Cited references to follow up on	https://www.sciencedirect.com/science/article/pii/S1364661300015680 - Temporal binding and the neural correlates of sensory awareness
Follow up Questions	• Can **gamma neurofeedback effects** be replicated with **larger and more diverse samples**? • Would targeting **other brain regions** (e.g., frontal cortex) strengthen intelligence effects? • How long do the observed **binding and intelligence improvements** persist? • Can beta-band neurofeedback selectively improve **visuomotor binding**, as theorized? • Could gamma neurofeedback be applied to **clinical populations** with binding or executive-control deficits?

Patent #1 Notes: Monitoring learning performance using neurofeedback

Source Title	Monitoring learning performance using neurofeedback
Source citation (APA Format)	Carr, K. G., & Das, P. (2020). *Monitoring learning performance using neurofeedback* (United States Patent No. US10839712B2). https://patents.google.com/patent/US10839712B2/en
Original URL	https://patents.google.com/patent/US10839712B2/en
Source type	Patent
Keywords	N/A
#Tags	
Summary of key points + notes (include methodology)	• Patent describes a system and method to monitor a user's learning performance using NF data from a learning experience • Uses neuroimaging measurements (like EEG) to infer cognitive state and evaluate learning performance in real time. • A feedback component receives continuous neural measurements while a learner is engaged in a task • The system can be implemented as wearable hardware (headset, band) that streams EEG/NIRS data to a server for processing and evaluation. • Video or audio recordings of the learning situation can be correlated optionally with the neurofeedback data to identify specific content or moments where the learner struggled.
Research Question/Problem/ Need	There is a need for real-time monitoring tools that can detect cognitive performance issues (attention lapses, poor working memory engagement) while learning is happening, not after.

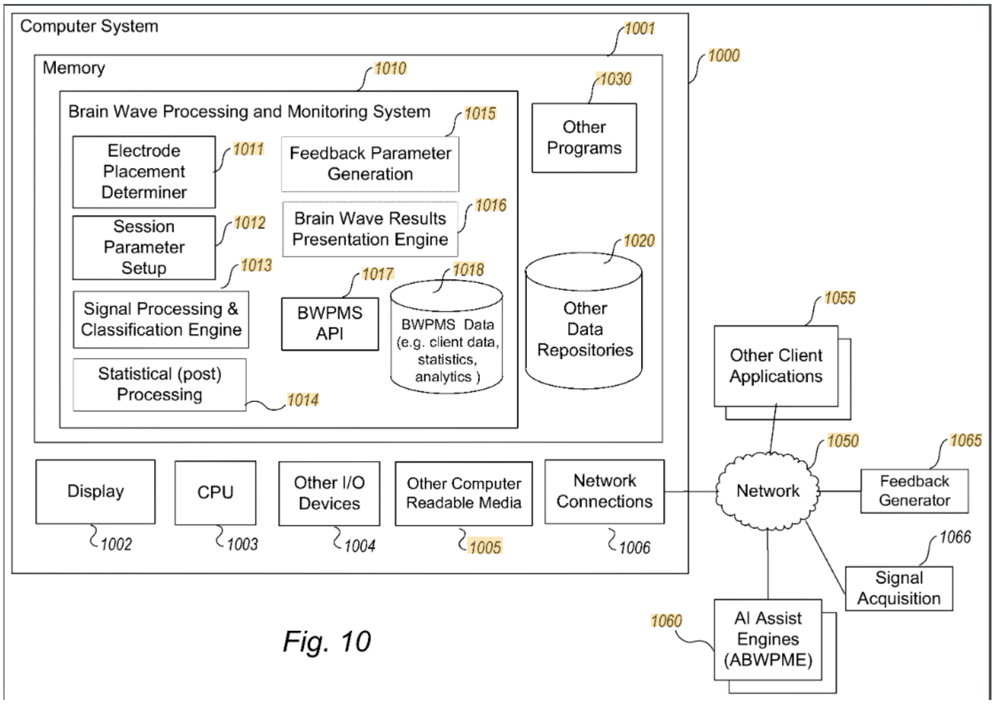
Important Figures	

	 **FIG. 1**
VOCAB: (w/definition)	• Near-infrared spectroscopy (NIRS): non-invasive method that measures changes in brain blood oxygenation related to neural activity • Learning performance information: Quantitative evaluation of a learner's cognitive function derived from NF signals • Notification component: module that issues alerts when learning performance is below a specific level, allows for intervention • Cognitive function areas: defined mental processes like attention, mental effort, or working memory
Cited references to follow up on	• Near-Infrared Spectroscopy (NIRS) in cognitive monitoring: https://doi.org/10.1016/j.neuroimage.2011.05.028 • EEG in neurofeedback and cognitive load: https://doi.org/10.1016/j.neuropsychologia.2008.06.023 • Real-time brain state monitoring for adaptive learning: https://doi.org/10.1109/TBME.2015.2468615 • Machine learning classification of cognitive states from EEG: https://doi.org/10.3389/fnins.2018.00244
Follow up Questions	• Can real-time EEG markers used in this patent be applied to **predict neurofeedback training success** as in your project? • What specific EEG features (e.g., alpha, beta, gamma power) would best correlate with in-session learning performance as defined here? • How might the **notification components** be adapted to give actionable feedback in a cognitive training context rather than a classroom context? • Could machine learning improve the assessment component to predict **future performance or protocol adjustments**?

	• How does combining NIRS with EEG improve cognitive state detection compared to EEG alone?

Patent #2 Notes: Multiple frequency neurofeedback brain wave training techniques, systems, and methods

Source Title	Multiple frequency neurofeedback brain wave training techniques, systems, and methods
Source citation (APA Format)	Keane, C. (2025). *Multiple frequency neurofeedback brain wave training techniques, systems, and methods* (United States Patent No. US12232882B2). https://patents.google.com/patent/US12232882B2/en
Original URL	https://patents.google.com/patent/US12232882B2/en
Source type	Patent
Keywords	N/A
#Tags	
Summary of key points + notes (include methodology)	• Describes a Brain Training Feedback System (BTFS) that allows participants to learn how to increase, suppress, or inhibit specific brain-wave activity using NF. • BTFS uses both EEG signal obtaining and classification components and feedback generators that present real-time feedback based on processed neural data. • Innovates the ability to train multiple brain-wave modalities at the same time, rather than just one frequency band at a time. • System can use standard signal processing (like FFT) or AI-assisted machine learning engines (like LSTM neural networks) to deconstruct, classify, and model EEG signals for better real-time performance and customized feedback. • System can also include adaptive triggers that detect when a user is about to lose focus or shift state, which automatically generates interventions (ex. Sound bursts, flashes, or electromagnetic stimulation) to maintain desired brain states
Research Question/Problem/ Need	Traditional neurofeedback systems are generally limited to training one brain-wave modality at a time and often rely on simple feedback signals, which may result in slower learning and reduced effectiveness.

Important Figures	 Fig. 10
VOCAB: (w/definition)	- Fast Fourier Transform (FFT): mathematical technique to convert time-based signals into frequency components for analysis - Long Short-Term Memory (LSTM): type of recurrent neural network used for temporal pattern learning, used in this system to model EEG dynamics - Moving average: statistical trend indicator calculated over multiple samples to detect the direction of patterns in EEG signals - Adaptive Feedback Generation: dynamic adjustment of feedback modalities based on real-time EEG analysis and ML predictions
Cited references to follow up on	- Machine learning for EEG signal classification: https://doi.org/10.3389/fnins.2018.00244 - LSTM neural networks in brain signal processing: https://doi.org/10.1016/j.patcog.2018.05.009 - Real-time adaptive neurofeedback systems: https://doi.org/10.1109/TBME.2015.2468615 - EEG based feature extraction and classification: https://doi.org/10.1016/j.neuroimage.2010.03.022 - Quantitative EEG and neural modulation techniques: https://doi.org/10.1016/j.clinph.2009.07.034
Follow up Questions	- How does simultaneous multi-frequency training influence learning outcomes compared to single-frequency training in cognitive performance? - How does the use of machine learning models (e.g., LSTMs) compare to FFT-only systems in terms of predictive accuracy and responsiveness? - Can the AI-assisted adaptive feedback mechanism be used to predict individual trainability early in sessions?