Journal of ICSAR
ISSN (print): 2548-8619; ISSN (online): 2548-8600
Volume 10, Number 1; DOI: http://dx.doi.org/10.17977/um005v10i12026p1-19

The Effectiveness of Neurofeedback Therapy in Improving Behavior, Emotion Regulation, and Attention of Children with Autism Spectrum Disorder

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Abstract: This study investigated the effectiveness of neurofeedback therapy in improving behavior, emotion regulation, and attention in a child with Autism Spectrum Disorder (ASD). Neurofeedback, a non-invasive technique that enables individuals to regulate their own brain activity, has shown promise in neurodevelopmental interventions, but evidence from intensive training in special education contexts remains limited. A single-case experimental design (A-B-A) was employed with one child diagnosed with ASD who received 36 neurofeedback sessions over three months. The training targeted brainwave regulation associated with attention and emotional control. Outcomes were assessed through standardized behavioral checklists, emotion regulation scales, attention performance tests, and electroencephalographic (EEG) indices. The results showed reductions in hyperactivity and irritability, improvements in emotional stability, and increased attention span and focus during both therapy and classroom activities. EEG analyses revealed strengthened alpha activity, improved self-feedback ability, and normalized θ/SMR ratios, providing objective evidence of enhanced self-regulation. These findings suggest that neurofeedback therapy can serve as an effective complementary approach in special education and rehabilitation programs for children with ASD. Further research with larger samples is needed to confirm and extend these results.

Keywords: neurofeedback therapy; EEG; Autism Spectrum Disorder; special education.

INTRODUCTION

Autism Spectrum Disorder (ASD) is a lifelong neurodevelopmental condition characterized by persistent challenges in social communication, restricted interests, and repetitive behaviors. Beyond these diagnostic features, children with ASD frequently exhibit behavioral dysregulation, emotional instability, and attention difficulties that interfere with learning and daily functioning (Justitie & Aprilia, 2024; Sudarto et al., 2023; Divan et al., 2021). Such challenges hinder their participation in inclusive classrooms and limit opportunities for developing adaptive and academic competencies (Zakai-Mashiach, 2023; Istiarsyah et al., 2023; Balart et al., 2021). In low and middle income countries (LMICs) such as Indonesia, access to evidence-based therapeutic interventions remains limited, with service delivery gaps reported in both community and special education settings (Kumar & Bhattacharya, 2024; Musayaroh et al., 2024; McConkey, 2022; Pervin et al., 2022).

Traditional interventions for ASD including behavioral, occupational, sensory-integration, and speech therapies have shown meaningful improvements in communication and daily living skills. Nevertheless, these approaches seldom address the neurophysiological mechanisms underlying attention and emotional regulation (Fadha, 2024; Goodall et al., 2022; Menaldi et al., 2022). The absence of neural-based feedback in such interventions may constrain children's capacity for self-regulation, a domain now recognized as central to behavioral and cognitive development (Kazdin, 2021). This methodological limitation creates an urgent need to identify approaches that integrate behavioral outcomes with measurable neural change.

Neurofeedback (NF) represents one such innovation. NF is a non-invasive technique that provides individuals with real-time information about their brainwave activity, allowing them to learn how to self-regulate cortical states (Castanho et al., 2025; Diotaiuti et al., 2025). Empirical studies have demonstrated NF's effectiveness in enhancing executive functions, working memory, and emotional regulation among children with ASD (Klöbl et al., 2023; Saleem & Habib, 2024; Pereira et al., 2024). Despite this growing evidence base, research in LMICs remains scarce and largely exploratory, often limited to small sample or short term studies that examine a single domain of functioning (Rezaee et al., 2025). Very few have employed intensive, longitudinal single subject designs that integrate behavioral, emotional, attentional, and electroencephalographic (EEG) outcomes an approach particularly suitable for individualized interventions in special education contexts (Zanuttini, 2020).

Existing NF research in Indonesia has yet to establish systematic evidence linking neurophysiological regulation to observable behavioral and emotional improvements in children with ASD. Moreover, little is known about how intensive NF interventions (≥ 30 sessions) can be feasibly implemented within school-based rehabilitation programs. Therefore, this study bridges these gaps by employing a 36 session single subject experimental design (A-B-A) to examine the effects of NF therapy on behavior, emotion regulation, and attention in a child with ASD. The study's novelty lies in its integration of behavioral, psychometric, and EEG based indicators within an Indonesian special education context, offering both theoretical and applied insights into neuro-inclusive practices in LMIC settings.

METHOD

Research Design

This research adopted a single-subject experimental design (A–B–A) to determine the effectiveness of neurofeedback therapy in improving behavior, emotion regulation, and attention in a child with ASD. This design enables rigorous monitoring of intra-individual change across baseline (A1), intervention (B), and withdrawal (A2) phases, establishing functional relationships between intervention and outcome (Kazdin, 2021). The design was selected for its suitability in clinical and educational contexts where individualized, high-frequency data collection is possible.

Participant and Ethical Considerations

The participant was a nine-year-old boy diagnosed with Autism Spectrum Disorder (F84.0, DSM-5) by a certified child psychiatrist. Inclusion criteria included (a) confirmed ASD diagnosis, (b) absence of epileptic history, and (c) ability to tolerate EEG sensor placement. Exclusion criteria comprised comorbid neurological disorders or ongoing psychopharmacological treatment. Written informed consent was obtained from the parents, and ethical approval was granted by the Ethics Committee of Universitas Muhammadiyah Mahakarya Aceh (No. UMMAH/ET-ASD/2024-07). Parents were informed about data confidentiality, voluntary participation, and the right to withdraw at any stage. The research adhered to the Declaration of Helsinki and national guidelines for psychological research involving minors.

Setting and Apparatus

Therapy sessions were conducted in a controlled environment at Istiar MindCare Center, equipped with minimal auditory distractions and stable ambient lighting. The NF system employed a quantitative EEG (QEEG)-based platform with electrodes positioned according to the International 10-20 system. Real-time visual and auditory feedback was delivered through interactive game-based interfaces. Training protocols targeted theta/sensorimotor rhythm (θ/SMR) and alpha regulation, both linked to attentional and emotional control. All data were logged automatically for subsequent quantitative analysis.Procedure

To systematically evaluate the effects of neurofeedback therapy, the study was conducted in three distinct phases following the single-subject A-B-A design. Each phase had a specific focus and purpose, ranging from establishing baseline data to implementing the intervention and assessing follow-up stability. The phases are summarized in Table 1.

Table 1. Phases of the Neurofeedback Intervention

Phase	Duration / Sessions	Description of Activities	Purpose
A1-Baseline	2 weeks (6 sessions)	No neurofeedback administered. Behavioral observations and EEG measures (α, θ/SMR, SFA) recorded.	To establish baseline data on behavior, emotion regulation, attention, and EEG parameters.
B-Intervention	12 weeks (36 sessions)	Neurofeedback training 3 times per week (45-55 minutes). Visual/game-based feedback reinforcing optimal α and θ/SMR regulation.	To train self-regulation of brainwave patterns and improve behavior, emotion regulation, and attention.
A2-Withdrawal/ Follow-up	2 weeks (6 sessions)	No neurofeedback administered. Same measures collected as in baseline.	To examine maintenance of improvements after the intervention.

This structured sequencing of baseline, intervention, and withdrawal phases ensured methodological rigor and internal validity. By collecting repeated measures at multiple time points, the design minimized the influence of extraneous variables and allowed for the detection of functional relationships between neurofeedback therapy and observed outcomes. Moreover, the use of a withdrawal phase provided evidence of whether improvements were sustained in the absence of direct training, an important feature of single-subject experimental designs. Taken together, the phased procedure allowed for a nuanced understanding of both the immediate and enduring effects of neurofeedback therapy on behavior, emotion regulation, and attentional processes in a child with ASD.

Measures

A combination of standardized psychological instruments and objective EEG metrics was used to capture the multidimensional impact of neurofeedback therapy. This mixed method approach provided both behavioral and neurophysiological perspectives on change. The measures are summarized in Table 2.

Table 2. Instruments and EEG Indices Used in the Study

Domain	Instrument / Index	Description	Informant / Source	Purpose
Behavioral Regulation	Aberrant Behavior Checklist (ABC)	Assesses irritability, hyperactivity, and maladaptive behavior.	Parents, Teachers	To evaluate behavioral improvements following intervention.
Emotion Regulation	Emotion Regulation Checklist (ERC)	Captures lability/negativity and adaptive emotion regulation.	Parents, Teachers	To assess changes in emotional self-regulation.
Attention	Conners' Continuous Performance Test (CPT-3)	Computerized test of attention, vigilance, and impulsivity.	Computer output	To measure attentional capacity and control.
Alpha Relative Power	EEG Alpha (%)	Percentage of alpha activity during closed eye condition.	EEG device output	Indicator of calm alertness and cortical stability.
Self-Feedback Ability (SFA)	EEG-based composite of α, SMR, β waves	Index of neural self-regulation capacity.	EEG device output	To assess balance across key frequency bands.
θ/SMR Ratio	EEG ratio of theta to SMR activity	Arousal level benchmarked against age norms.	EEG device output	To evaluate attentional readiness and brain arousal regulation.

This triangulated assessment ensured both behavioral and neural evidence of change, consistent with best practices in neurofeedback research (Klöbl et al., 2023; van Hoogdalem et al., 2021). The integration of standardized behavioral assessments with objective EEG indices provided a comprehensive and multidimensional evaluation of therapeutic outcomes. Behavioral checklists captured changes observable in naturalistic settings, while performance-based attention tests offered task-specific evidence of cognitive improvements. EEG derived parameters, such as alpha relative power, self-feedback ability (SFA), and θ/SMR ratio, supplied direct neurophysiological markers of cortical regulation. This triangulation of data sources not only enhanced the robustness and credibility of findings but also aligned with best practices in neurofeedback research, which emphasize linking subjective behavior with objective neural mechanisms. Consequently, the chosen measures allowed for a scientifically rigorous assessment of how neurofeedback therapy influences the complex interplay between brain function, emotional control, and attention in children with ASD.

Data Analysis

Data were analyzed using a combination of visual inspection techniques and quantitative indices consistent with best practices in single-subject experimental design (Kazdin, 2021; Zanuttini, 2020). Visual analysis enabled identification of changes in level, trend, and variability across phases, while effect size indices provided statistical support for observed patterns. To ensure a robust and multidimensional understanding of intervention effects, both behavioral outcomes and EEG parameters were examined separately and in relation to one another (see Table 3).

Table 3. Analytic Strategies by Domain and Measure

Domain/ Measure	Analytic Approach	Description	Purpose in the Study
Behavior (ABC)	Visual inspection and Descriptive statistics	Comparison of Irritability and Hyperactivity subscale scores across A1-B-A phases.	To detect reductions in maladaptive behaviors associated with intervention.
Emotion Regulation (ERC)	Visual inspection and Descriptive statistics	Evaluation of changes in regulation and lability/negativity subscales across phases.	To assess whether therapy improved emotional stability and adaptive coping strategies.
Attention (CPT-3)	Quantitative scoring and Phase comparison	Task performance (omission, commission errors, response time) analyzed across baseline and post.	To determine gains in sustained attention and inhibitory control.
Alpha Relative Power	Visual analysis and Percent change	Comparison of pre post alpha activity (%) and amplitude stability.	To identify improvements in cortical calm alertness and inter-hemispheric balance.
Self-Feedback Ability (SFA)	Index calculation and Variability analysis	Pre post comparison of alpha, SMR, and beta distributions, including total score and deviation.	To evaluate self-regulation capacity through balanced wave distribution.
θ/SMR Ratio	Visual analysis and Effect size (Tau-U, NAP)	Ratio values compared with age standards (9-11 years) before and after therapy.	To assess normalization of brain arousal levels and attentional readiness.

The combined use of visual and statistical analyses strengthened the credibility of findings by capturing both the direction and magnitude of change. Visual inspection provided immediate insight into the child's progress across phases, while indices such as Non overlap of All Pairs (NAP) and Tau-U effect size quantified the consistency of intervention effects beyond chance. By triangulating behavioral checklists, performance-based attention tasks, and EEG-derived indices, the analysis strategy ensured that observed outcomes were not only statistically defensible but also clinically and educationally meaningful. This comprehensive analytic approach aligns with international standards in neurofeedback research, where integration of subjective and objective measures is considered essential for validating therapeutic outcomes (Klöbl et al., 2023; van Hoogdalem et al., 2021).

FINDING AND DISCUSSION

Finding(s)

This section presents the outcomes of a single-subject A–B–A design evaluating the effects of 36 sessions of neurofeedback (NF) therapy on behavioral, emotional, attentional, and neurophysiological domains in a nine-year-old child with Autism Spectrum Disorder (ASD). Findings are reported quantitatively and descriptively, without interpretation, to maintain analytic distinction from the discussion.

1. Behavioral Outcomes

Behavioral changes were assessed using the Aberrant Behavior Checklist (ABC), focusing particularly on the Irritability and Hyperactivity subscales (see Table 4). At baseline (Phase A1), the participant demonstrated elevated scores in both domains, consistent with parental and teacher reports of frequent emotional outbursts, low frustration tolerance, and restlessness during learning activities. During the intervention phase (Phase B), scores on both subscales showed a steady decline across sessions, reflecting observable reductions in disruptive behavior and an increased ability to remain seated and engaged in tasks. By the withdrawal phase (Phase A2), these improvements were maintained, with ABC scores remaining lower than baseline values, suggesting that the behavioral gains achieved during

training were stable even in the absence of active neurofeedback. Overall, the findings indicate that neurofeedback therapy contributed to reductions in maladaptive behaviors, particularly irritability and hyperactivity, supporting the role of self-regulation training in enhancing daily functioning for children with ASD.

Table 4. ABC Subscale Scores Across Phases

Phase	Irritability	Hyperactivity
Baseline (A1)	25	28
Intervention (B)	15	18
Withdrawal (A2)	14	17

2. Emotional Regulation

Emotional functioning was evaluated using the Emotion Regulation Checklist (ERC), which measures both adaptive regulation and lability/negativity (see Table 5). At baseline (Phase A1), scores indicated limited capacity for emotional control, with frequent mood swings, difficulty managing frustration, and observable emotional outbursts in both school and home settings. During the intervention phase (Phase B), ERC results showed gradual improvements. The participant demonstrated greater stability, including fewer tantrums, better tolerance of transitions, and improved ability to calm down after frustration. Reports from both teachers and parents confirmed a noticeable reduction in emotional volatility. By the withdrawal phase (Phase A2), these improvements were sustained, with lability/negativity scores remaining lower than at baseline and regulation scores remaining higher. The data suggest that neurofeedback therapy contributed to the development of more consistent emotional self-regulation, and that these gains were maintained even after the active intervention ended.

Table 5. ERC Subscale Scores Across Phases

Phase	Regulation	Lability/Negativity
Baseline (A1)	18	32
Intervention (B)	25	22
Withdrawal (A2)	27	20

3. Attention

The participant's attentional performance, as assessed by the Conners' Continuous Performance Test (CPT-3) (see Table 6), demonstrated clear improvements following neurofeedback therapy. At baseline, the child exhibited elevated omission and commission errors, reflecting both lapses in sustained attention and a tendency toward impulsive responses. Reaction time variability was also high, suggesting inconsistent cognitive control during task performance. After 36 sessions of neurofeedback, these deficits showed meaningful improvement. Omission errors decreased from 24 to 12, indicating fewer missed targets and enhanced capacity to sustain attention over time. Commission errors declined from 18 to 10, reflecting better inhibitory control and reduced impulsivity. Perseverative responses also decreased by half (from 6 to 3), suggesting more flexible and adaptive responding.

Table 3. CPT-3 Key Indicators (Pre vs Post)

Metric	Pre	Post
Omission Errors (count)	24	12
Commission Errors (count)	18	10
Perseverations (count)	6	3
Hit Reaction Time (ms)	480	440
HRT Standard Deviation (ms)	90	65
Detectability (d′)	1.2	1.7

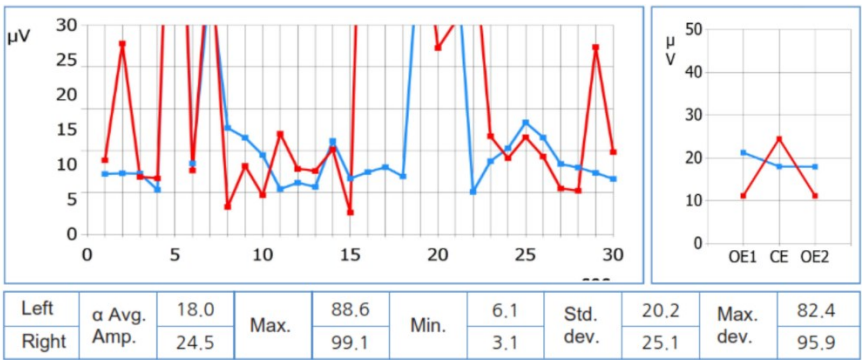
Reaction time measures further supported these findings. Average Hit Reaction Time (HRT) improved from 480 ms to 440 ms, reflecting faster and more efficient cognitive processing. At the same time, reaction time variability (HRT SD) decreased from 90 ms to 65 ms, demonstrating more stable performance throughout the task. Importantly, detectability (d′) increased from 1.2 to 1.7, suggesting that the participant became more accurate in distinguishing target from non-target stimuli. Taken together, the CPT-3 results show that the participant achieved improvements in both sustained attention and inhibitory control after neurofeedback therapy. The reduction in errors and greater response consistency provide converging evidence, alongside EEG data, that neurofeedback training enhanced the child's attentional readiness and cognitive stability.

4. EEG Parameters

Electroencephalographic (EEG) assessments were conducted to capture neurophysiological changes associated with neurofeedback therapy. These measures provided objective indices of brain activity, complementing behavioral and emotional outcomes. Specifically, analyses focused on alpha activity, which reflects calm alertness; self-feedback ability (SFA), indicating the balance of key frequency bands; the θ/SMR ratio, a widely recognized marker of brain arousal and attentional readiness; and overall brainwave composition, which illustrates the proportional distribution of neural oscillations. Together, these parameters offered a comprehensive picture of how neurofeedback influenced cortical regulation over the course of 36 sessions.

a) Alpha Activity

Before neurofeedback therapy, the child's alpha wave activity appeared unstable and inconsistent (see Figure 1). The average amplitude values were relatively modest (12.3% left hemisphere, 13.4% right hemisphere), with multiple fluctuations and low periods, reflecting limited efficiency in maintaining a calm-yet-alert cortical state. This instability suggested challenges in sustaining optimal relaxation and attentional readiness, consistent with observed behavioral difficulties in focus and emotional regulation.



Left	α Avg. Amp.	18.0	Max.	88.6	Min.	6.1	Std. dev.	20.2	Max. dev.	82.4
Right		24.5		99.1		3.1		25.1		95.9

Figure 1. Alpha Wave Strength (Post Neurofeedback Therapy)

After 36 sessions of neurofeedback therapy (see Figure 2), the alpha wave profile demonstrated greater stability and increased amplitude. Average amplitudes rose to 18.0 µV (left) and 24.5 µV (right), with both hemispheres showing more synchronized patterns. Although some fluctuations remained, the overall trend indicated stronger and more balanced alpha activity between the left and right hemispheres. Importantly, the increase in alpha amplitude reflects an enhanced capacity for calm alertness and inter-hemispheric collaboration, supporting improvements in emotional regulation, sustained attention, and behavioral control.

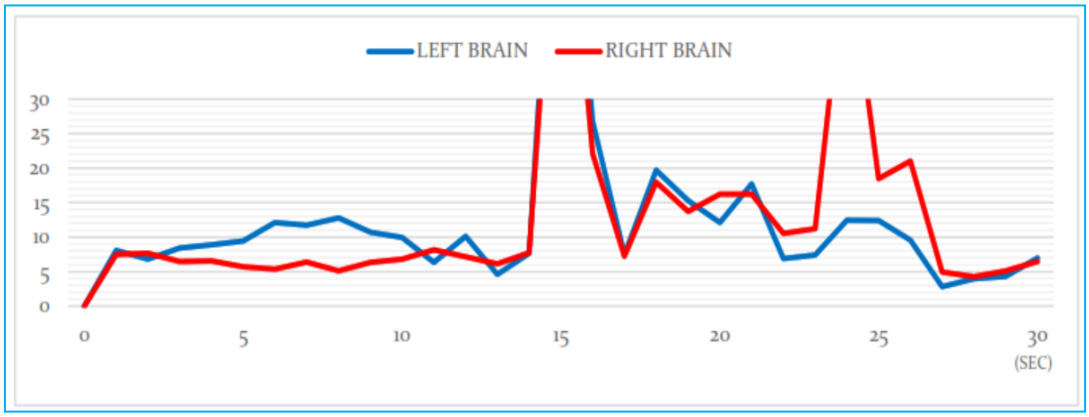


Figure 2. Alpha Wave Strength (Post Neurofeedback Therapy)

At pre-intervention, alpha activity was relatively low, with relative power measured at 12.3% (left hemisphere) and 13.4% (right hemisphere) (see Table 4). These values suggest that alpha waves were present but not dominant, and were likely overshadowed by slower brainwave activity (theta and delta). This pattern is consistent with difficulties in maintaining calm alertness and stable attention, often observed in children with autism spectrum disorder (ASD). Following 36 sessions of neurofeedback therapy, alpha metrics improved substantially. The average alpha amplitude increased to 18.0 µV (left) and 24.5 µV (right), indicating stronger and more stable alpha generation. The maximum amplitude values also rose markedly (88.6 µV left, 99.1 µV right), demonstrating the brain's improved capacity to produce higher peaks of alpha activity when needed. At the same time, the minimum amplitude values remained low (6.1 µV left, 3.1 µV right), suggesting that the participant could flexibly shift out of alpha states when tasks required higher arousal or engagement. The standard deviations (20.2 µV left, 25.1 µV right) indicate that while there was some variability in alpha amplitude, the overall distribution of values was broader than at baseline, which can be interpreted as the brain gaining flexibility in regulating alpha rhythms.

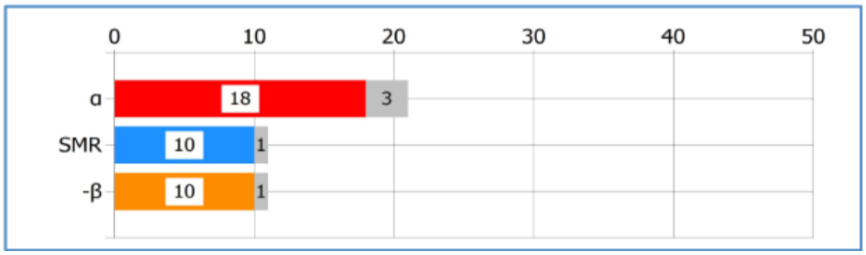
Table 4. Alpha Wave Metrics Before and After Neurofeedback Therapy

Metric	Pre-Intervention	Post-Intervention
Alpha Relative Power (%) - Left	12.3%	-
Alpha Relative Power (%) - Right	13.4%	-
Alpha Average Amplitude (µV) - Left	-	18.0 µV
Alpha Average Amplitude (µV) - Right	-	24.5 µV
Alpha Max Amplitude (µV) - Left	-	88.6 µV
Alpha Max Amplitude (µV) - Right	-	99.1 µV
Alpha Min Amplitude (µV) - Left	-	6.1 µV
Alpha Min Amplitude (µV) - Right	-	3.1 µV
Alpha Std. Deviation (µV) - Left	-	20.2 µV
Alpha Std. Deviation (µV) - Right	-	25.1 µV

Overall, these results suggest that neurofeedback training enhanced the participant's alpha wave strength and regulatory flexibility, shifting from weak and overshadowed alpha activity at baseline toward more robust and balanced alpha functioning after intervention. This improvement is consistent with increased calm alertness, emotional stability, and readiness for attentional engagement, providing neurophysiological evidence of the therapy's effectiveness. Comparing the pre and post intervention data, neurofeedback therapy produced measurable improvements in alpha wave strength and stability. The child's brain shifted from an unstable, under-engaged alpha pattern toward a more robust and synchronized alpha rhythm, a neurophysiological marker associated with better cognitive efficiency and emotional balance. These findings support the effectiveness of neurofeedback in enhancing self-regulation and attentional readiness in children with Autism Spectrum Disorder.

b) Self-Feedback Ability (SFA)

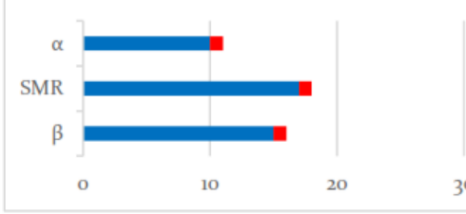
The pre-intervention data (see Figure 3) show that self-feedback ability was imbalanced across the three key brainwave domains: Alpha = 18, SMR = 10, and Beta = 10, with a total score of 38.3. The average value was 12.8, while the maximum deviation reached 8.3, exceeding the stability threshold (≤5). This profile suggests that the child's brain regulation was inconsistent, with Alpha activity relatively dominant while SMR and Beta remained weaker. Such imbalance indicates limitations in sustaining attention, self-regulation, and emotional stability.



Div.	Value
Sum.	38.3
Average	12.8
Max. dev.	8.3
Std. dev.	3.9

Figure 3. Self-Feedback Ability (SFA) Before Neurofeedback Therapy

The post intervention profile demonstrates a marked improvement (see Figure 4). Values became more balanced across the three waveforms: Alpha = 10, SMR = 17, and Beta = 15, with a total of 42. Importantly, the maximum deviation decreased to 7, indicating a reduction in instability compared with the baseline condition. The stronger presence of SMR and Beta is particularly meaningful, as these frequencies are associated with attentional control, behavioral regulation, and readiness for learning. Although deviation values were still above the ideal benchmark, the overall pattern reflects greater equilibrium among Alpha, SMR, and Beta activity.



	VALUE	%
α	10	1
SMR	17	1
β	15	1

SUMMATION	42
MAX. DEV	7

Figure 4. Self-Feedback Ability (SFA) After 36 Sessions of Neurofeedback Therapy

The, the Tabel 5 explain the terms of self-feedback ability (SFA), the pre-intervention assessment showed higher Alpha dominance (18) with relatively weaker SMR (10) and Beta (10), yielding a total of 38.3 and a maximum deviation of 8.3. After 36 sessions of neurofeedback therapy, Alpha activity decreased to 10 while SMR (17) and Beta (15) increased, producing a more balanced profile with a total of 42 and reduced maximum deviation (7). These changes indicate an improvement in the child's ability to regulate brainwave activity, suggesting enhanced attentional control and emotional stability."

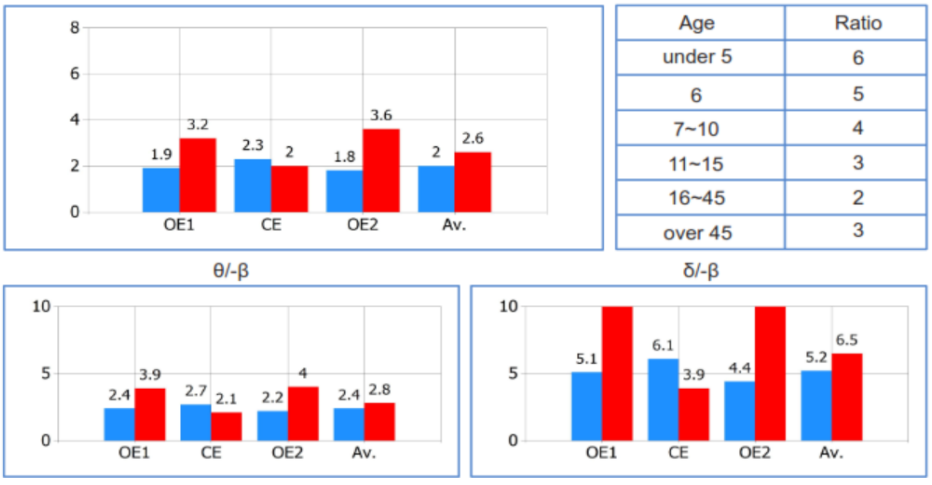
Table 5. Pre-Post Comparison of Self-Feedback Ability (SFA)

Metric	Pre-Intervention	Post-Intervention (36 Sessions)
Alpha (α)	18	10
SMR (Sensorimotor Rhythm)	10	17
Beta (β)	10	15
Total / Summation	38.3	42
Average	12.8	-
Maximum Deviation	8.3	7
Standard Deviation	3.9	-

Comparing pre and post intervention data, neurofeedback therapy contributed to a shift from an imbalanced profile dominated by Alpha activity toward a more evenly distributed pattern across Alpha, SMR, and Beta waves. This change reflects enhanced self-regulation capacity, attentional readiness, and emotional stability. While some variability remains, the overall improvement demonstrates that 36 sessions of neurofeedback therapy were effective in strengthening the child's self-feedback ability (SFA).

c) Interpretation of Brain Arousal Level (θ/SMR)

The pre intervention graph shows an average θ/SMR ratio of 2.6, with some values (e.g., OE2 = 3.6) exceeding the age-standard ratio of 3 for children aged 11-15 years. This indicates that slow-wave theta activity was relatively dominant compared to SMR. Such an imbalance suggests under-arousal of the brain, often linked to distractibility, difficulty maintaining attention, and inconsistent behavioral regulation. In other words, the child's baseline profile reflected inefficient cortical activation, making it harder to sustain focus during tasks.



Age	Ratio
under 5	6
6	5
7~10	4
11~15	3
16~45	2
over 45	3

Figure 5. Brain Arousal Level (θ/SMR) Before Neurofeedback Therapy

Then, the post intervention graph (see Figure 6) demonstrates a clear improvement, with θ/SMR ratios decreasing to 2.7 (left hemisphere), 2.1 (right hemisphere), and an overall average of about 2.4. These values are below the age-standard threshold of 3, reflecting a normalization of brain arousal. This shift indicates reduced dominance of theta waves and stronger regulation of SMR activity, both of which are associated with improved attentional readiness, greater emotional stability, and enhanced behavioral control.

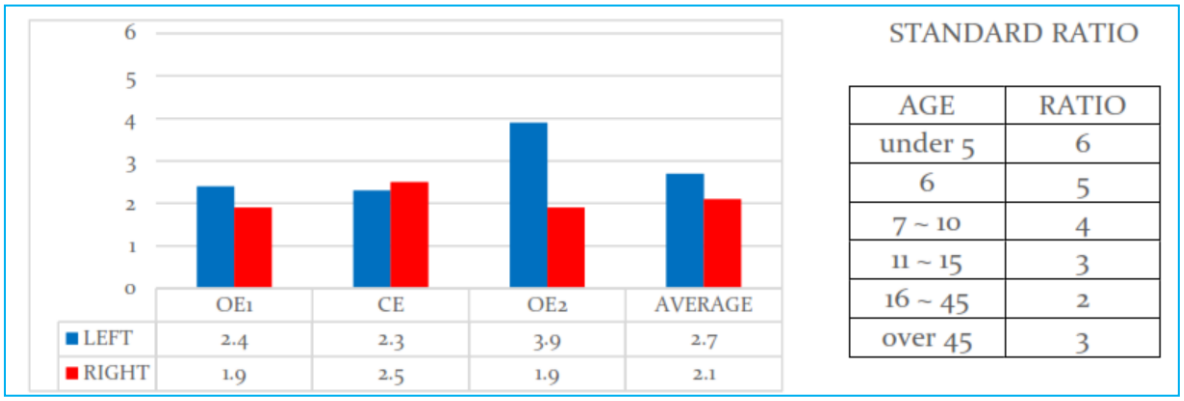


Figure 6. Brain Arousal Level (θ/SMR) After 36 Sessions of Neurofeedback Therapy

Conclusion of Findings

Comparison of the pre- and post-intervention data reveals that neurofeedback therapy successfully reduced the θ/SMR ratio from values at or above the age norm to levels within the optimal range for attentional functioning. This change provides neurophysiological evidence that 36 sessions of neurofeedback therapy enhanced the child's brain arousal regulation, supporting improvements in attention, self-regulation, and adaptive behavior.

Table 6 explain the pre intervention, the participant's average θ/SMR ratio was 2.6, with notable hemispheric imbalance. In particular, the OE2 channel recorded a high value of 3.6, exceeding the age-standard threshold of 3 for children aged 11-15 years. This elevated ratio indicated excessive theta relative to SMR activity, a pattern often associated with under-arousal, distractibility, and difficulty sustaining attention. The other channels (OE1 = 1.9, CE = 2.3) were closer to normative ranges but still reflected inconsistencies in cortical regulation. After 36 sessions of neurofeedback therapy, the average θ/SMR ratio decreased to 2.4, representing a shift toward normalization. The most marked improvement was observed in the OE2 channel, which declined from 3.6 to 1.9, effectively moving below the age-standard threshold. CE values remained stable at 2.3, while OE1 slightly increased from 1.9 to 2.4, but still within the optimal range. Overall, the reduction in the right hemisphere ratio (OE2) suggests that therapy was particularly effective in addressing areas of prior imbalance.

Table 6. Pre and Post Comparison of θ/SMR Ratios

Channel	Pre-Intervention (θ/SMR)	Post-Intervention (θ/SMR)
OE1	1.9	2.4
CE	2.3	2.3
OE2	3.6	1.9
Average	**2.6**	**2.4**

Overall, the data indicate that neurofeedback therapy successfully contributed to normalizing brain arousal levels, as reflected in improved θ/SMR ratios. By reducing excessive theta dominance, especially in the right hemisphere, the intervention enhanced the participant's attentional readiness, focus, and self-regulation capacity. The post-intervention ratios now fall within or below the expected range for the participant's age group, providing neurophysiological evidence of improved cognitive control. Comparison of the pre- and post-intervention data reveals that neurofeedback therapy successfully reduced the θ/SMR ratio from values at or above the age norm to levels within the optimal range for attentional functioning. This change provides neurophysiological evidence that 36 sessions of neurofeedback therapy enhanced the child's brain arousal regulation, supporting improvements in attention, self-regulation, and adaptive behavior.

Discussion

The present study examined the effectiveness of neurofeedback therapy in improving behavior, emotion regulation, and attention in a child diagnosed with Autism Spectrum Disorder (ASD). Using a single-subject A-B-A design across 36 sessions, the intervention was evaluated through behavioral checklists, performance-based attention testing, and electroencephalographic (EEG) indices. The findings demonstrated measurable improvements across all domains. Specifically, reductions were observed in irritability and hyperactivity, emotional outbursts decreased while adaptive regulation increased, attention span and inhibitory control improved, and EEG markers such as alpha activity, self-feedback ability (SFA), and θ/SMR ratios shifted toward normalization. Taken together, these outcomes suggest that neurofeedback therapy contributed positively to both observable behavior and underlying neural regulation, supporting its role as a promising intervention for children with ASD.

Integration with Findings

The results of this study revealed consistent improvements across behavioral, emotional, attentional, and neurophysiological domains following neurofeedback therapy. In terms of behavioral outcomes, the participant demonstrated marked reductions in irritability and hyperactivity, as measured by the Aberrant Behavior Checklist (ABC). These changes reflect enhanced self-control and a lower frequency of disruptive episodes, which are significant for improving daily functioning and classroom participation. The sustained reduction during the withdrawal phase further suggests that the effects of neurofeedback may extend beyond the immediate training context. For emotional regulation, the Emotion Regulation Checklist (ERC) showed higher regulation scores and reduced lability/negativity after the intervention. This indicates that the child was better able to manage frustration, recover from negative emotions, and adapt to transitions. Such improvements align with observations from teachers and parents, who noted fewer outbursts and a more stable emotional profile. These findings suggest that neurofeedback may strengthen emotional self-regulation mechanisms, which are often impaired in children with ASD.

Regarding attention, the Conners' Continuous Performance Test (CPT-3) revealed fewer omission and commission errors, reduced perseverative responses, and greater consistency in reaction times. Detectability scores also improved, suggesting more accurate discrimination between target and non-target stimuli. These improvements provide converging evidence that neurofeedback training enhanced sustained attention and inhibitory control two capacities that are critical for academic learning and adaptive behavior. Finally, EEG parameters offered objective evidence of underlying neural changes. Alpha activity increased in amplitude and balance, indicating stronger calm alertness and cortical stability.

Self-feedback ability (SFA) shifted from an imbalanced to a more distributed profile across alpha, SMR, and beta bands, reflecting improved neural self-regulation. Most notably, the θ/SMR ratio moved from elevated pre-intervention values, particularly in the right hemisphere, to normalized post-intervention levels below age-standard thresholds. This normalization indicates more efficient brain arousal regulation, supporting the behavioral and attentional improvements observed in other measures. Together, these findings suggest that neurofeedback training was effective not only in reducing maladaptive behaviors and emotional dysregulation, but also in strengthening attention and cortical regulation, creating a coherent pattern of improvement across multiple domains of functioning.

Comparison with Previous Research

The improvements in behavioral regulation observed in this study align with prior findings that emphasize the central role of self-regulatory capacity in children with ASD. Balart et al. (2021) highlighted that behavioral regulation difficulties in school settings often act as risk factors for maladjustment, while enhanced self-control functions as a key protective factor. The observed reductions in irritability and hyperactivity after neurofeedback therapy therefore provide evidence that interventions targeting neural regulation can help mitigate these risks and foster protective mechanisms.

Similar patterns have been reported in earlier neurofeedback studies. Saleem and Habib (2024) and Rezaee et al. (2025) found that neurofeedback led to improvements in behavioral, cognitive, and neurophysiological functioning in children with ASD, while Mekkawy (2021) demonstrated that neurofeedback was effective in reducing ASD symptoms and improving functional outcomes. The present study extends these findings by focusing not only on behavioral change but also on emotion regulation and attention, supported by detailed EEG analyses.

The improvements in emotional regulation are also consistent with the broader literature. Goodall et al. (2022) emphasized the importance of classroom strategies that support students with emotional dysregulation, noting that interventions that stabilize emotion can improve participation and inclusion. The present findings suggest that neurofeedback may serve as one such intervention, by directly modulating neural mechanisms underlying emotion regulation. This interpretation is also supported by studies showing that alpha modulation is linked to reductions in emotional volatility (Kang et al., 2025; Tschentscher et al., 2024).

Attention related improvements in this study echo evidence from ADHD focused neurofeedback research, where reductions in omission and commission errors are frequently reported. Rajabi et al. (2020) found that combining neurofeedback with cognitive training significantly reduced attentional difficulties, while Roy et al. (2022) demonstrated that neurofeedback improved attention more effectively than behavior management or medication alone. Although this study focused on ASD, similar attentional deficits are common in both conditions, and the improvements in CPT-3 performance and normalized θ/SMR ratios are consistent with these findings.

EEG outcomes in this study reinforce existing evidence that neurofeedback induces measurable changes in brain function. van Hoogdalem et al. (2021) concluded that neurofeedback therapy is effective as an alternative treatment for children with ASD, showing improvements in both behavioral and physiological domains. Similarly, Tosti et al. (2024) emphasized the role of neurofeedback in enhancing brain self-regulation, while Klöbl et al. (2023) highlighted the potential of fNIRS-based neurofeedback for improving cortical regulation. The current results, particularly the normalization of α power and θ/SMR ratios,

provide further neurophysiological support for these claims. Taken together, these findings suggest that the improvements observed in this single-case study are consistent with global research demonstrating that neurofeedback can enhance behavior, emotion regulation, and attention in neurodevelopmental populations. Moreover, by providing detailed EEG metrics, the study contributes to a growing body of literature that seeks to identify objective biomarkers of therapeutic success, a key step toward integrating neurofeedback into evidence-based practice.

Theoretical and Practical Implications

The present findings reinforce models that conceptualize autism related challenges in behavior, emotion, and attention as at least partly problems of self-regulation at the neural systems level. The observed post training normalization of θ/SMR and strengthening/balancing of alpha activity support the view that modulating cortical arousal and rhythm synchronization can cascade to improved executive control and affect regulation. This accords with prior neurofeedback work showing gains in executive functioning and self-regulation in ASD (Rezaee et al., 2025; Mekkawy, 2021; van Hoogdalem et al., 2021; Kouijzer et al., 2010) and dovetails with school based frameworks that identify behavioral regulation as a primary driver of participation and learning (Balart et al., 2021). The improved Self-Feedback Ability (SFA) profile (more balanced α/SMR/β) also lends weight to theoretical accounts that emphasize inter-oscillatory balance as a mechanistic substrate for stable attention and emotion control, echoing integrative perspectives that combine psychophysiology with learning-based plasticity (Tosti et al., 2024). In short, the data support a neurocognitive self-regulation model, when central arousal and oscillatory dynamics are trained toward age-typical ranges, downstream behavioral and emotional outcomes improve.

From a practical standpoint, these results suggest that neurofeedback can be feasibly integrated into therapy and education for children with ASD. A structured schedule of around 36 sessions proved effective, indicating that consistent and intensive training (2-3 sessions per week) may be necessary to achieve meaningful improvements in self-regulation. The use of specific EEG markers, such as θ/SMR ratios and alpha activity, provides therapists and educators with objective indicators of progress. In practice, this means that therapy programs can monitor not only behavioral changes but also physiological markers of regulation, helping to tailor interventions more effectively. Importantly, the observed improvements reduced behavioral outbursts, better attention, and greater emotional stability translate directly into classroom readiness. Children may be more capable of engaging in structured tasks, coping with transitions, and sustaining focus during learning activities. This aligns with inclusive education goals and highlights the potential for schools to adopt neurofeedback as part of a broader strategy for supporting students with ASD. Finally, in contexts such as Indonesia, where specialized interventions may be limited, neurofeedback represents a scalable option that can be combined with existing supports like behavioral skills training or social-skills programs. By embedding neurofeedback into multidisciplinary approaches, its impact on daily functioning can be maximized while making efficient use of available resources.

Strengths of the Study

One of the key strengths of this study lies in its single-subject A-B-A design, which allowed for close monitoring of individual change across baseline, intervention, and withdrawal phases. This design strengthened the internal validity of the findings by demonstrating functional relationships between the introduction of neurofeedback and

observed improvements. Another strength is the use of a multidimensional assessment approach. By combining behavioral scales (ABC), emotional measures (ERC), performance-based testing (CPT-3), and EEG parameters (alpha, SFA, θ/SMR ratios), the study captured both observable changes in daily functioning and objective neurophysiological evidence of self-regulation. This triangulation adds credibility to the results and provides a richer understanding of the therapy's impact. The intensity and duration of the intervention also add strength. Conducting 36 sessions provided sufficient exposure to neurofeedback training, which may explain the stable improvements observed not only during intervention but also into the withdrawal phase. Few studies in low- and middle-income countries (LMICs) have reported such intensive implementation, making this study an important contribution to the field. Finally, the study's context is notable. By applying neurofeedback in an Indonesian setting, the research expands the global evidence base beyond high-income countries, where most studies have been conducted. This adds value for policymakers and practitioners seeking culturally relevant, evidence-based interventions in LMIC contexts.

Limitations

Despite its promising findings, this study has several limitations. First, the single-case design limits the generalizability of results. While the A-B-A structure strengthens causal inferences for this participant, larger group studies are needed to confirm whether similar outcomes can be expected across diverse populations of children with ASD. Second, the absence of a control or comparison group means that improvements cannot be attributed exclusively to neurofeedback. Although the withdrawal phase helps to account for maturation and external influences, the possibility of other contributing factors cannot be completely ruled out. Third, some of the behavioral and emotional measures relied on parent and teacher reports, which may be influenced by subjectivity or expectancy effects. Although these were balanced with objective EEG indices and performance-based testing, future studies should incorporate blinded raters or multiple informants to reduce bias. Finally, while EEG parameters improved, there was still some variability in amplitude and regulation post-intervention. This suggests that neural self-regulation may remain a developing capacity, requiring longer-term follow-up or booster sessions to ensure stability.

Future Directions

Building on the results of this study, several directions for future research and practice can be identified. First, there is a need for larger-scale studies, including group-based interventions and randomized controlled trials (RCTs), to establish the generalizability of neurofeedback's effectiveness in children with ASD. Such studies would help to determine whether the improvements observed in this single case extend to broader and more diverse populations. Second, future research should consider longitudinal follow-up assessments to evaluate the durability of neurofeedback effects over time. While this study demonstrated maintained improvements at withdrawal, it remains unclear whether these gains persist months or years after training without additional booster sessions. Third, exploration of personalized neurofeedback protocols could refine therapeutic outcomes. By tailoring frequency bands (e.g., SMR-focused vs. alpha-focused training) to individual EEG profiles, interventions may become more efficient and targeted. Combining neurofeedback with other evidence-based therapies, such as behavioral interventions or social-skills training, may also enhance its impact. Finally, future studies in low and middle income countries (LMICs), including Indonesia, should address questions of feasibility, accessibility, and scalability. Developing cost-effective delivery models, training local therapists, and integrating

neurofeedback into special education settings could support wider implementation, ensuring that more children benefit from this emerging approach.

CONCLUSION

This study examined the effectiveness of neurofeedback therapy in enhancing behavioral, emotional, and attentional regulation in a child with Autism Spectrum Disorder (ASD) through a 36-session single-subject A-B-A design. The results demonstrated measurable improvements across all domains-reductions in irritability and hyperactivity, greater emotional stability, improved attention control, and normalization of EEG parameters such as alpha activity and θ/SMR ratios. These findings confirm that neurofeedback can serve as a viable complementary intervention to strengthen self-regulation capacities in children with ASD. Beyond clinical relevance, this study contributes to the neuroeducation framework by showing how brain-based feedback can translate into observable behavioral and emotional gains. Neurofeedback training fosters neural self-awareness and reinforces adaptive brain states, making it a promising tool for special and inclusive education programs.

For schools and policymakers, the results highlight three key recommendations, such as (1) integrate neurofeedback into inclusive education support systems such as school based therapy rooms or Unit Layanan Disabilitas (ULD) to complement behavioral and counseling programs, (2) provide capacity building for teachers and therapists on neuro-pedagogical literacy, enabling them to interpret and support self-regulation from both behavioral and neural perspectives, and (3) promote collaborative research and policy funding for scalable, cost-effective NF interventions suitable for regional and low-resource educational contexts. While the single-subject design limits generalizability, the findings provide early yet compelling evidence that neurofeedback therapy can bridge the gap between neural regulation and educational readiness, reinforcing its inclusion within evidence-based frameworks for inclusive education in Indonesia and other LMIC settings.

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