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Preliminary Study of Human Performance and Neuroscience in Indonesia

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Abstract

Effective work performance is driven by motivation, emotional regulation, and the ability to build social relationships, which collectively influence professional outcomes. Quantitative electroencephalography (qEEG) offers an objective measure of brain activity related to these factors, providing insights into the neural mechanisms underlying workplace behavior. This study is an exploratory pilot investigation of associations between quantitative EEG (qEEG) parameters at left DLPFC (Fp1) and workplace-relevant functions (emotional regulation, motivation, social relations) assessed with selected MMPI-180 subscales. Brain activity was recorded at the left dorsolateral prefrontal cortex (Fp1), focusing on Theta, Alpha, and Beta power. Data were collected from 68 employees in Indonesia over two months and analyzed using linear regression in SPSS 23. Results showed that Beta power at Fp1 significantly predicted emotional regulation ($B = 6.85$, $p = .04$, $R^2 = 6.4\%$), Alpha power at Fp1 predicted motivation ($B = 6.02$, $p = .048$, $R^2 = 5.8\%$), and Theta power at Fp1 predicted social relationship skills ($B = 14.15$, $p = .006$, $R^2 = 16.3\%$). These findings provide empirical evidence that specific brainwave activities are linked to different aspects of workplace performance. The contribution of this study lies in demonstrating the applicability of qEEG as an objective tool to evaluate employee performance, offering new insights for neuroscience-based organizational interventions in the Indonesian context.

Keywords: emotional regulation, human performance, motivation, MMPI, neuroscience, qEEG, social relationships

Abstrak

Kinerja karyawan yang efektif ditentukan oleh motivasi, regulasi emosi, dan kemampuan dalam membangun hubungan sosial. Quantitative electroencephalography (qEEG) merupakan pengukuran objektif terhadap aktivitas otak yang berkaitan dengan faktor-faktor tersebut, memberikan wawasan mengenai mekanisme saraf yang mendasari perilaku di tempat kerja. Penelitian ini adalah studi eksploratif mengenai hubungan antara parameter EEG kuantitatif (qEEG) pada DLPFC kiri (Fp1) dan fungsi mental yang relevan di tempat kerja (regulasi emosi, motivasi, hubungan sosial) yang dinilai dengan subskala MMPI-180. Aktivitas otak direkam pada korteks dorsolateral prefrontal kiri (Fp1), dengan fokus pada daya gelombang Theta, Alpha, dan Beta. Data dikumpulkan dari 68 karyawan di Indonesia selama dua bulan dan dianalisis menggunakan regresi linear dengan SPSS 23. Hasil menunjukkan bahwa daya Beta di Fp1 secara signifikan memprediksi regulasi emosi ($B = 6.85$; $p = .04$; $R^2 = 6.4\%$), daya Alpha di Fp1 memprediksi motivasi ($B = 6.02$; $p = .048$; $R^2 = 5.8\%$), dan daya Theta di Fp1 memprediksi keterampilan hubungan sosial ($B = 14.15$; $p = .006$; $R^2 = 16.3\%$). Temuan ini memberikan bukti empiris bahwa gelombang otak tertentu terkait dengan aspek-aspek berbeda dari kinerja kerja. Kontribusi penelitian ini adalah menunjukkan potensi qEEG sebagai alat objektif dalam mengevaluasi kinerja karyawan, sekaligus menawarkan wawasan baru untuk intervensi organisasi berbasis neurosains di Indonesia.

***Kata kunci**: hubungan sosial, motivasi, MMPI, neurosains, performa manusia, qEEG, regulasi emosi*

Introduction

Human resources are one of the most abundant resources and have a significant influence on a company. Data from the Indonesian Central Bureau of Statistics (BPS) as of February 2022 shows that Indonesia has approximately 135 million workers. Companies, both private and governmental, require human resources with good performance to enhance their competitiveness in the era of Industry 4.0. Employee performance is the result of work produced by employees based on the tasks assigned to them. Companies with good performance will have employees with good performance, and vice versa.

The global shift toward the Industry 4.0 era has intensified the need for organizations to focus on the human side of performance (Maryono et al., 2022; Khairina, 2022). As automation and artificial intelligence increasingly take over routine tasks, human employees are required to develop higher-order skills, including creativity, emotional intelligence, decision-making, and interpersonal communication. These evolving demands have prompted organizations to explore new methods of enhancing employee performance. While traditional models primarily emphasize external factors, such as workplace policies, and internal psychological factors, like job satisfaction, they often fail to address the underlying neurobiological mechanisms that shape behavior, cognition, and motivation. Understanding these mechanisms through the lens of neuroscience offers a more comprehensive approach, enabling organizations to identify and leverage the biological factors that influence performance. This deeper insight not only enhances the effectiveness of interventions but also allows for more targeted strategies that can optimize cognitive, emotional, and social functioning, ultimately improving overall workplace performance.

Emerging research highlights the importance of neurophysiological processes in shaping employee outcomes (Cheung, 2022; Ghosh & Kumar, 2024; McCreedy, 2024; Menon & Bhagat, 2022; Yeole & Benkur, 2023). Brain activity, as captured by technologies like Quantitative Electroencephalography (qEEG), provides a window into the neural mechanisms underlying emotional regulation, decision-making, motivation, and interpersonal skills. However, there is still limited neuroscience research in many countries, including Indonesia. A study by Fatahilah et al. (2024) demonstrated that combining brain gym activities with instrumental music significantly enhanced beta and gamma brainwave activity, leading to improved concentration among athletes. Similarly, Negara et al. (2021) found a negative correlation between gamma wave activity and movement performance in gymnastics, indicating the potential impact of brainwave patterns on physical performance. These studies highlight the emerging interest in understanding the neurophysiological underpinnings of performance in Indonesia. However, comprehensive research that connects brainwave activity with broader aspects of human performance, such as emotional regulation, motivation, and social relationship-building, remains scarce. Additionally, research on brainwaves in organizational and industrial contexts is rarely conducted due to limited access to brainwave assessment tools (Sharma et al., 2023). Most employee performance studies only examine external factors (work environment, coworkers, etc.) and internal psychological factors (intolerance of uncertainty, happiness, subjective well-being, etc.) (Thompson & Burk-Lee, 2021; Yuniardi et al., 2023). Therefore, a neuropsychological approach is needed to explore how brainwaves influence human performance.

Employee performance is essential for increasing the productivity and quality of an institution or organization. Terminologically, employee performance is defined as the achievement or accomplishment in work, which is the result of an individual's efforts (Nurain et al., 2024; Pradhan & Jena, 2017). Employee performance can also be associated with the level of motivation and capability possessed while working, as well as how employees manage emotions and build social relationships with coworkers. Hence, employee performance in this study is categorized into three dimensions: emotional regulation, motivation, and the ability to build social relationships.

The first dimension, emotional regulation, in this study is defined as an individual's ability to manage emotions in the workplace (Hirschle & Gondim, 2022; Grandey, 2000). The second dimension, motivation, is defined as the internal energy or drive to perform a certain task (Prastiwi et al., 2022). In the work context, work motivation is understood as an individual's drive to complete tasks with optimal effort. In the workplace, employees interact with supervisors and coworkers, making the social relationship dimension crucial, as positive interactions with others will positively impact employee performance.

Neuroscience is a multidisciplinary field that focuses on understanding the structure and function of the nervous system, encompassing the brain, spinal cord, and peripheral nervous networks. Within this expansive domain, the study of the brain's electrical activity has gained increasing attention for its role in influencing cognitive, emotional, and behavioral functions. The brain orchestrates nearly all human bodily and psychological activities. This includes decision-making, emotional regulation, goal-directed behavior, and the capacity to build and maintain social relationships (Dewantari, 2022). These processes are mediated by neural oscillations—commonly referred to as brainwaves—which represent rhythmic patterns of electrical activity generated by neurons as they communicate with one another.

Brainwaves are categorized based on their frequency, measured in Hertz (Hz), into several bands: Delta (.5–4 Hz), Theta (4–8 Hz), Alpha (8–13 Hz), Beta (13–30 Hz), and Gamma (30+ Hz). Each of these frequency bands is associated with distinct cognitive and psychological states, reflecting the brain's dynamic adaptability to internal and external demands. For example, Delta waves are prominent during deep sleep, while Gamma waves are linked to high-level cognitive functions such as problem-solving and learning. This study focuses on Theta, Alpha, and Beta waves, which have been identified as key contributors to workplace-relevant functions, including emotional regulation, motivation, and social cognition. By specifically linking these brainwave activities to employee performance dimensions, such as emotional regulation, motivation, and social relationship-building, this research addresses the gap in existing studies that often overlook the neurobiological mechanisms influencing workplace behavior. It provides a deeper understanding of how brainwave patterns can inform strategies to optimize human performance in organizational settings. Given the limitations of sample size, non-probabilistic sampling, and cross-sectional design, this study is framed as an exploratory/pilot study aimed at mapping initial associations between brain wave activity and work functions for hypothesis generation in subsequent studies.

The Mechanisms Behind Brainwaves

Brainwaves are generated by synchronized neural activity across populations of neurons. This synchronization reflects the balance between excitatory and inhibitory signals within neural circuits, which enables the brain to efficiently process information. Brainwaves are not isolated phenomena but rather reflect the integration of multiple brain regions working together to perform specific tasks. This is particularly evident in higher-order functions, such as those governed by the dorsolateral prefrontal cortex (DLPFC) which is labelled as Fp1 in EEG.

The DLPFC is a critical hub for executive functions, including attention, planning, decision-making, and social interactions (Zholobenko, 2022). It acts as the brain's control center, integrating sensory inputs, memory, and emotional cues to guide adaptive behavior. The selection of Theta, Alpha, and Beta waves for this study is based on their theoretical relevance to DLPFC-mediated functions, which are integral to employee performance. These brainwave frequencies were analyzed across three distinct frequency bands—absolute power, relative power, and power ratio—to provide a comprehensive understanding of their contribution to performance dimensions. First, absolute power refers to the raw amplitude of a specific brainwave frequency, indicating the overall strength of that wave within a given brain region. For example, higher absolute power in Alpha waves may reflect a state of relaxed focus, conducive to sustained attention and motivation. Then, relative power measures the proportion of a specific brainwave frequency relative to the total power of all brainwaves. This metric provides insight into the dominance of a particular frequency in regulating cognitive or emotional states. For instance, a higher relative power of Theta waves in the DLPFC might suggest enhanced emotional processing or social cognition. Finally, power ratio involves comparing the relative strengths of different frequency bands, such as Theta/Beta or Theta/Alpha ratios. These ratios have been used as biomarkers for various cognitive and emotional states. For example, a high Theta/Beta ratio is often associated with creativity and divergent thinking, while a low ratio may indicate difficulties with attention or focus. We will explain the three main waves analysed in this study below.

Theta Waves

Theta waves (4–8 Hz) are slow-frequency oscillations that are closely linked to memory, emotional processing, and creative thinking. They are most prominent during states of deep relaxation or light meditation, where the brain integrates internal and external stimuli. In the workplace, Theta waves are associated with activities requiring empathy, interpersonal understanding, and adaptability—key components of social relationships. For example, higher Theta wave activity in the DLPFC has been linked to improved perspective-taking and emotional regulation, enabling individuals to navigate complex social interactions effectively (Balconi & Fronda, 2020).

Theta waves also play a crucial role in problem-solving and creativity by facilitating access to unconscious thought processes and novel connections. This makes them particularly relevant in roles that require innovation and out-of-the-box thinking. In the context of this study, Theta waves in the DLPFC are analyzed for their contribution to employees' ability to build and maintain meaningful social relationships, an essential dimension of workplace success.

Alpha Waves

Alpha waves (8–13 Hz) are medium-frequency oscillations that represent a state of relaxed alertness, often referred to as the "flow state." Alpha waves dominate when individuals are calm yet focused, allowing for optimal cognitive processing and task engagement. This frequency band acts as a bridge between conscious and subconscious processing, enabling individuals to switch seamlessly between task-oriented behavior and reflective thought.

In the context of employee performance, Alpha waves in the DLPFC are strongly associated with motivation. High Alpha activity has been linked to enhanced attention, emotional stability, and the ability to stay engaged in tasks over extended periods. Watanabe (2008) demonstrated that Alpha waves support goal-directed behavior by reducing the interference of irrelevant stimuli, allowing individuals to focus on their objectives. This makes Alpha waves particularly important for roles that require sustained concentration and resilience in the face of challenges.

Beta Waves

Beta waves (13–30 Hz) are high-frequency oscillations associated with active mental engagement, problem-solving, and decision-making. These waves are most prominent during activities that require logical reasoning, critical thinking, and emotional regulation. Beta waves in the DLPFC enable individuals to suppress impulsive responses, evaluate complex scenarios, and maintain cognitive control in high-pressure situations.

This study focuses on the role of Beta waves in emotional regulation, a key dimension of employee performance. Beta wave activity in the DLPFC reflects the brain's capacity to manage stress, resolve conflicts, and maintain composure in challenging circumstances. Dixon et al. (2017) highlighted the importance of Beta activity in enabling adaptive emotional responses, particularly in environments characterized by uncertainty or rapid change.

Relevance to Employee Performance

By analyzing Theta, Alpha, and Beta waves in the DLPFC (Fp1), this study provides a neurophysiological perspective on employee performance. Each brainwave frequency offers unique insights into the cognitive and emotional processes that drive behavior in the workplace. For example, theta waves illuminate the neural basis of empathy and social cognition, highlighting their role in fostering collaboration and teamwork. A study by Abid et al. (2025) found that higher frontal theta power predicted positive affect, suggesting its role in mood regulation and emotional well-being. Meanwhile, alpha waves reveal the mechanisms underlying sustained motivation and focus, offering pathways for enhancing employee engagement and productivity (Knyazev, 2007). Then, beta waves explain the neural foundations of emotional regulation, shedding light on how employees manage stress and maintain professionalism (Roshanaei et al., 2025).

The use of Quantitative Electroencephalography (qEEG) to measure these brainwaves represents a significant advancement in organizational research. Unlike traditional psychological assessments, which rely on self-report data, qEEG provides objective, real-time measurements of brain activity, enabling researchers to identify specific neural patterns associated with performance outcomes. By combining these insights with behavioral data, this study aims to develop a comprehensive framework for understanding and enhancing employee performance in the modern workplace.

Brainwave Activity and Performance

Emotional Regulation Eden et al. (2015) conducted a study on emotional regulation prediction by examining the structural fiber connection between the amygdala and the prefrontal cortex. The amygdala and prefrontal cortex play a role as the emotional regulation center through a process called top-down inhibition, which inhibits unwanted responses to enable more appropriate actions. Dixon et al. (2017) discussed emotions and the prefrontal cortex, finding that the PFC contributes significantly to regulating emotional responses, a fundamental aspect of adaptive human behavior (Gross, 1998). Dysfunction in the PFC can lead to affective disorders, including depression (Dixon et al., 2017). The PFC is highly sensitive to contextual information, such as spatiotemporal context, task context, or self-image context, which can modulate subcortical emotion generation processes.

Motivation

Motivation is a multifaceted construct that extends beyond immediate task engagement to encompass long-term goal-setting, perseverance, and adaptability. Its significance in workplace contexts cannot be overstated, as it directly correlates with employee productivity, innovation, and organizational success. While traditional models of motivation focus on psychological frameworks—such as Maslow's hierarchy of needs or Herzberg's two-factor theory—recent advances in neuroscience have revealed the intricate neural mechanisms underpinning this critical workplace attribute.

From a neurophysiological standpoint, motivation involves a dynamic interplay between subcortical reward centers, such as the ventral striatum, and higher-order cognitive regions, such as the dorsolateral prefrontal cortex (DLPFC). The ventral striatum processes immediate rewards, generating feelings of satisfaction and reinforcement, while the DLPFC evaluates the long-term consequences of actions and aligns behavior with overarching goals. This integration ensures that employees remain focused and persistent, even when immediate rewards are absent.

One of the key findings of this study is the association between Alpha wave activity in the DLPFC and motivation. Alpha waves, characterized by frequencies between 8–13 Hz, are commonly linked to states of relaxed alertness and optimal cognitive functioning. When Alpha activity is heightened in the DLPFC, individuals are better able to filter out distractions, sustain attention, and regulate emotional responses—all of which are essential for maintaining motivation in demanding environments. This finding aligns with Watanabe's (2008) research, which demonstrated that the prefrontal cortex facilitates motivational processes by balancing emotional and cognitive inputs. However, while Watanabe's study used a traditional cognitive task paradigm to assess motivation and brain activity, our study employs Quantitative Electroencephalography (qEEG) to directly measure Alpha wave activity in the DLPFC in real-time, offering more precise insights into the neural mechanisms involved in motivation. This methodological distinction allows for a more dynamic and specific understanding of how brainwave activity influences motivation in the workplace context.

Moreover, Kouneiher et al. (2009) identified a hierarchical organization within the medial and lateral prefrontal cortex, wherein the medial PFC processes reward-related signals, and the lateral PFC translates these signals into actionable plans. This parallel processing ensures that motivational states are not only initiated but also sustained over time. In workplace contexts, this mechanism may explain why some employees excel at long-term projects requiring sustained effort and focus, while others struggle with consistency.

Potential practical implications of this exploratory study include the use of Alpha wave-enhancing interventions to boost workplace motivation. Techniques such as mindfulness meditation, neurofeedback training, and even structured breaks during work hours have been shown to increase Alpha activity, promoting mental clarity and sustained engagement. For organizations, implementing such strategies could lead to measurable improvements in employee performance, particularly in roles requiring high levels of focus and resilience. However, their practical validity requires controlled trials before widespread implementation.

Social Relationships

Theta waves, which oscillate at frequencies between 4–8 Hz, are associated with memory retrieval, emotional processing, and creativity. In social contexts, these brainwaves enhance an individual's ability to interpret social cues, such as facial expressions, tone of voice, and body language. This is particularly relevant in workplaces where employees must collaborate with diverse teams, resolve conflicts, and negotiate complex interpersonal dynamics. Higher Theta activity in the DLPFC may reflect improved connectivity between the cognitive and emotional systems, enabling individuals to process and respond to social stimuli more effectively.

One of the most intriguing aspects of Theta wave activity is its role in fostering empathy and perspective-taking. Balconi and Fronda (2020) emphasized the importance of the DLPFC in regulating prosocial behaviors, such as helping others, sharing resources, and resolving conflicts. By integrating cognitive information with emotional insight, the DLPFC allows individuals to understand the needs and intentions of others, facilitating cooperative and harmonious interactions. In workplace settings, this translates to stronger team cohesion, better communication, and higher overall productivity.

The link between language comprehension and social relationships, as highlighted by Jiang et al. (2018), further underscores the importance of DLPFC activity. Effective communication is a fundamental aspect of workplace interactions, enabling employees to articulate their ideas, provide feedback, and resolve misunderstandings. Theta wave activity in the DLPFC appears to enhance these abilities by supporting the integration of verbal and non-verbal cues, ensuring that communication is clear, empathetic, and contextually appropriate.

Practical applications of these findings include incorporating training programs that enhance Theta wave activity, such as empathy-building workshops, mindfulness exercises, and team-building activities. For example, mindfulness practices have been shown to increase Theta activity, leading to greater emotional awareness and interpersonal sensitivity. Similarly, role-playing exercises that simulate workplace scenarios can help employees practice perspective-taking and improve their social relationship skills.

Methods

Participants

The population for this study comprised employees at educational institutions in Indonesia. The study passed ethical review by UPN Veteran Jakarta. From this population, 68 employees from an educational institution in Depok were selected using a non-probability sampling method, specifically accidental sampling, over two months. This method was chosen due to practical accessibility and the limited availability of participants willing to undergo qEEG assessments, which require specialized equipment and time commitment. Although this approach does not guarantee representativeness, it is commonly used in exploratory neuroscience studies where experimental control and feasibility are prioritized over population generalizability. To mitigate bias, participants were drawn from diverse functional roles (academic, administrative, and support staff) within the institution.

Instruments

Work-related functions were operationalized using selected MMPI-180 subscales that assess emotional regulation, motivation, and social relations. While MMPI is primarily a clinical personality assessment tool, it was used here as a proxy for work-relevant traits, referencing local adaptations and foundational reliability evidence ($\alpha > .70$) and acceptable construct validity indexes. In this study, only the subscales relevant to the three dimensions were used, consistent with earlier research linking MMPI scores to occupational performance indicators. The use of MMPI-180 ensured that the constructs examined aligned with established psychometric evidence while remaining time-efficient for participants undergoing both psychological testing and neurophysiological assessment. The independent variables were Theta, Alpha, and Beta brainwaves in the prefrontal cortex (Fp1) across absolute power, relative power, and power ratio frequency bands. Brainwave data were recorded using a 21-channel EEG (Electroencephalography) and the qEEG (Quantitative Electroencephalography) data was processed using Neuroguide software to obtain Z-scores for each brainwave at each frequency band.

Figure 1. The Process of 21-channel qEEG Recording

The figure shows the configuration for 21-channel qEEG recording. Brainwave activity from the prefrontal cortex (Fp1) is recorded using equipment, namely the Neurosoft Neuron-Spectrum-64 EEG device seen in the first image, over a number of frequency bands, including Theta, Alpha, and Beta. These brainwave signals are then processed using Neuroguide software to provide Z-scores, which quantify the activity levels in each frequency band. The actual configuration, in which a participant is linked to the EEG device to enable real-time data gathering, is shown in the second image.

Ethical Considerations

This study did not receive formal review by an institutional ethics board; however, all procedures followed recognized ethical principles for research involving human participants. Prior to participation, individuals were fully informed about the study, and written consent was obtained. Participation was entirely voluntary, with the option to discontinue at any stage without consequence. Confidentiality and anonymity were strictly maintained, and all data were used solely for research purposes. As the study relied on self-report questionnaires addressing non-sensitive topics and neuroscience technology (EEG), it was assessed as presenting negligible risk, and no adverse effects were experienced by participants.

Data Analysis

Data analysis employed linear regression techniques to determine the strength and direction of influence among variables using SPSS version 23. Independent variables were analyzed using the backward regression method to identify models with significant variables ($p < .05$). The backward regression method was chosen to identify the most significant predictors, because it consistently eliminates less significant variables. By concentrating on the variables that have the most effects on the dependent variable, this method helps to create a more effective model while also increasing its accuracy and interpretability. It also ensures that just the most pertinent variables are kept for study, which is helpful when there are many predictors.

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Results and Discussion

Results

Emotional Regulation

After performing backward regression analysis, the researchers identified a model, summarizing the R square of independent variables' effects on emotional regulation. The R-square value of .064 (6.4%) indicates that the independent variable (Absolute Power Beta at Fp1) explains 6.4% of the variance in emotional regulation. While this percentage is relatively small, it is statistically significant, as confirmed in the subsequent tables. A smaller R-square suggests that other factors not included in the model also contribute to emotional regulation, but the focus here is on the specific relationship between brainwave activity and performance dimensions.

Table 1. Coefficients for Beta Wave on Emotional Regulation

Model	Unstandardized Coefficients	Standardized Coefficients	t	Sig.
	B	Beta		
Absolute Power Beta Fp1	6.85	.25	2.13	.04

The coefficient value (B = 6.85) shows that for every one-unit increase in Absolute Power Beta at Fp1, emotional regulation improves by 6.845 units. The significance value (p = .04) confirms that this effect is statistically significant. In practical terms, it suggests that higher Beta wave activity in the Fp1 region of the brain positively correlated with emotional regulation, likely due to the role of the dorsolateral prefrontal cortex in emotion management.

Motivation

This study identified a model summary for the R square of independent variables' effects on motivation after performing backward regression analysis. The R-square value of 0.058 (5.8%) indicates that Absolute Power Alpha at Fp1 explains 5.8% of the variance in motivation. While the effect size is modest, it is noteworthy because it highlights a specific neurophysiological factor associated with motivation, which is typically predicted by psychological and environmental factors.

Table 2. Coefficients for Alpha Wave on Motivation

Model	Unstandardized Coefficients	Standardized Coefficients	t	Sig.
	B	Beta		
Absolute Power Alpha Fp1	6.016	.240	2.012	.048

The coefficient value (B = 6.016) indicates that for every one-unit increase in Absolute Power Alpha at Fp1, motivation improves by 6.016 units. The significance value (p = .048) confirms the reliability of this relationship. This finding supports the theory that Alpha wave activity enhances focus and relaxation, which are conducive to intrinsic motivation.

Social Relations

Backward regression analysis revealed a model where the R-square value of .163 (16.3%) indicates that the combination of predictors explains 16.3% of the variance in social relationships. This is a larger proportion compared to emotional regulation and motivation, suggesting that brainwave activity plays a more substantial role in social interactions.

Table 3. Coefficients Regressions for Social Relation

Model	Unstandardized Coefficients	Standardized Coefficients	t	Sig.
	B	Beta		
Absolute Power Theta Fp1	14.153	.514	2.864	.006
Absolute Power Alpha Fp1	-3.188	-.130	-.759	.451
Relative Power Theta Fp1	-.961	-.031	-.191	.849
Power Ratio Theta/Beta Fp1	-3.751	-.141	-.825	.412

Based on the coefficients table, four types of brainwaves emerged in the analysis. Among them, the absolute power Theta wave at Fp1 showed a coefficient value of 14.153 with a significance value (p) of 0.006, which is less than .05. This indicates that the absolute power Theta wave at Fp1 has a positive and significant association on social relationship performance. In other words, the higher the absolute power Theta wave activity at Fp1, the better the individual's ability to build social relationships.

On the other hand, the following brainwave measures did not show statistically significant effects, as their p-values were greater than .05: Absolute power Alpha wave at Fp1, Relative power Theta wave at Fp1, Power ratio Theta/Beta at Fp1. Since these waves do not exhibit significant effects, they are considered statistically insignificant in predicting social relationship performance in this model.

The significant positive relationship between absolute power Theta waves at Fp1 and social relationships aligns with existing neuroscience theories. Theta waves are associated with cognitive processing, emotional regulation, and memory functions, all of which are critical for effective social interactions. Higher Theta wave activity in the prefrontal cortex (specifically Fp1, which corresponds to the left dorsolateral prefrontal cortex) may enhance empathy, perspective-taking, and communication skills, contributing to improved social relationships.

The lack of significant effects for other brainwave types (absolute power Alpha, relative power Theta, and power ratio Theta/Beta) indicates that these measures might not directly contribute to or strongly associated with the ability to build social connections in this context. This highlights the specificity of Theta wave activity as a neural correlate of social interaction performance.

Overall, although several coefficients were significant, the explained variance was low (R^2 emotional regulation 6.4%, motivation 5.8%, social relations 16.3%), indicating limited predictive power and the need for other predictors beyond qEEG. The findings should be read as small-to-medium associations in an exploratory study. In practical terms, this finding suggests that interventions or techniques that enhance Theta wave activity in the left prefrontal cortex—such as mindfulness, meditation, or cognitive training—could potentially improve an individual's ability to form and maintain social relationships.

Discussion

This study investigated the relationship between brainwave activity—measured via qEEG—and three key dimensions of employee performance: emotional regulation, motivation, and social relationships. By focusing on specific brainwave frequencies (Theta, Alpha, and Beta) in the left dorsolateral prefrontal cortex (DLPFC) region labelled as Fp1 in qEEG, this study provides a novel electrophysiological perspective on workplace performance.

First, the findings revealed a significant positive effect of absolute power Beta waves at Fp1 on emotional regulation. The coefficient value of 6.845 indicates that higher Beta wave activity correlates with improved emotional regulation. This aligns with the theoretical understanding that the DLPFC plays a pivotal role in emotion regulation. According to Eden et al. (2015), the amygdala and prefrontal cortex interact through top-down inhibition mechanisms, enabling individuals to suppress inappropriate emotional responses and select more contextually appropriate behaviors. Similarly, Dixon et al. (2017) emphasized the importance of subregions within the prefrontal cortex, including the dorsomedial and ventromedial PFC, in regulating emotional states. However, unlike their studies, which primarily focused on structural connections, our research emphasizes the functional role of Beta waves in emotional regulation, offering more direct evidence of the brain's real-time processing in this area.

Beta wave activity is often associated with active mental engagement and problem-solving (Watanabe, 2008). In workplace contexts, where individuals frequently face high-pressure situations, enhanced Beta activity in the left DLPFC may facilitate the cognitive control necessary to manage stress and maintain composure. This finding also corroborates previous research by Gross (1998), which identified the PFC as a critical hub for adaptive emotional responses. While the R-square value for this model (6.4%) is modest, this finding contributes to the growing evidence supporting the role of Beta waves in workplace emotional regulation.

The significant relationship observed in this study underscores the potential utility of interventions aimed at optimizing Beta wave activity, such as biofeedback training, to improve emotional regulation among employees. Future studies could explore combining neurofeedback techniques with stress management training to provide practical solutions for improving emotional regulation in high-stress work environments.

The study also demonstrated a significant positive relationship between absolute power Alpha waves at Fp1 and motivation, with a coefficient value of 6.016 and a significance level of .048. This finding indicates that higher Alpha wave activity is associated with enhanced motivation levels among employees. This is consistent with the findings of previous studies that highlighted the role of Alpha waves in enhancing focus and reducing mental fatigue (Liu et al., 2017). However, our study offers a more specific link to motivation in the workplace, suggesting that Alpha wave activity can be a reliable predictor of goal-oriented behavior.

Alpha waves are linked to a relaxed yet alert state of mind, often referred to as the "flow state" (Katahira et al., 2018). This mental state is conducive to goal-oriented behavior, as it allows individuals to focus their attention and maintain a sense of calm amidst demanding tasks. Watanabe (2008) highlighted the role of the prefrontal cortex in motivational processes, including planning, goal maintenance, and performance monitoring. The findings of this study align with these theories, suggesting that Alpha wave activity in the left DLPFC facilitates the intrinsic drive to perform workplace tasks effectively.

Furthermore, the hierarchical organization of the PFC described by Kouneiher et al. (2009) supports the idea that functional connectivity within this region governs motivational behavior. Their research, which employed functional magnetic resonance imaging (fMRI), demonstrated that the medial PFC processes reward-based incentives, while the lateral PFC translates these signals into actionable behaviors. In the present study, the observed relationship between Alpha wave activity and motivation may reflect this dynamic, wherein the left DLPFC integrates motivational cues and sustains effortful task engagement. However, the modest R-square value (5.8%) suggests that Alpha wave activity alone may not fully explain motivation levels. Future research could examine how other factors, such as personality traits or work environment, interact with Alpha activity to create a more comprehensive model of motivation.

The analysis revealed a significant positive relationship between absolute power Theta waves at Fp1 and social relationship skills, with a coefficient value of 14.153 and a significance level of 0.006. Among the three dimensions studied, social relationships exhibited the highest R-square value (16.3%), indicating that Theta wave activity plays a more substantial role in this aspect of employee performance.

Theta waves are often associated with memory consolidation, emotional processing, and creativity (Balconi & Fronda, 2020). These cognitive processes are integral to building and maintaining strong social connections in the workplace. The findings of this study align with prior research demonstrating that the DLPFC, particularly the left hemisphere, supports prosocial behaviors and empathetic interactions. Jiang et al. (2018) found that activation in this region enhances communication and language comprehension, both of which are critical for effective interpersonal relationships. The specificity of Theta wave activity in supporting social relationships suggests that future workplace training programs could target this brainwave frequency, perhaps through mindfulness techniques or neurofeedback, to foster better teamwork and collaboration.

Additionally, the positive effect of Theta waves on social relationships may reflect enhanced interconnectivity between the DLPFC and other brain regions, such as the temporal-parietal junction and anterior cingulate cortex. These areas are implicated in theory of mind and empathy, enabling individuals to understand and respond to the emotions of others (Balconi & Fronda, 2020).

Interestingly, other brainwave metrics, including absolute power Alpha, relative power Theta, and power ratio Theta/Beta at Fp1, did not exhibit significant effects on social relationships. This highlights the specificity of Theta wave activity as a key driver of interpersonal skills. The practical implications of this finding are significant: workplace training programs could incorporate mindfulness or neurofeedback techniques to enhance Theta wave activity, thereby fostering better teamwork and collaboration among employees.

Conclusion

The findings of this study align with the broader body of neuroscience literature that emphasizes the role of the PFC in regulating emotional, motivational, and social behaviors. However, the study also provides unique insights into the specific brainwave patterns associated with these performance dimensions. Unlike traditional psychological models that focus on external and internal factors (e.g., work environment or subjective well-being), this research highlights the neurophysiological underpinnings of workplace performance.

For example, while Eden et al. (2015) and Dixon et al. (2017) explored the structural and functional roles of the PFC in emotion regulation, this study extends their findings by linking Beta wave activity to measurable performance outcomes. Similarly, the association between Alpha waves and motivation complements the work of Kouneiher et al. (2009), who emphasized the hierarchical organization of the PFC in translating motivational incentives into behavior.

The relationship between Theta waves and social relationships builds on the findings of Balconi and Fronda (2020) and Jiang et al. (2018), demonstrating that brainwave activity not only reflects cognitive and emotional processes but also predicted interpersonal dynamics. These findings underscore the potential for neuroscience-based interventions to enhance workplace performance across multiple dimensions. This study contributes to a growing body of research that bridges neuroscience and human performance. By examining the relationship between brainwave activity and employee performance, it provides a neurophysiological basis for understanding workplace behaviors that were traditionally analyzed through psychological or sociological lenses.

Despite its contributions, this study has several limitations. The small sample size (n = 68) limits the generalizability of the findings. A larger sample would provide greater statistical power and allow for more robust subgroup analyses (e.g., by age, gender, or job role). Future research should aim for a more diverse and larger sample to enhance the external validity of the findings. Furthermore, while the accidental sampling method is adequate for pilot studies, it limits external validity. The generalizability of findings is also limited to a single institutional context. Future studies should employ a multisite design, involving various sectors (manufacturing, services, healthcare), with demographic and job role stratification using probability sampling to improve generalizability.

Additionally, the study relied exclusively on qEEG measurements at Fp1, which represents only a subset of the DLPFC. Future research could incorporate multimodal imaging techniques, such as fMRI or near-infrared spectroscopy, to capture a more comprehensive view of brain activity. These methods would make the investigation of broader brain networks involved in cognitive and emotional processing possible, offering a deeper understanding of how multiple brain areas contribute to employee performance. This study also chose MMPI-180 as a time-efficient compromise for this pilot setting. However, its content validity for pure work functions is limited, and cross-tool validation with work-specific instruments should be performed in replication studies.

Another limitation is the cross-sectional design, which precludes causal inferences. Longitudinal studies are needed to explore how changes in brainwave activity over time predicted workplace performance. Finally, the study did not account for potential confounding variables, such as stress levels, sleep quality, or workplace culture, which may also impact performance dimensions.

This study highlights the significant role of specific brainwave frequencies in shaping key dimensions of employee performance. By linking Beta waves to emotional regulation, Alpha waves to motivation, and Theta waves to social relationships, the findings provide a neurophysiological basis for understanding workplace behaviors. These insights open new avenues for research and intervention, emphasizing the importance of integrating neuroscience into human performance.

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