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Audio Entrainment Effects Upon Executive Function

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Introduction

The scientific study of perceptual consciousness, as the emergent property of cognitive processes, out of the 'dynamic unconscious' of neurological functions has undergone significant development in the realm of cognitive neuroscience over the past three decades [12]. Whereas our conscious experience of perception was once thought inaccessible to the empirical sciences, contemporary neuropsychological research conceptualises it as a structured, organised, dynamic, and mechanistically causated phenomenon grounded in coordinated neural synaptic system feedback loop oscillations organising themselves into a mental representation of our conscious physical experience.

Modern theories in neuroscience, such as Global Workspace Theory, Integrated Information Theory, and hierarchical predictive-processing architectures, together state that conscious experience arises not from the isolated function of localised neural activity, but from temporally organised, large-scale patterns of coherent cognitive association distributed across the central nervous system linking intracausal node-networks intercausally across the whole brain. These systems engineering models contend that the brain's oscillatory electromagnetic feedback loop rhythms form the coherence of a temporal scaffolding across which perception, cognition, and self-awareness are intertwined. As such, psychological therapeutic interventions which are capable of modulating synaptic oscillatory coherence and unity offer psychological scientists a unique gateway through which to experimentally investigate the alignments of our cognitive neural information processing architecture underlying our emergent epiphenomenal conscious state.

Within this neurocognitive psychophysiological context, auditory entrainment of two divergent frequency stimuli following their transduction into electrochemical energy into a recombined synthesised frequency as an auditory perception, specifically engendered through sound-engineered binaural beat meditation commercial audio productions, is now receiving increasing scientific interest by the mainstream psychological community. When two different frequencies of divergent frequencies are presented dichotically, the brain generates a perceptual experienced wavelength "beat" which is equal to the frequency difference. This phenomenon of experienced perceptual consciousness was first described by Gerald Oster (1973); it reflected the neural computations processed in the superior olivary complex that produces frequency-following neurological responses that are detectable across thalamocortical circuits higher up in the neural information processing architecture of the human brain.

Contemporary research as such appears to demonstrate that binaural beats can modify the brainwave oscillatory power, coherence, and phase synchronisation in specific targeted frequency bands within the rhinal cortex, medial temporal lobes, and hippocampus [11]. These findings therefore indicate that auditory entrainment constitutes a non-invasive method of investigating consciousness, perception, and state-of-mind dynamics through influencing the higher-order temporal areas of neural information processing structural architecture [21].

However, the foundations of the empirical research into binaural beat phenomena still remain largely fragmented, with significant variability in the obtained results due to inconsistent methodological protocols or experimental control over interactive factor variables (Orozco-Perez, Dumas and Saporta, 2020). Many studies also appear to lack sufficient theoretical grounding to make significant advances to the field, or fail to incorporate autonomic arousal markers, such as heart rate variability and perspiration, that are essential to evaluating changes from the baseline cognitive performance and physiological arousal [32].

Theoretical Background

The theoretical paradigm from which the operationalised conceptual framework of this dissertation is constructed draws upon five distinct fields of psychology: cognitive neuroscience, computational models of mind, meditation research, autonomic physiology, and neurophenomenology. Global Workspace Theory, advanced by Stanislas Dehaene, forwards the notion in which the experience of moments of consciousness directly corresponds to the moments in which neural information processes become globally accessible to the whole central nervous system through beta and gamma brainwave frequency synchronisation distributed across multiple integrated cortical systems [27]. The dynamics of predictive-processing theory, shaped by the work of Karl Friston, conceptualises experiential consciousness as the information systems outcome qualia produced by hierarchical cognitive inferences being regulated by precision-weighted neural-node-network prediction error synthesis into holistic neuromath synchrony, where this synchrony signifies the reliability of the sensory data when aligned to a priori neurocognitive data [31].

In contrast, the work of Giulio Tononi's Integrated Information Theory introduces the informational complexity "phi" value of synchronised neural state preservation of entropy, focusing on the system's capacity for the conservation of neural energy through cognitive information systems integration [49]. Despite their differences, these theories share the fundamental assumption that the neural oscillatory unity required for information coherence is indeed foundational to understanding how the dynamics of consciousness, perception, and our state-of-mind qualia form the synaptic electrochemical neural processing quanta [29].

In addition to these neuro-computational and theoretical psychological frameworks, the field of neurophenomenology creates an essential link between the nature of our subjective mental experiences and objective neural processes underlying their mental supervenience emergence as stratified states [34]. Developing out of the mental philosophy of Immanuel Kant (1998)—that the dimension of time is imposed by the conscious mind upon our experience of reality and is not an innate property of reality in itself—the work of Francisco Varela (1996) develops neurophenomenology, suggesting that the stream of consciousness we experience follows an intrinsic temporal structure formatively organised through the rhythmic functions of associative neural processes. Experiences of deep meditative absorption, for example, whilst listening to transcendental audio tapes have demonstrated that shifts in alpha, theta, and gamma brainwave frequency oscillation do indeed correspond to experiential changes in introspective awareness, sensory decoupling, emotional regulation, physiological relaxation, and higher-order self-referential thought. Meditation audio binaural frequency research therefore offers psychologists fertile inspiration for further groundbreaking and pioneering investigation into understanding how deliberate shifts in cognitive ability through attentional focus executive function relate to autonomic physiological arousal, restructuring the subconscious epiphenomenal architecture of conscious perceptual cognitive states.

This thesis investigates how induced transitions between oscillatory frequencies within and between cortical areas should correspond with transitions in cognitive subjective experience, cognitive ability, autonomic arousal, and state of mind. Alpha brainwave frequency increase accompanies top-down suppression of incoming sensory information and the internalisation of focused attention; theta frequency brainwave increases reflect enhanced introspective self-monitoring; gamma frequency synchronisation shows heightened perceptual integration of information and, in the case of advanced meditative states, a capacity for non-conceptual conscious awareness. These parallels between objective brainwave activity states and subjective conscious experiential states suggest that there may be an underdeveloped knowledge of how auditory entrainment has the potential to artificially induce brainwave frequency state transitions resembling those of dedicated meditative contemplative practice cultivated over many years. If this is so, then the burgeoning field of binaural beat research represents not merely an auditory curiosity within the psychospiritual new-age circles of modern pseudoscience, but a mechanistically coherent investigative tool for synthetically inducing experimentally controlled shifts in our state-of-mind mental representation qualia through our neurological precept intuitive cognitive architecture.

A fundamental part of the theory of this research dissertation relates to the nature and function of autonomic physiology. The capacity for metacognitive attentional control of incoming sensory data through top-down executive inhibition of physiological impulse and how this top-down focus mediates our attentional stability are intertwined through sympathetic and parasympathetic nervous system integrative regulation of association pathway cognitive information processes. The neurovisceral integration model holds that low levels of sympathetic arousal support optimal prefrontal lobe functioning, and that heightened sympathetic nervous system arousal has the tendency of disrupting latent inhibitory control [48]. Electrodermal activity (EDA), which indexes through changes in skin conductance levels the perspiration causated indication of the level of sympathetic nervous system activation, is one of the most sensitive and non-invasive measures of an individual subject's level of autonomic arousal and negatively correlated levels of sympathetic to parasympathetic nervous system control and physiological state organisation. Furthermore, analytical study of transcendental meditation repeatedly shows that continued deepened practice of meditative techniques negatively correlates to decreases in EDA, suggesting a shift in the physiological subconscious organisation of the individual's state-of-mind toward a modus operandi of predominant parasympathetic dominance [50].

This research dissertation aims to integrate the investigative experimental techniques of EDA into emerging binaural-beat cognitive entrainment paradigms as a novel method for the quantifying of autonomic shifts in arousal level which may influence the levels of a participant's executive function capability. This integration of the experimental technique is both timely to current research trends and also methodologically necessary, given that much of the published research prior to this into the binaural-beat field often ignores autonomic variables. Without such strict experimental measures, it often becomes difficult to disentangle inferences and deductions as to whether behavioural effects observed are due to oscillatory neurological brainwave modulation, autonomic arousal changes, the expectancy effects of research participants, or combinations of interactive effects between these factors thereof.

The final cornerstone of the theoretical paradigm for this research dissertation regards the function of executive inhibitory processes. 'The gorilla executive function task' offers in this regard a robust experimental measure of automatic response suppression and executive function attentional control. If auditory entrainment shifts neocortical neuro-oscillatory and autonomic nervous system arousal states, then the participatory subject's performance on both administrations of the task will require explicit inhibitory control over autonomic instinctual impulse; the collected data should, if the premise is accurate, reflect these transitory changes in arousal and improved performance on the aforementioned test. Evidence from meditation neuroscience suggests that increased frontal-midline theta supports behavioural inhibition and conflict monitoring [23]. If theta-frequency entrainment produces a similar modulation of frontal networks, then behavioural benefits should be observable.

Taken together, these three strands of intercortical oscillatory neuroscience, autonomic arousal physiology, and executive function cognitive inhibition form the basis of this research rationale. Despite the increasing levels of now widespread public use of binaural beats for personal development and self-improvement, our empirical foundations for developing the scientific understanding of the objective processes behind and engendered benefits from engaging with such media still remains sparse and incomplete, as existing research papers into the area frequently suffer from methodological inconsistencies in paradigm constructive research, insufficient theoretical grounding in paradigm testing research, and limited integration of neural and physiological measures to extend the research data from the purely speculative and subjective relativistic data to include concrete and objective physiological and neurological data to triangulate more accurate inferences and conclusions thereof.

Literature Review

Modern cognitive neuroscience often conceptualises consciousness, the core functions of our executive control, and our surface-level perceptual awareness not as isolated neural node functions of discrete independent cortical regions, but as properties emergent from synchronised cognitive network-scale interactions distributed across neural systems operating as large-scale oscillatory synapse architectures. The previous formulation of the localisationist model of neurocognition causates the reduction of individual psychological functions to singular neuroanatomical centres. However, electrophysiology, neuroimaging, and computational neuroscience now emphasise systems-level theories of oscillating neural synapse synchronisation into a temporally coherent stream of consciousness through inter-network communication as the subconscious foundation underlying the apex of conscious cognition [27, 31, 49]. Combining type-identity frameworks of attentional regulation, executive inhibition, emotional processing, and subjective conscious awareness as dynamically organised phenomenological qualia emerging as token-identity aspectual shape oscillatory synaptic firing patterns, coordinated into mental representations throughout cortical and subcortical neural networks, the strata of cognitive consciousness emerge [17, 30, 52].

Neurocomputational paradigms of consciousness converge on the principle of temporal synchronisation as a structural basis for coherent cognition emerging from the distribution of patterns of neural activity. Global Workspace Theory proposes that our conscious awareness arises as neural information becomes globally accessible cognitive neurocode qualia, widespread across cortical systems through coherent oscillatory broadcasting mechanisms integrating perception, memory, and behavioural regulation into a unified conscious state [10, 27]. Predictive-processing frameworks model the qualia of cognition as engendered from hierarchically organised inferential processes of electromagnetic oscillatory synchronisation regulating the precision-weight of interstrata prediction-error apex alignment in the minimisation of energy expenditure across interconnected electromagnetic cortical systems [31, 22, 43].

Integrated Information Theory further extends this systems perspective by suggesting that consciousness emerges from the informational complexity and integrative capacity of synchronised neural architectures functioning as unified informational structures preserving coherent neural entropy states across distributed networks [49]. Although differing substantially in theoretical emphasis, these models collectively position oscillatory synchronisation and temporal neural coherence as foundational mechanisms underlying conscious cognition and adaptive behavioural organisation.

Neural oscillations between electrolytes and neurotransmitters constitute the principal organisational mechanism through which nodes of cognition become integrated into coherent consciousness. Oscillatory synchronisation enables communication between anatomically separated neural populations temporally coordinated into firing patterns which facilitate efficient information transfer across functional brain systems [17, 30]. Distinct oscillatory frequency bands have repeatedly been associated with different cognitive and behavioural states [18]. Beta oscillations are strongly associated with externally directed attention, sensorimotor integration, and active cognitive engagement [28].

Alpha-frequency synchronisation is commonly associated with relaxed wakefulness, sensory inhibition, and top-down attentional gating, with subconscious mechanisms suppressing irrelevant perceptual processing [35]. Theta oscillations, particularly within frontal-midline cortical regions, appear to be involved in the introspection, working memory, behavioural inhibition, and conflict-monitoring processes of executive control [19]. Delta oscillations are strongly associated with deep sleep states, reduced environmental responsiveness, and regenerative physiological and cognitive processes [45]. Oscillatory energy systems do not operate independently, but instead through matter form interacting temporal energy resonance architectures through which cognition, perception, and self-awareness can become dynamically organised from lower into higher coherent experiential states of manifestation.

Within this broader neurophysiological framework, scientific attention has increasingly focused upon whether or not externally applied rhythmic sensory stimulation influences endogenous neural synchronisation, altering cognitive and autonomic functioning. One of the most widely investigated forms of rhythmic sensory modulation is auditory entrainment through binaural beat stimulation. Binaural beats occur when two pure tones of slightly different frequency are presented dichotically to each ear, producing the perceptual experience of a third internally generated oscillating frequency which corresponds to the mathematical difference between the two tones [40]. Oster's foundational research demonstrated that this phenomenon reflects the phase-sensitive nature of neural processing occurring within the superior olivary complex and associated thalamocortical auditory pathways.

Electrophysiological investigations have also suggested that binaural beat stimulation influences oscillatory power, coherence, and phase synchronisation within cortical and limbic structures including the hippocampus, rhinal cortex, and medial temporal systems [11]. Research into auditory entrainment is theoretically grounded in the broader context of the principle of the frequency-following response, where neurological brainwaves exhibit the tendency to align towards a partial synchronisation with the transduced external rhythmic sensory stimuli input [38].

Auditory entrainment at a foundational level of transduction into axon action potentials in set sequences bias the oscillatory activity of brainwaves toward the particular frequency states associated with several distinct patterns of cognition and physiological organisation within targeted neurological areas. Qualitative and quantitative empirical investigations have reported an association between exposure to binaural beat stimuli and alterations in reported states of mind towards vigilance, attentional processing, anxiety reduction, memory performance, and emotional regulation [2, 36, 53]. However, despite growing public interest and scientific literature into the binaural beat phenomena, objective empirical literature of the subject at the academic level still remains largely fragmented and adherence to standardised methodological criteria for investigation into its quantitative dynamics and qualitative effects is still too varied in parameters and inconsistent in results for a corpus of solid theory to be formed.

Meta-analytic reviews which tried to gather data from multiple studies and research papers into a methodologically consistent and solid theoretical foundation to establish the subject area in academic psychological research have repeatedly highlighted a substantial degree of heterogeneity throughout the conducted individual pieces of binaural beat research relating to stimulus duration, carrier frequencies, participant expectancy effects, sample sizes, and behavioural outcome measures [32, 39]. Currently available studies additionally have failed to incorporate the measurement of physiological indices of autonomic state directly, thereby limiting the ability of psychologists to determine whether the observed cognitive-behavioural effects observed after experimentation do in fact reflect genuine sympathetic and autonomic nervous system oscillatory modulation, or in fact reveal an expectancy-driven recording of observed false-positive placebo responses. The mechanistic relationship between transduced auditory entrainment, neural synchronisation, autonomic regulation, and executive cognitive functioning until this paper still remains largely unexplored.

The interaction between the neural dynamics of the prefrontal cortex, anterior cingulate, amygdala, and hypothalamus with autonomic physiology are important to modern contemporary models of cognitive state regulation. The neurovisceral integration model explicates that executive functioning, emotional regulation, and attentional stability are engendered by the reciprocal feedback interactions of the prefrontal cortex, limbic networks, and autonomic nervous system being organised as the resulting network-level consciousness events [47, 48]. Prolonged activation of the sympathetic nervous system is often considered as resulting in impaired inhibitory control, attentional instability, and reduced prefrontal efficiency; increased parasympathetic regulation however supports the individual in successful adaptive emotional regulation and flexibility in their executive functioning abilities [9]. The experimental investigative technique of monitoring electrodermal activity, measured through changes to galvanic skin response, provides a non-invasive measure of sympathetic nervous system arousal, as changes in skin conductance levels associated with the perspiration caused by sweat gland activity indicate the participant's physiological arousal states [14, 25].

Meditation research in psychology and the attentional training paradigm has consistently demonstrated the relationship between oscillatory synchronisation between neural and sonic systems with a resulting effect upon autonomic modulation. Increased alpha and theta synchronisation achieved through meditation often corresponds with reductions in electrodermal activity, a decreased level of sympathetic alertness and arousal with enhanced states of restorative parasympathetic dominance [46, 50]. Detection of frontal-midline theta activity often indicates increases in the capacities of behavioural inhibition, conflict monitoring, and improved executive attentional control evident as one engages in cognitively demanding tasks [19, 23]. These research pieces align beliefs that oscillating auditory stimulation when transduced is capable of synchronising alpha and theta brainwave oscillations, states of neurocognitive functioning which result in altered executive function ability through influencing the autonomic parasympathetic physiological modus operandi organisation through frontocortical synchronisation dynamics.

Executive function is now conceptualised as a distributed neurological systems-level cognitive phenomenon, rather than independent frontal-lobe cognitive activity. The capacity of individuals to exhibit inhibitory suppression, attentional regulation, working-memory manipulation, and behavioural adaptation are emergent properties of coordinated association between frontal, parietal, and cingulate cortical areas [37, 41]. Involved in this, the dorsolateral prefrontal cortex influences the individual's functional working-memory processes and behavioural organisation, while the anterior and midcingulate cortex areas seem to be implicated in the processes of conflict monitoring, effort allocation, and executive behavioural correction [13, 44]. Parietal attentional networks within the intraparietal sulcus coordinate the individual's attentional orientation and cognitive resource allocation being directed through intentionalisation upon relevant stimuli [24].

Recent research studies into the neurocognitive effects of meditation upon the individual have highlighted the significance of interaction between self-referential neurological systems and externally directed attentional and sensory networks. The precuneus acts as a major neurological hub within the cognitive dynamics of the Default Mode Network, appearing as having a functional role in the mental processes of autobiographical reconstruction, self-referential cognition, and generating internal simulations as mental representations [16, 20]. Changes to the dynamics of precuneus activity have been observed during meditation and altered attentional states of awareness, further suggesting there will be underlying relationships between oscillatory neural synchronisation, the emergence of introspective awareness, and engagement of executive control processes [15]. Conversely, the intraparietal sulcus functions within the dorsal attention network to mediate top-down attentional allocation and visuospatial indexing, giving greater metacognitive control of information which is amplified in working memory [42]. While the midcingulate cortex appears to integrate autonomic regulation, motor planning, and behavioural adaptation through integrating physiological responses to the environment with goal-directed and cognitive control orientated behaviour [3, 44].

Taken together, these findings suggest that conscious cognitive state regulation emerges through continuous reciprocal interaction between sensory nodes in oscillatory synchronisation at the synaptic level with cognitive neural networks and autonomic physiological organisation of these neural networks into neurocognitive alignment with executive-control systems such as the precuneus. Auditory entrainment may therefore represent a gateway to subconsciously influencing through externally imposed rhythmic stimulation the neural timing and cognitive state organisation between such areas: developing a potentially valuable experimental paradigm at the forefront of modern psychology. Nevertheless, a rigorous empirical understanding of the mechanisms by which binaural beat auditory entrainment acts upon these different areas still remains limited according to meta-analysis by the inconsistent methodologies, insufficient theoretical integration, and inadequate incorporation of objective physiological measures used by the psychological community whilst investigating this new area of research.

This dissertation therefore seeks to add clarity to the area by addressing these limitations through further adding executive-function assessment along with continuous electrodermal measurement during the structured binaural beat stimulation session. Through examining galvanic skin response data alongside inhibitory-control performance results across the transition between oscillatory frequency conditions, this research paper seeks to investigate whether the cognitive effects of binaural beat auditory entrainment do in fact correspond with measurable indicators of change in parasympathetic autonomic arousal and therefore executive cognitive functioning inhibitory ability as a result. As such, this study shall attempt to contribute towards a more complete paradigm of binaural beat auditory entrainment through adding the neurophysiological dynamics which includes the relationship between oscillatory synchronisation, autonomic regulation, and executive cognition to contemporary cognitive neuroscience literature.

Methodology

Rationale

The Monroe Institute of Applied Sciences on behalf of the American Central Intelligence Agency (CIA) developed an intelligence gathering psychological operation designed to train military personnel and agents 'remote viewing' psychic espionage abilities in a secret operation known simply as: The Gateway Program, [5]. Through deploying a process known as cognitive entrainment, where brainwave states respond to external stimuli, including Robert Monroe's binaural beats and Hemi-Sync-style sine-wave frequency modulation, has been widely investigated for its effects on cognition, attention, relaxation, and mood. Research has largely focused on cortical activity, demonstrating that frequency-following responses in alpha, beta, and gamma bands correspond to mental states such as focus, relaxation, and 'fight or flight' response, [6, 8]. However, there is limited exploration of peripheral physiological measures, particularly electrodermal activity (EDA), as a non-invasive index of autonomic arousal during auditory entrainment. EDA provides a sensitive measure of sympathetic nervous system activation, reflecting both cognitive load and emotional engagement [1, 25].

Current literature has also not fully addressed how cognitive entrainment affects peripheral autonomic responses, or how baseline cognitive states, such as executive function versus relaxation. By measuring galvanic skin response (GSR) during structured auditory entrainment enables assessment of sympathetic arousal across high-frequency (beta and gamma) and low-frequency (alpha, theta, delta) audio stimuli. Investigating these effects under distinct cognitive conditions allows insight into individual variability in physiological responsiveness to auditory entrainment.

This research is significant because it offers a practical, non-invasive methodology to study autonomic reactivity. Understanding the interaction between cognitive state and auditory entrainment may inform interventions in cognitive enhancement, stress reduction, and wellness. The phased auditory approach progressing through beta, gamma, beta, alpha, theta, and delta bands allows systematic evaluation of how different frequencies influence sympathetic activation.

Hypotheses

The nature of this research is exploratory and will utilise single-case design to examine whether GSR is a robust measure for cognitive entrainment. Based on current knowledge of the literature, it is possible that electrodermal activity will vary systematically across the audio cognitive entrainment sequence, with higher sympathetic activation during high-frequency blocks (beta and gamma) and lower activation during low-frequency blocks (alpha, theta, delta).

This exploratory study may provide insight into cognitive and autonomic functional interactions and potentially demonstrate the effect of cognitive entrainment upon executive function. To explore the cognitive effects, an executive function task from the Gorilla repository will be delivered pre- and post-intervention. Participants who exhibit greater overall sympathetic activation than those who do not, are predicted to score improved results for their executive functioning ability, reflecting their less active baseline cognitive brainwave frequency state.

As a result of successful alteration of brainwave frequency through audio entrainment, participants are expected to show faster initiation, fewer inhibition errors and reduced response latencies and a smaller latency difference after delta-range entrainment, indicating improved inhibitory control corresponding to reduced sympathetic activation of the bodies 'fight or flight' response.

Participants

Three adults aged 18 and over with normal hearing, right-handedness, and no neurological or psychiatric disorders will participate in this study. Recruitment will occur through the University of South Wales Psychology Department participant pool and noticeboards, without compensation. All participants will complete the executive function task, both prior to and post of the experiment to explore effects of Delta wavelength entrainment states upon executive function as indicated by galvanic physiological responses.

Design

A within-subjects experimental design will be used. The independent variable is the binaural beat ten-minute audio stimulus. The primary dependent variable is physiological response recorded by the Galvanic Skin Response (GSR) and the secondary dependent variable is the test score recorded on the executive function task post exposure to the entrainment audio. The skin conductance level (SCL) and number of skin conductance responses (SCRs) may indicate the extent of the psychophysical effects upon brainwave entrainment by the audio stimulus upon the cognitive state of the individual measured through the participants recorded autonomic skin responses.

Apparatus & Materials

The binaural beat auditory stimulus used in this experiment consisted of a ten-minute stereo recording delivered through noise cancelling stereo headphones, to minimize the extraneous variable of the external source of noise of a nearby construction site, presenting the stimulus at a comfortable standardised listening volume across all three participants. The recording was designed to present four different pure-tone frequencies at 110Hz, 220Hz, 330Hz and 440Hz independently to each ear, creating a precept experience of an entrained binaural beat which corresponds to the frequency difference between left and right auditory sensory channels. Conventional binaural beat stimuli employ a fixed and sustained interaural frequency difference throughout the exposure period, this stimulus according to frequency following theories of entrainment incorporated a gradually shifting frequency gradient in which the left and right-channel carrier frequencies gradually converged over the duration of the recording, as the Hertz of the wavelength of the left ear ascended, the Hertz of the right ear descended; with the frequency offset between the two gradually decreasing from 17Hz to 4Hz. Therefore, allowing the perceived binaural beat frequency to decrease to decrease progressively enhancing the frequency following effects of the audio according to the brains bilateral structure as to the pre-established laws of the sensory entrainment of perception; an adaptive rather than fixed static stimuli.

The mean interaural frequency difference between right and left sensory inputs gradually reduced systematically throughout the ten minutes of the stimulus, beginning at 17 Hz corresponding to a Beta brainwave state, then gradually declining towards approximately 8 Hz at the Alpha-Theta junction, then by the conclusion of the recording at 4Hz the bridge between Theta and Delta. The auditory stimulus continuously progressed through the oscillatory frequency ranges commonly associated in neuroscience literature with externally orientated attentional engagement to relaxed wakefulness, and then to increasingly internally directed cognitive states. Instead of utilising a series of isolated frequency bands in separate isolated discrete blocks, this recording deployed a smooth transition gradient between these identified frequency ranges, thereby minimising any abrupt change to the perception of the binaural beat; maintaining continuous auditory stimulation throughout the transition period between recognised brainwave frequency dependent cognitive states, (Gelfand, S. A., 2011). Executive function was assessed using the Alternate Task Switching, Digit Span, Spatial N Back & Sustained Attention tasks from the Gorilla Library.

Procedure

Participants provide informed consent and receive an overview of the study, after which the GSR electrodes are attached and a 5-minute baseline was recorded. Following baseline acquisition, participants complete the assigned pre-entrainment task, which is immediately followed by the playback of the 10-minute audio sequence under continuous GSR recording conditions. Once the audio sequence finishes, participants complete the assigned post-entrainment task, and the session concludes as participants are debriefed and reminded of their right to withdraw data before final analysis.

Ethical Concerns

Risk: Audio stimuli will be ≤75 dB to prevent discomfort. Continuous monitoring ensures participant safety, and sessions may be paused or terminated at any time. GSR electrodes pose minimal risk aside from potential minor skin irritation. Laboratory safety protocols will protect both participants and researchers.

Valid Consent: Participants receive an information sheet detailing aims, procedures, risks, and expected duration. Written and verbal consent will be obtained, including explicit agreement for data use in reporting. No deception is used, and participants may withdraw at any point prior to final report submission.

Deception: No deception is employed. Procedures are fully disclosed prior to consent, preserving autonomy and dignity.

Confidentiality, Anonymity, and Right to Withdraw: Data will be anonymized and stored securely on password-protected servers. Participants may withdraw at any time, with data removal upon request given if prior to the report submission.

Briefing & Debrief: Participants will receive a full briefing and debrief explaining the aims of the study, the rationale for auditory entrainment, and the expected outcomes. They may request a summary of results after analysis.

Giving Advice: Researchers will clarify they cannot provide individualized medical or psychological advice and will signpost participants to appropriate professional support if needed.

Results

See Tables (1-4) and Figures {1-7).

Discussion

Participant VM

Participant VM revealed a multifaceted behavioural profile following the auditory binaural beat intervention. The participants performance across the Alternate Task Switching, Digit Span Forward, Spatial N-Back and Sustained Attention assessments highlighted differential changes between processing speed and behavioural accuracy rather than a universal cognitive enhancement across all measured domains. These behavioural findings suggest that auditory entrainment may have facilitated specific executive cognitive mechanisms according to the demands imposed by each assessment. This understanding is concordant with contemporary cognitive neuroscience models which define executive cognition as a distributed network level interaction between multiple neural systems rather than a single independent ability [22, 37].

Furthermore, the Alternate Task Switching performance of Participant VM exhibited a slower behavioural response following the intervention, whilst maintaining stable accuracy. Alternate Task Switching primarily investigates executive cognitive flexibility, requiring the participant to rapidly modify behavioural strategies, suppress previously relevant responses and update task requirements,

Table 1: Sustained Attention Test.

	Condition	Accuracy	Average RT	Baseline 1 EDA	Baseline 2 EDA	Music Average EDA
VM	Pre-Condition	1202.690909	21	2.13	2.07	2.02
VM	Post-Condition	1196.472727	20			
AM	Pre-Condition	1288.081818	22	3.38	2.49	2.62
AM	Post-Condition	1262.722727	22			
AJ	Pre-Condition	1271.231818	22	5.34	2.75	3.52
AJ	Post-Condition	1287.940909	22			

Table 2: Digit Span Forwards.

	Condition	Accuracy	Average RT	Baseline 1 EDA	Baseline 2 EDA	Music Average EDA
VM	Pre-Condition	2163.72	49	2.13	2.07	2.02
VM	Post-Condition	1944.21	49			
AM	Pre-Condition	2040.72	48	3.38	2.49	2.62
AM	Post-Condition	2018.02	47			
AJ	Pre-Condition	1838.76	50	5.34	2.75	3.52
AJ	Post-Condition	R7C3	49			

Table 3: Spatial N Back.

	Condition	Accuracy	Average RT	Baseline 1 EDA	Baseline 2 EDA	Music Average EDA
VM	Pre-Condition	912	13	2.13	2.07	2.02
VM	Post-Condition	884.9693208	13			
AM	Pre-Condition	615.2153846	5	3.38	2.49	2.62
AM	Post-Condition	777.3384615	9			
AJ	Pre-Condition	923.6769231	13	5.34	2.75	3.52
AJ	Post-Condition	891.607923	13			

Table 4: Alternate Task Switching.

	Condition	Accuracy	Average RT	Baseline 1 EDA	Baseline 2 EDA	Music Average EDA
VM	Pre-Condition	1128.4875	15	2.13	2.07	2.02
VM	Post-Condition	1490.23125	15			
AM	Pre-Condition	1362.90625	9	3.38	2.49	2.62
AM	Post-Condition	1290.875	12			
AJ	Pre-Condition	1156.6125	16	5.34	2.75	3.52
AJ	Post-Condition	772.4125	15			

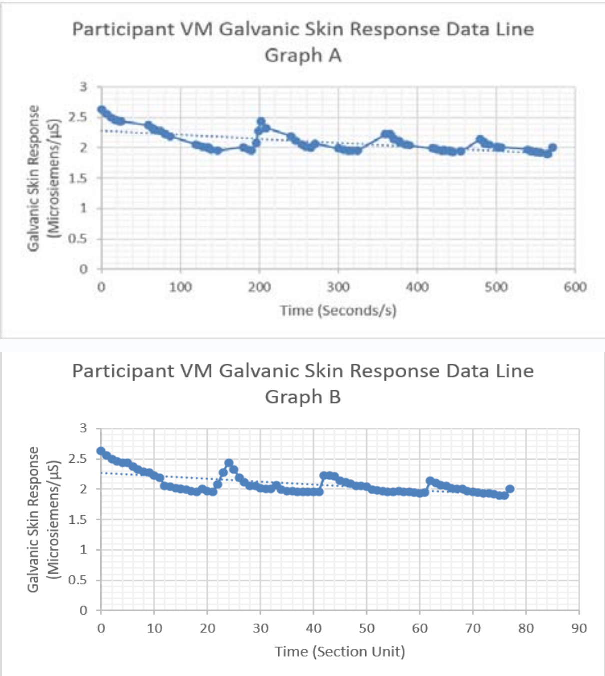

Figure 1:

(Monsell, 2003). The observed pattern suggests that VM may have adopted a more cautious response approach rather than demonstrating reduced cognitive capability. Slower completion time combined with preserved accuracy may reflect increased allocation of executive resources towards behavioural monitoring and response verification. Therefore, the result should not automatically be interpreted as cognitive decline because executive performance requires a balance between processing speed, accuracy and behavioural control, (Heitz, 2014).

Digit Span Forward performance demonstrated a quicker completion time alongside maintained accuracy for Participant VM.

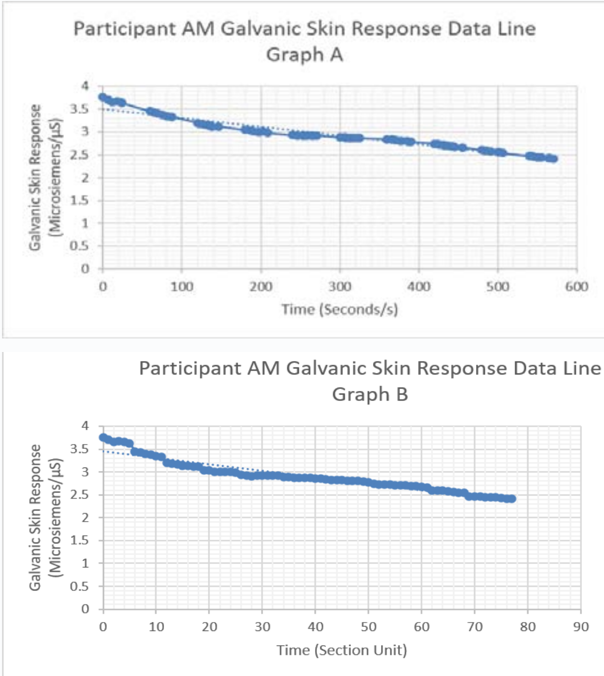

Figure 2:

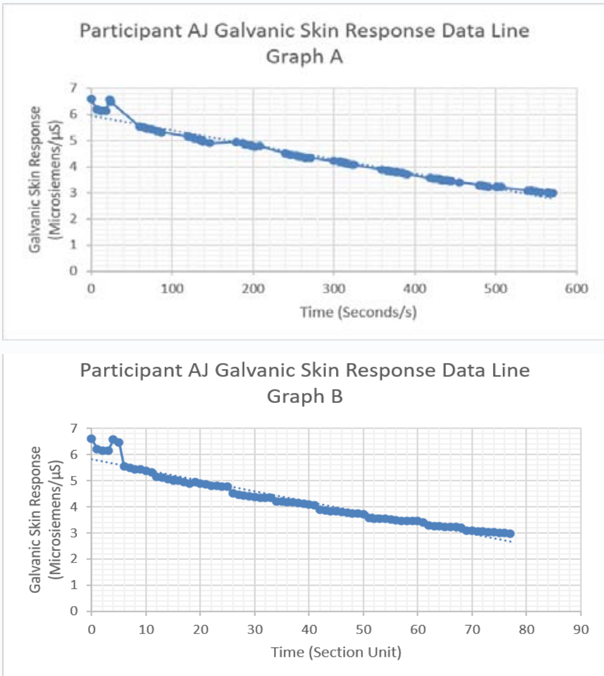

Figure 3:

Digit Span Forward principally evaluates immediate attentional encoding together with temporary phonological memory rather than active executive manipulation of information, (Baddeley, 2012). The improvement in completion speed suggests that auditory stimulation may have influenced attentional readiness and immediate information processing efficiency. However, because accuracy remained unchanged rather than increasing, the findings may reflect enhanced cognitive efficiency rather than increased short-term memory capacity. This distinction is significant because

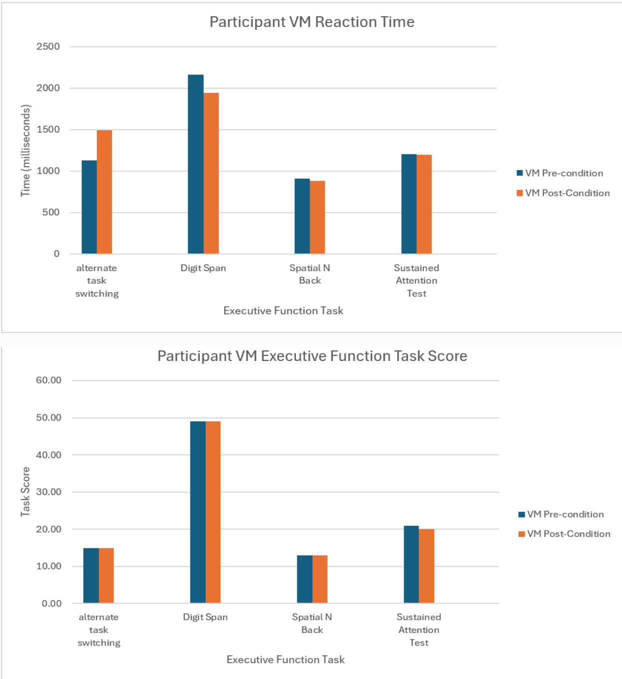

Figure 4:

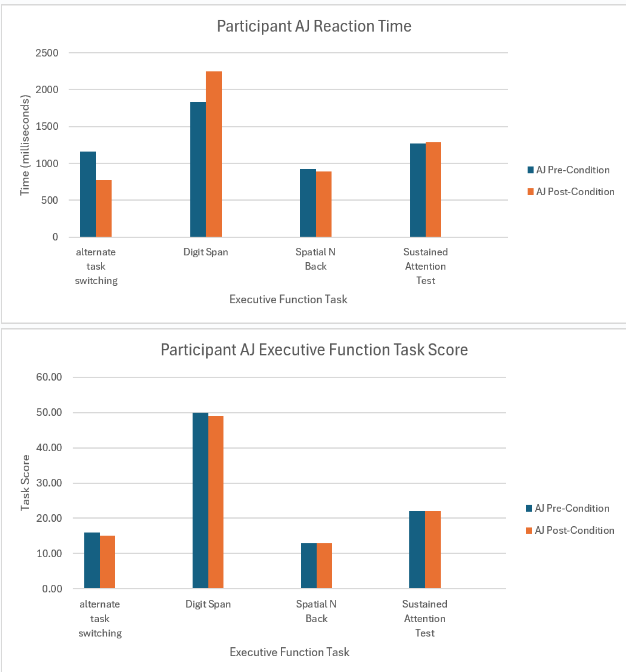

Figure 5:

improvements in response speed do not necessarily represent broader cognitive enhancement unless accompanied by maintained or improved accuracy.

The Spatial N-Back assessment produced one of the most consistent behavioural outcomes for Participant VM. Spatial N-Back primarily assesses executive working-memory updating, requiring continuous comparison between current and previously presented visuospatial information, (Owen et al., 2005). Participant VM demonstrated faster responding whilst maintaining behavioural

Figure 6:

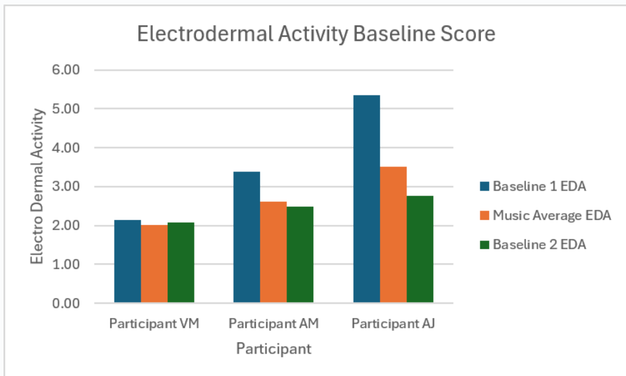

Figure 7:

accuracy, suggesting a more efficient executive processing response following auditory stimulation. These findings suggest that frontoparietal executive networks may have become more efficiently engaged during working-memory operations. Such an interpretation is compatible with research identifying frontal-midline theta activity and prefrontal-parietal communication as important mechanisms underlying working-memory performance and cognitive control [19].

Nevertheless, the Sustained Attention assessment demonstrated a further variable response pattern. Participant VM demonstrated faster behavioural responding,indicating a possible increase in processing efficiency during prolonged attentional demands. Sustained Attention primarily investigates vigilance, attentional persistence, resistance to fatigue and the ability to maintain goal-directed behaviour over time, (Robertson et al., 1997). The observed improvement in speed indicates increased attentional readiness; however, interpretation must consider the relationship between speed and accuracy. A faster response pattern may reflect improved attentional allocation, although it may also represent a strategic adjustment towards rapid behavioural execution.

Consequently, when considered collectively, Participant VM's behavioural results demonstrate a selective cognitive response following auditory binaural beat stimulation. The strongest improvements occurred within processing speed measures, particularly Digit Span Forward, Spatial N-Back and Sustained Attention, whereas Alternate Task Switching demonstrated preserved accuracy with slower completion. This overall profile suggests that auditory entrainment may have modulated executive processing efficiency without producing a universal increase in cognitive performance. VM's results therefore provide evidence that cognitive responses to auditory stimulation may depend upon the specific executive processes recruited, baseline cognitive strategy and individual neurophysiological characteristics.

Additionally, the integration of VM's behavioural findings with galvanic skin response analysis will provide further insight into whether observed cognitive changes occurred alongside alterations in autonomic regulation. Participant VM demonstrated an overall decline in skin conductivity across the ten-minute auditory stimulation period following a stable pre-test baseline characterised by minimal fluctuation. These physiological reductions may represent altered sympathetic nervous system activity and increased autonomic regulation during auditory stimulation, providing additional context for interpreting behavioural adaptation.

Participant 1 VM displayed a progressive reduction in GSR across the recording, interrupted by three pronounced increases in skin conductivity during changes in the imagery and attentional focus of the body scan guided meditation vocals. The participant began at approximately 2.63μS, after which skin conductance declined during the opening instructions to "close or soften the eyes", acknowledge continuing thoughts and "settle into the present moment". A further evident fall occurred between approximately 86.90 and 119.74 seconds, when GSR decreased from around 2.19μS to 2.06μS during instructions concerning bodily support, exhalation and attention to breathing. This interval represented a calmer more-settled phase of physiological activity.

The most substantial rise occurred during the leaf-and-stream visualisation. At approximately 190 seconds, GSR was around 1.96μS as the participant imagined the visualisation of placing thoughts onto leaves. The response then rose to approximately 2.44μS as the imagined stream was then described as carrying the thoughts away from the subject and the participant was encouraged to move from engaging active conscious effort into passive autonomous ease. This temporary increase in arousal may indicate the heightened attentional awareness gained through engagement with the visual imagery rather than the immediate relaxation of disengagement with attentional thought processes. GSR subsequently declined during the safe and reassuring imagery of lying in a darkened room beneath a warm blanket. Overall, VM Participant 1 displayed a fluctuating GSR pattern through combining general relaxation periods with episodic attentional activation.

Participant AM

Participant AM exhibited the most consistent behavioural profile across the cognitive assessment battery. Performance improvements were observed within Alternate Task Switching, Digit Span Forward and Sustained Attention, whilst Spatial N-Back demonstrated improved behavioural accuracy. These findings suggest that auditory binaural beat stimulation may have enhanced multiple executive cognitive processes rather than producing isolated changes within a single domain. Such a behavioural response is consistent with contemporary theories of executive cognition, which describe cognition as an integrated interaction between attentional control, working-memory updating, cognitive flexibility and behavioural regulation [38].

The Alternate Task Switching assessment provided important behavioural outcomes for Participant AM because this assessment primarily assesses executive cognitive flexibility. Successful task switching requires the ability to suppress previous response patterns, update changing task demands and maintain accurate behavioural performance under competing cognitive conditions, (Monsell, 2003). Participant AM demonstrated faster completion together with maintained behavioural accuracy, creating a positive executive performance pattern. This behavioural improvement demonstrates increased efficiency within executive control mechanisms rather than simply increased response speed. The outcome may reflect improved communication between prefrontal executive regions and associated attentional networks responsible for behavioural switching and response inhibition [38].

Digit Span Forward performance also demonstrated a more efficient completion time for Participant AM, although behavioural accuracy declined. Digit Span Forward primarily investigates immediate attentional maintenance together with temporary phonological traces, rather than active executive manipulation of information, (Baddeley, 2012). The faster completion time suggests better attentional processing efficiency following auditory stimulation; however, the reduction in accuracy introduces a more multifaceted interpretation. Rather than representing a straightforward cognitive improvement, the result may reflect a shift towards faster information processing with reduced response verification. This finding highlights the importance of interpreting cognitive performance through both behavioural speed and accuracy rather than relying upon a single outcome measure, (Heitz, 2014).

Participant AM produced the strongest Spatial N-Back outcome within the present investigation, with improved behavioural accuracy following the auditory intervention. Spatial N-Back primarily investigates executive working-memory control, requiring continuous comparison and modification of stored visuospatial information, (Owen et al., 2005). Improved accuracy within this assessment provides important evidence of enhanced executive monitoring because successful performance requires simultaneous maintenance, evaluation and updating of information. These findings suggest that auditory entrainment may have strengthened working-memory processes through improved coordination of frontoparietal executive networks. This interpretation is consistent with research demonstrating that frontal-midline theta activity contributes to working-memory regulation and cognitive control [19].

In contrast the Sustained Attention assessment further demonstrated a consistent behavioural response for Participant AM. Faster responding following the intervention suggests possible improvement in attentional processing efficiency, particularly during tasks requiring prolonged concentration and behavioural persistence. Sustained Attention primarily evaluates vigilance, attentional endurance, maintenance of goal-directed behaviour and resistance to cognitive fatigue (Robertson et al., 1997). The observed behavioural change demonstrates that Participant AM maintained attentional regulation whilst processing information more rapidly. This pattern may demonstrate improved allocation of attentional resources rather than simply increased behavioural speed.

When Participant AM's complete behavioural profile is considered collectively, the results provide the strongest evidence for enhanced executive functioning following auditory stimulation. Improvements across executive flexibility, working-memory accuracy and sustained attention demonstrate that the intervention may have influenced several interconnected cognitive functions. The findings support existing literature by demonstrating that short-duration auditory entrainment may produce measurable behavioural changes within higher-order cognition. However, the variation observed between assessments also reveals that cognitive enhancement is unlikely to occur uniformly across every cognitive process.

Participant AM's galvanic skin response data provides additional information regarding whether behavioural improvements occurred alongside physiological regulation. Participant AM demonstrated a gradual decline in skin conductivity across the ten-minute intervention period following a stable pre-test baseline period characterised by minimal increase or decrease.

Participant AM presented the most stable and consistent GSR pattern of the three participants, characterised by a largely uninterrupted and sustained decline throughout the whole of the relaxation exercise. The recording began at approximately 3.76µS, followed by a reduction to around 3.70µS during the opening instructions to settle, soften the eyes and focus upon the present moment. Skin conductance continued to decrease steadily throughout the permission statements, body scan and breathing stages, with very few upward ascending deviations.

A particularly clear and evident fall in GSR identified in the data occurred between approximately 24.56 and 59.72 seconds, when GSR decreased from around 3.63µS to 3.45µS. This interval followed the statement: “You do not need to force this,” and preceded the instruction to bring attention into the head and face. This reduction in GSR corresponded with the transition from general introspective reassurance into focused and directed concentrated bodily awareness. A further decrease from approximately 3.33µS to 3.20µS occurred between 86.90 and 119.74 seconds during the meditation sequence instructions to allow the body’s weight to be supported and to turn attention towards the breath, signalling rest and digest behaviour.

Unlike the other participants, AM did not display any major or substantial pronounced rises during the visual imagery sequences. The minor increases in GSR were extremely small, limited and negligible and may reflect ordinary extraneous signal variability of the equipment. Overall, Participant 2 AM demonstrated a smooth and orderly progressive decline towards reduced physiological activation.

Participant AJ

In contrast, Participant AJ showed the most complex behavioural trend within the present investigation. Unlike Participants VM and AM, where improvements were comparatively consistent across several cognitive measures, AJ displayed a more domain-specific response following auditory binaural beat stimulation. Performance improvements occurred within Alternate Task Switching and Spatial N-Back, whilst reductions were observed within Digit Span Forward and Sustained Attention. These behavioural results suggest that auditory entrainment may have affected specific executive cognitive systems rather than producing a universal enhancement across all measured domains. This interpretation is compatible with contemporary neuroscience perspectives which identify cognition as an interaction between multiple specialised but interconnected neural systems [42].

The Alternate Task Switching assessment demonstrated an observable behavioural improvement for Participant AJ, with faster completion following the intervention; however, this improvement occurred alongside reduced behavioural accuracy. Alternate Task Switching primarily assesses executive regulation, requiring rapid modification of behavioural strategies, inhibition of previous responses and continuous monitoring of changing task requirements, (Monsell, 2003). The faster completion time suggests increased processing efficiency during executive switching demands. However, reduced accuracy introduces a more multidimensional interpretation because improved speed without maintained precision may demonstrate reduced response monitoring or increased willingness to prioritise rapid execution. Therefore, AJ’s performance may indicate enhanced cognitive flexibility alongside altered speed-accuracy regulation rather than straightforward improvement.

Consequently, Spatial N-Back provided one of the strongest behavioural outcomes for Participant AJ, demonstrating improved performance following auditory stimulation. Spatial N-Back primarily examines/ executive working-memory manipulation, requiring continuous comparison between current and previously stored visuospatial representations, (Owen et al., 2005). Improvement within this test indicates enhanced executive monitoring and information updating capacity. These findings may demonstrate improved engagement of frontoparietal executive networks involved in working-memory regulation. The positive response within Spatial N-Back despite weaker outcomes within other assessments highlights the task-dependent nature of cognitive adaptation following auditory entrainment. Such variation is consistent with research demonstrating that different executive processes display different levels of sensitivity to binaural interventions.

Digit Span Forward demonstrated a less efficient behavioural outcome for Participant AJ following the intervention. Digit Span Forward primarily evaluates immediate attentional storage together with temporary phonological representation rather than active executive manipulation of information, (Baddeley, 2012). The reduction in performance may suggest that auditory stimulation failed to enhance every aspect of immediate verbal memory processing. Alternatively, the obtained outcome may represent individual variability rather than being indicative of a direct negative effect of the binaural intervention. This interpretation is critical because cognitive interventions frequently demonstrate mixed responses across domains, particularly when different assessments recruit partially distinct neural mechanisms.

The Sustained Attention assessment also demonstrated a less favourable behavioural response for Participant AJ. Sustained Attention primarily assesses prolonged attentional vigilance and the capacity to sustain goal-directed behaviour over time, (Robertson et al., 1997). The slower performance observed following binaural stimulation may suggest reduced attentional efficiency, increased cognitive caution or individual differences in attentional strategy. However, interpretation should remain cautious, because sustained attention is highly influenced by fatigue, motivation, baseline arousal and momentary cognitive state.

When AJ's complete behavioural profile is considered collectively, the findings demonstrate an individualised response to auditory binaural beat stimulation. Improvements within executive switching and working-memory updating occurred alongside reductions within immediate verbal attention and sustained attentional performance. This combination of outcomes suggests that auditory entrainment may interact with particular cognitive systems differently depending upon individual neurophysiological characteristics, baseline cognitive state and the demands of the task itself. AJ's results therefore provide important evidence that cognitive adaptation following auditory stimulation should not be interpreted solely through overall ability and performance scores but through examination of individual cognitive domains and underlying processes.

Participant AJ demonstrated a decline in skin conductivity across the ten-minute intervention period following a stable pre-test baseline period characterised by minimal fluctuation. These physiological changes may represent altered autonomic regulation during auditory stimulation and provide additional insight into the area of autonomic function, executive control and 'rest and digest' to 'fight or flight' modus operandi that can be triggered by binaural entrainment AJ's behavioural outcomes contribute an important interpretation within the present investigation because they demonstrate that cognitive responses to auditory stimulation are unlikely to follow a single predictable pathway. The presence of both positive and negative behavioural changes within the same participant highlights the complexity of interactions between neural entrainment, executive cognition and individual physiological state. Consequently, AJ's findings strengthen the argument that future investigations should incorporate multiple cognitive measures alongside physiological markers to accurately characterise individual responses to non-invasive cognitive interventions.

When the behavioural observations from Participants VM, AM and AJ are synthesised collectively, the overall pattern provides evidence of a multifaceted relationship between auditory binaural beat stimulation and executive cognitive performance. Rather than producing a universal cognitive change across every assessment, the intervention appeared to produce domain-related effects across executive processes. The Alternate Task Switching, Digit Span Forward, Spatial N-

Back and Sustained Attention assessments each evaluated distinct mechanisms, meaning behavioural changes must be interpreted according to the specific neuropsychological demands of each task. This interpretation is associated with contemporary cognitive neuroscience models which define executive cognition as a distributed interaction between multiple specialised neural networks rather than a single unified ability [38].

The comparison between participants demonstrates several participant-specific responses following auditory stimulation. Participant AM displayed the most robust behavioural improvement, suggesting greater responsiveness across multiple executive domains. Participant VM demonstrated a more processing-focused pattern, with improvements primarily associated with processing speed and maintained accuracy across several measures. Participant AJ demonstrated the greatest variability, with improvements in some executive domains alongside reductions in others. These contrasting outcomes suggest that auditory entrainment interacts with individual cognitive organisation, baseline executive functioning and neurophysiological characteristics rather than operating through a single consistent Mechanism. The combined Alternate Task Switching findings provide important evidence regarding the influence of auditory stimulation upon executive flexibility. Across participants, responses varied between faster performance, slower performance with preserved accuracy and faster performance accompanied by reduced accuracy.

Alternate Task Switching primarily assesses cognitive flexibility, behavioural switching, response inhibition and executive monitoring, (Monsell, 2003). The variability observed across participants suggests that binaural auditory stimulation may influence the balance between processing speed and behavioural regulation differently between individuals. Improved switching performance may represent enhanced executive efficiency, whereas slower but accurate performance may reflect increased cognitive control, response verification or strategic behavioural adaptation. Furthermore, the Digit Span Forward outcomes provide further evidence that auditory stimulation may influence attentional processing differently from executive manipulation. Digit Span Forward primarily assesses immediate attentional encoding together with temporary phonological storage rather than active executive manipulation of information, (Baddeley, 2012). Across participants, two individuals demonstrated faster performance, one demonstrated slower performance, two demonstrated reduced accuracy and one remained unchanged. This pattern implies that immediate verbal memory processes may be less consistently responsive to auditory entrainment than higher-order executive functions. The findings therefore reinforce existing research suggesting that attentional regulation and executive control may demonstrate greater sensitivity to neural synchronisation interventions than simple storage-based memory processes [33].

The Spatial N-Back demonstrated the most meaningful behavioural response across the participant groups. Two participants demonstrated faster performance, one demonstrated slower performance, two maintained equivalent outcomes and one demonstrated improved accuracy. Spatial N-Back primarily investigates executive working-memory updating, continuous monitoring and manipulation of visuospatial information, (Owen et al., 2005). The comparatively favourable outcomes within this assessment demonstrate that working-memory processes may be particularly responsive to auditory stimulation. Such changes may indicate improved coordination within frontoparietal executive networks responsible for maintaining, updating and manipulating active information. This interpretation is consistent with evidence linking frontal-midline theta oscillations with working-memory regulation and cognitive control [19].

The Sustained Attention findings further demonstrate the complex nature of cognitive responses following auditory stimulation. Two participants demonstrated faster performance, one demonstrated slower performance, two maintained equivalent outcomes and one demonstrated reduced performance. Sustained Attention primarily investigates vigilance, attentional endurance, sustained concentration and resistance to cognitive fatigue (Robertson et al., 1997). These behavioural patterns demonstrate that auditory stimulation may influence attentional processing efficiency, although improvements are dependent upon individual cognitive strategies and physiological state. Consequently, sustained attention outcomes should be interpreted alongside physiological measures rather than behavioural performance alone.

The integration of galvanic skin response data provides an essential physiological component for understanding the mechanisms underlying behavioural change. Across all three participants, skin conductivity demonstrated a decline throughout the ten-minute auditory stimulation period following a stable pre-test baseline period characterised by minimal increase or decrease. This decline along with apparent individual differences may represent changes that demonstrate reduced sympathetic nervous system activation and increased autonomic regulation during auditory stimulation, consistent with models linking physiological regulation with cognitive performance [49].

Participant 3 AJ began with the highest GSR level, at approximately 6.60μS, and showed the most intense and substantial pronounced changes exhibited in the data obtained during the recording session. An immediate sharp and rapid marked fall to approximately 6.21μS occurred during the transition following from the initial instruction to 'settle and soften the eyes' into the prompted self-acknowledgement that the mind might remain active regardless. This period of GSR decline represented an early and immediate initial reduction in measured skin conductance early on.

The strongest increase in the GSR of participant 3 occurred between approximately 18.22 and 22.80 seconds. GSR rose from around 6.14μS to 6.57μS during the transition period from giving the nervous system permission to slow down to the statement, "You do not need to force this." This sudden and abrupt rise in GSR may represent a mental self-orienting response to an introspective change triggered by wording, vocal emphasis or the attentional demand of the meditation sequence. It was followed by the largest decline observed across all participants. Between approximately 24.56 and 59.72 seconds, GSR fell from around 6.47μS to 5.55μS, corresponding with the interval between the reassurance statement and the beginning of the body scan.

Further significant decreases also occurred during the breathing instructions, the transition from effort into ease and the imagery of resting within a safe, darkened room. Additional falls in GSR were associated with staircase imagery, bodily heaviness and slower rhythmic awareness. Overall, Participant 3, AJ exhibited heightened early physiological reactivity followed by a substantial and extensive progressive reduction in GSR.

When behavioural and physiological findings are combined, the present investigation provides a broader psychophysiological and neurocognitive multidimensional understanding of auditory binaural beat effects. Behavioural improvements occurring alongside reduced skin conductivity would support the interpretation that auditory stimulation may influence cognition through interaction between executive neural networks and autonomic regulation. Conversely, differences between physiological adaptation and behavioural performance would highlight the complexity of individual responses themselves. Overall, the findings provide meaningful preliminary evidence supporting further investigation into the relationship between neural entrainment, executive cognition and physiological regulation.

Conclusion

Considered together, the GSR profiles obtained from the three participants demonstrate a clear discernible pattern of progressively decreasing physiological arousal throughout the relaxation exercise of the audio stimuli. Although each subject showed unique individual participant-specific differences in the recorded magnitudes and timings of the sympathetic responses, all three participants recordings converged upon the same general overarching fundamental trajectory of declining skin conductance during the session. The results therefore provide consistent and convergent complementary evidence that the binaural relaxation protocol was correctly associated with a gradual reduction in autonomic nervous system activation across the total duration of the recording.

The most noteworthy and significant observation which emerged from the present analysis is that the largest reductions in GSR did not consistently coincide with the spoken instructions of the meditation voiceover itself. Yet rather that the greatest and most substantial and pronounced declines frequently occurred during the intervals immediately following spoken guidance, particularly during the silent periods separating successive transcript sections where the binaural frequency will have had greatest effect. These intervals contained no verbal stimulation, allowing participants to remain within the imagery, breathing pattern or bodily sensations established by the preceding meditation audio instructions, without introducing additional cognitive demands upon the participants. Consequently, the physiological data suggest that the absence of verbal input may have provided an optimal and favourable environment for the autonomic settling through binaural entrainment.

These findings are consistent and congruent with contemporary models of relaxation and attentional nervous system regulation, whereby verbal guidance functions primarily act as a catalyst for directing intentional awareness, while the ensuing silent binaural interval provides the individual sufficient time for parasympathetic processes to become established and consolidated. Rather than producing an immediate physiological response, many spoken instructions appeared to initiate a delayed reduction in skin conductance, with the greatest declines occurring once the participants were permitted to remain quietly engaged with the binaural beat during the breathing exercises, body scan or visual imagery. The transcript therefore appears to operate through a sequential or cumulative progressive interaction between verbal instruction, cognitive processing and subsequent physiological adaptation occurring in set stages.

Participant 1 VM displayed the greatest number of temporary and transient short-lived increases during transitions between imagery sections, suggesting periodic attentional engagement before returning to a progressively relaxed physiological state. Participant 2 AM exhibited the most stable and consistent downward trajectory, with minimal interruption from sympathetic reactivity, indicating a comparatively continuous relaxation response throughout the recording. Participant 3 AJ demonstrated the largest absolute fluctuations, including both the strongest early orienting responses and the most pronounced subsequent declines, before converging upon the same overall downward pattern observed across the dataset.

Overall, these findings indicate that the therapeutic value of binaural beats relaxation recordings may depend not solely upon the spoken content of the audio, but equally upon the carefully timed periods of frequency propagating silence that follow each instructional segment. The alternating sequence of verbal guidance and frequency dominating consolidation periods appears to facilitate a gradual and progressive cumulative reduction in physiological arousal, enabling the autonomic nervous system to respond without continual linguistic stimulation. Consequently, the present findings suggest that future relaxation recordings should consider both the wording of therapeutic instructions and the duration of intervening binaural intervals as potentially influential and integral components in maximising reductions in sympathetic activity and promoting sustained physiological relaxation.

Taken together the present investigation examined the potential influence of auditory binaural beat stimulation upon executive cognitive performance through measurement of Alternate Task Switching, Digit Span Forward, Spatial N-Back and Sustained Attention tests from the Gorilla Library alongside galvanic skin response analysis. The combined behavioural data demonstrated a complex and multifaceted pattern of cognitive adaptation rather than that of universal cognitive enhancement across all participants and assessments. These outcomes suggest that auditory stimulation may influence specific cognitive functions according to the demands of each assessment and the individual characteristics of each participant. Therefore, the present findings advance understanding of how non-invasive auditory stimulation may interact with executive cognition and physiological regulation.

The behavioural outcomes demonstrate that different executive cognitive systems responded in distinct ways following the intervention. Alternate Task Switching findings highlighted variation in executive flexibility and behavioural regulation, with participants showing differences between processing speed and accuracy. Digit Span Forward outcomes demonstrated that immediate attentional encoding and phonological storage may be influenced differently from higher-order executive processes. Spatial N-Back produced the most positive behavioural outcomes, suggesting that working-memory updating and executive monitoring may represent particularly responsive cognitive domains. Sustained Attention findings further exhibited the importance of considering attentional regulation as a dynamic process influenced by individual strategy, cognitive state and physiological factors.

However, an individual participant analyses demonstrates that responses to auditory binaural beat stimulation was not uniform across individuals. Participant AM displayed the most widespread behavioural improvement across multiple cognitive measures, providing the strongest preliminary evidence for enhanced executive functioning following stimulation. Participant VM demonstrated a more selective response pattern, with improvements primarily associated with processing efficiency and maintained accuracy within several assessments. Participant AJ demonstrated the greatest variation, showing improvements within some executive domains alongside reductions within others. These differences confirm the interpretation that individual neurophysiological characteristics may influence responsiveness to auditory entrainment.

The present findings should not be interpreted as demonstrating a simple direct relationship between auditory stimulation and improved cognition. Instead, the results provide evidence for a more complex relationship involving executive processing, attentional control, working-memory regulation and autonomic activity. Cognitive performance represents the interaction between multiple neural systems, including prefrontal executive regions, attentional networks and frontoparietal control mechanisms [37]. Consequently, changes observed within the present study may suggest altered efficiency, coordination or regulation within these interconnected systems rather than isolated improvement within one cognitive ability.

The integration of galvanic skin response findings provides an additional physiological assessment of participant response throughout the intervention period. All three participants demonstrated a decline in skin conductivity across the ten-minute auditory binaural stimulation period following a stable pre-test baseline characterised by minimal fluctuation. These physiological reductions may represent reduced sympathetic activation and increased autonomic regulation during auditory stimulation, consistent with the Neurovisceral Integration Model proposed by [48].

Hence, when the behavioural and physiological findings are incorporated, the present investigation provides preliminary evidence that auditory binaural beat stimulation may influence cognition through interaction between executive neural networks and autonomic regulation. The observed decline in skin conductivity alongside behavioural adaptation advances theoretical perspectives suggesting that cognitive performance is closely linked with physiological state and regulatory processes. However, the variability between participants reveals the importance of individual differences when evaluating cognitive interventions.

The present investigation provides valuable preliminary evidence supporting further research into auditory neural entrainment as a potential method for influencing executive cognitive processes. Future investigations should consider larger participant samples, additional physiological measures, extended intervention periods and neuroimaging approaches to determine the mechanisms underlying observed behavioural and autonomic changes. Further research should also investigate whether individual differences in baseline cognition, personality characteristics, attentional state and neurophysiological activity predict responsiveness to auditory stimulation.

Finally, the findings demonstrate that cognitive adaptation following auditory binaural beat stimulation is complex rather than predictable through a single behavioural outcome. The combination of executive cognitive testing and physiological measurement provides a more advanced understanding of participant responses. Although the present study cannot establish definitive causation, it provides a foundation for future research examining the interaction between auditory stimulation, executive cognition and autonomic regulation. The evidence obtained suggests that auditory entrainment represents a promising area for further investigation within cognitive neuroscience, particularly regarding its potential influence upon attention, working memory, cognitive flexibility and physiological regulation.

References

1. Boucsein W. Electrodermal activity. Springer: New York. 2012.
2. Chaieb L, Wilpert E. C, Reber T. P & Fell J. Auditory beat stimulation and its effects on cognition and mood states. Frontiers in Psychiatry, 2015; 6, 70.
3. Critchley H. D. Electrodermal responses: What happens in the brain. The Neuroscientist, 2002; 8(2), 132–142.
4. Gelfand S. A. Essentials of Audiology. 3rd edn. New York: Thieme, 2011; p. 87.
5. Monroe Institute of Applied Sciences, (2003): [DECLASSIFIED] The Gateway Program, CIA Archives: https://www.cia.gov/readingroom/docs/CIA-RDP96-00788R001700270006-0.pdf.
6. Monroe R. A. Journeys Out of the Body. Anchor Press: New York. 1977.

7. Ogilvie R.D. The process of falling asleep. Sleep Medicine Reviews, 2001; 5(3), 247-270.

8. Sadigh M. R and Kozicky P. W. The Effects of Hemi-Sync® on Electrocortical Activity: A Review of Three Empirical Studies. Faber, VA: The Monroe Institute. Available at: https://www.monroeinstitute.org (Archived from the original on 15 November 2006).

9. Arnsten A. F. Stress signalling pathways that impair prefrontal cortex structure and function, Nature Reviews Neuroscience, 2009; 10(6), pp. 410-422.

10. Baars B. J. A cognitive theory of consciousness. Cambridge: Cambridge University Press. 1988.

11. Becher A. K, Höhne M, Axmacher N, Chaieb L, Elger C. E and Fell J. Intracranial electroencephalography power and phase synchronization changes during monaural and binaural beat stimulation, European Journal of Neuroscience, 2015; 41(2), pp. 254-263.

12. Berlin H. A. The neural basis of the dynamic unconscious, Neuropsychoanalysis, 2011; 13(1), pp. 5-31.

13. Botvinick M. M, Braver T. S, Barch D. M, Carter C. S and Cohen J. D. Conflict monitoring and cognitive control, Psychological Review, 2001; 108(3), pp. 624-652.

14. Boucsein W. Electrodermal activity. New York: Springer Science & Business Media. 2012.

15. Brewer J. A, Worhunsky P. D, Gray J. R, Tang Y. Y, Weber J and Kober H. Meditation experience is associated with differences in default mode network activity and connectivity, Proceedings of the National Academy of Sciences, 2011; 108(50), pp. 20254-20259.

16. Buckner R. L, Andrews-Hanna J. R and Schacter D. L. The brain s default network: anatomy, function, and relevance to disease, Annals of the New York Academy of Sciences, 2008; 1124(1), pp. 1-38.

17. Buzsáki G. Rhythms of the Brain. Oxford: Oxford University Press. 2006.

18. Buzsáki G and Draguhn A. Neuronal oscillations in cortical networks, Science, 2004; 304(5679), pp. 1926-1929.

19. Cavanagh J. F and Frank M. J. Frontal theta as a mechanism for cognitive control, Trends in Cognitive Sciences, 2014; 18(8), pp. 414-421.

20. Cavanna A. E and Trimble M. R. The precuneus: a review of its functional anatomy and behavioural correlates, Brain, 2006; 129(3), pp. 564-583.

21. Chaieb L, Wilpert E. C, Reber T. P and Fell J. Auditory beat stimulation and its effects on cognition and mood states, Frontiers in Psychiatry, 2015; 6, pp. 70-79.

22. Clark A. Whatever next? Predictive brains, situated agents, and the future of cognitive science, Behavioral and Brain Sciences, 2013; 36(3), pp. 181-204.

23. Cooper P. S, Wong A. S, Fulham W. R, Thienel R, Mansfield P, Michie P. T and Karayanidis F. Fronto-midline theta power predicts changes in cognitive control demands, Psychophysiology, 2019; 56(4), pp. e13311-e13324.

24. Corbetta M and Shulman G. L. Control of goal-directed and stimulus-driven attention in the brain, Nature Reviews Neuroscience, 2002; 3(3), pp. 201-215.

25. Critchley H. D. Electrodermal responses: what are they and what do they tell us? The Neuroscientist, 2002; 8(2), pp. 132-142.

26. Critchley H. D, Corfield D. R, Chandler M. P, Mathias C. J and Dolan R. J. Explicit and implicit neural mechanisms for modulation of sympathetic autonomic arousal: a functional magnetic resonance imaging study, Journal of Neuroscience, 2000; 20(10), pp. 3736-3744.

27. Dehaene S and Changeux J. P. Experimental and theoretical approaches to conscious processing, Neuron, 2011; 70(2), pp. 200-227.

28. Engel A. K and Fries P. Beta-band oscillations—signalling the status quo? Current Opinion in Neurobiology, 2010; 20(2), pp. 156-165.

29. Fodor J. A and Pylyshyn Z. W. Connectionism and cognitive architecture: A critical analysis, Cognition, 1988; 28(1-2), pp. 3-71.

30. Fries P. A mechanism for cognitive dynamics: neuronal communication through coherence, Trends in Cognitive Sciences, 2005; 9(10), pp. 474-480.

31. Friston K. The free-energy principle: a unified brain theory? Nature Reviews Neuroscience, 2010; 11(2), pp. 127-138.

32. Garcia-Argibay M, Santed M. A and Reales J. M. Binaural auditory beats affect long-term memory, Psychological Research, 2019; 83(6), pp. 1124–1136.

33. Kant I. Critique of Pure Reason. Translated by P. Guyer and A. W. Wood. Cambridge: Cambridge University Press. 1998.

34. Kim J. Psychophysical supervenience, Philosophical Studies, 1982; 41(1), pp. 51-70.

35. Klimesch W. EEG alpha and theta oscillations reflect cognitive and memory performance: a review and analysis, Brain Research Reviews, 1999; 29(2-3), pp. 169-217.

36. Lane J. D, Kasian S. J, Owens J. E and Marsh G. R. Binaural auditory beats affect vigilance performance and mood, Physiology & Behavior, 1998; 63(2), pp. 249-252.

37. Miller E. K and Cohen J. D. An integrative theory of prefrontal cortex function, Annual Review of Neuroscience, 2001; 24(1), pp. 167-202.

38. Nozaradan S, Peretz I and Mouraux A. Steady-state evoked potentials as an index of multisensory temporal binding, NeuroImage, 2012; 60(4), pp. 2111-2119.

39. Orozco-Perez H. D, Dumas G and Saporta S. Binaural beats through the auditory pathway: from brainstem to connectivity patterns, eNeuro, 2020; 7(2), pp. ENEURO.0232-19.2020 (1-16).

40. Oster G. Auditory beats in the brain, Scientific American, 1973; 229(4), pp. 94-103.

41. Pessoa L. On the relationship between emotion and cognition, Nature Reviews Neuroscience, 2008; 9(2), pp. 148-158.

42. Ptak R. The frontoparietal attention network of the human brain: action, user intention, and perceptual selection, The Neuroscientist, 2012; 18(5), pp. 502-515.

43. Seth A. K. Being You: A New Science of Consciousness. London: Faber & Faber. 2021.

44. Shackman A. J, Salomons T. V, Slagter H. A, Fox A. S, Winter J. J and Davidson R. J. The integration of negative affect, pain and cognitive control in the cingulate cortex, Nature Reviews Neuroscience, 2011; 12(3), pp. 154-167.

45. Steriade M. Grouping of brain rhythms in corticothalamic systems, Neuroscience, 2006; 137(4), pp. 1087-1106.

46. Tang Y. Y, Fan Y, Lu Q, Tan L H, Tang R, Kaplan G. J and Posner M. I. Central and autonomic nervous system interaction is altered by short-term meditation, Proceedings of the National Academy of Sciences, 2009; 106(22), pp. 8865-8870.

47. Thayer J. F, Hansen A. L, Saus-Rose E and Johnsen B. H. Heart rate variability, prefrontal neural function, and cognitive performance: the neurovisceral integration model, Annals of Behavioral Medicine, 2009; 37(2), pp. 141-153.

48. Thayer J. F and Lane J. D. A model of neurovisceral integration in emotion regulation and dysregulation, Journal of Affective Disorders, 2000; 61(3), pp. 201-216.

49. Tononi G, Boly M, Massimini M and Koch C. Integrated information theory: from consciousness to its physical substrate, Nature Reviews

Neuroscience, 2016; 17(7), pp. 450-461.

50. Travis F, Haaga D. A, Hagelin J, Tanner M, Arenander A, Nidich S and Schneider R. H. A self-referential default-mode-network for consciousness and a self-transcendence mode of experience, Cognitive Neuroscience, 2009; 1(1), pp. 76-85.
51. Varela F. J. Neurophenomenology: A methodological remedy for the hard problem, Journal of Consciousness Studies, 1996; 3(4), pp. 330-349.
52. Varela F, Lachaux J. P, Rodriguez E and Martinerie J. The brainweb: Phase synchronization and large-scale integration, Nature Reviews Neuroscience, 2001; 2(4), pp. 229-239.
53. Wahbeh H, Calabrese C and Zwickey H. Binaural beat technology in humans: a pilot study to assess psychologic and physiologic effects, The Journal of Alternative and Complementary Medicine, 2007; 13(1), pp. 25-32.