



Preliminary Outcomes and Acceptability of Neuro-Nutrition Biofeedback and Balinese Gamelan Sensorimotor-Rhythm Stimulation for Children with Cognitive Disabilities: A Mixed-Methods One-Group Pilot Study

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Abstract: Children with cognitive disabilities frequently experience interconnected nutritional, cognitive, and behavioral challenges that may restrict learning participation. This mixed-methods one-group pilot study examined the preliminary outcomes and acceptability of an integrated Neuro-Nutrition Biofeedback and Balinese Gamelan Sensorimotor-Rhythm (SMR) stimulation program. Twenty children aged 6–12 years from special education schools in Bali participated in an eight-week intervention. Quantitative outcomes included BMI-for-age z-score, sustained attention, working memory, and EEG-recorded SMR amplitude, while qualitative data were obtained from parent and teacher interviews, behavioral observations, and field notes. Repeated-measures MANOVA indicated a significant multivariate effect of time. Holm-adjusted follow-up analyses showed significant changes in attention and working memory. BMI-for-age and SMR amplitude showed positive changes but did not remain statistically significant after adjustment. Qualitative findings revealed gradual food acceptance, improved learning focus, calmer behavioral responses, and strong cultural acceptance of Balinese gamelan. The integrated findings provide preliminary support for a culturally responsive neuro-educational framework linking nutritional readiness, neuroregulatory support, and culturally mediated engagement. SMR should be regarded as a candidate neurophysiological indicator rather than a demonstrated mediator. Larger controlled studies are required to establish efficacy and causal mechanisms.

Keywords: balinese gamelan; cognitive disabilities; electroencephalography; neuro-nutrition biofeedback; sensorimotor rhythm

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INTRODUCTION

Children with cognitive disabilities experience interconnected nutritional, developmental, behavioral, and educational challenges that may restrict their health, independence, and participation in learning (Antari et al., 2025; Antariani et al., 2021). Evidence from disability and health research indicates that children with cognitive and developmental disabilities face a greater risk of anthropometric deficits and adverse nutritional outcomes because of feeding difficulties, communication barriers, functional dependence, and unequal access to appropriate health services (Alam et al., 2024; Antara et al., 2025; Nyakato et al., 2026). Selective eating, food refusal, sensory sensitivity, gastrointestinal problems, and difficulties in chewing or swallowing may further reduce dietary diversity and increase the risk of insufficient energy and micronutrient intake (Eodanable & MacLean, 2025; Pancheva et al., 2024). Nutritional interventions for this population therefore need to address physical growth, eating behavior, caregiver knowledge, and the child's cognitive and sensory characteristics as mutually related dimensions rather than as separate concerns (Ren et al., 2025; Xu et al., 2025).

Adequate nutrition plays a fundamental role in the neurological processes that support attention, working memory, emotional regulation, and learning readiness. Nutrient deficiencies during childhood may intensify cognitive difficulties because protein, iron, essential fatty acids, and other micronutrients contribute to brain maturation and information processing (Cannavale et al., 2022; Ren et al., 2025). Persistent learning difficulties may become more complex when nutritional vulnerability coexists with disrupted schooling, limited cognitive stimulation, and insufficient access to adaptive educational support (Kertih et al., 2023; Reichenberger et al., 2025). Active, cognitively structured learning activities have been shown to promote scientific literacy, creative thinking, metacognitive awareness, and critical thinking, suggesting that nutrition-related interventions should also engage children through meaningful, developmentally responsive experiences (Puger et al., 2024; Pujawan et al., 2022). Educational and nutritional support must consequently be designed as an integrated process that strengthens children's physical condition while facilitating their cognitive participation. Digital

technology provides opportunities to improve nutritional monitoring, personalized guidance, and communication among children, parents, teachers, and therapists. Technology-supported systems can record eating patterns, visualize nutritional information, provide individualized recommendations, and facilitate monitoring across school and home settings (Pancheva et al., 2024; Shin et al., 2025). Inclusive digital interventions nevertheless depend on perceived usefulness, accessibility, facilitating conditions, interface simplicity, and compatibility with diverse learner characteristics (Shin et al., 2025; Suarjana et al., 2026). Children with cognitive disabilities may require multisensory instructions, repeated guidance, child-friendly visualizations, and continuous assistance from familiar adults to engage meaningfully with digital platforms (Eodanable & MacLean, 2025; Xu et al., 2025). Neuro-nutrition biofeedback may meet these requirements by combining dietary monitoring with accessible feedback that supports caregivers' decisions and children's engagement in healthier food choices.

Electroencephalographic monitoring offers an additional mechanism for examining neurophysiological responses during technology-supported intervention. EEG-based biofeedback records patterns of brain activity and provides objective information that complements behavioral observations, cognitive assessments, and caregiver reports (Antara et al., 2024; Wirawan et al., 2022). Sensorimotor rhythm commonly refers to EEG activity within the 12–15 Hz range and is associated with calm alertness, attentional control, motor regulation, and behavioral stability (Antara et al., 2024; Cannavale et al., 2022). Rhythmic auditory stimulation may support these processes because repetitive and predictable musical patterns can influence arousal, attention, and emotional regulation (Antara et al., 2024; Reichenberger et al., 2025). Balinese gamelan presents a particularly relevant stimulus because its layered rhythms, repetitive structures, and dynamic patterns may facilitate sensorimotor engagement while remaining familiar to children within the Balinese sociocultural environment.

The theoretical rationale for integrating Neuro-Nutrition Biofeedback, Balinese gamelan stimulation, and SMR monitoring lies in their complementary roles in supporting learning readiness. The proposed framework comprises three pathways. First, a nutritional-readiness pathway assumes that improved nutritional practices support neural development and cognitive functions such as attention and working memory, with Neuro-Nutrition Biofeedback assisting caregivers in monitoring and improving children's dietary patterns (Cannavale et al., 2022; Ren et al., 2025). Second, a neuroregulatory pathway posits that predictable rhythmic stimulation may support arousal, attention, and sensorimotor regulation, while EEG-recorded SMR serves as a neurophysiological indicator of these responses (Antara et al., 2024; Martin-Moratinos et al., 2023). Third, a culturally mediated engagement pathway positions the familiarity of Balinese gamelan as a factor that may strengthen comfort, participation, and stakeholder acceptance (Lee et al., 2025; Parmiti et al., 2021). Thus, the three components are theoretically connected through nutritional readiness, neuroregulation, and culturally supported engagement. SMR is treated as a neurophysiological outcome and candidate indicator of regulatory change rather than an established mediator.

Viewed through this framework, the research gap extends beyond the simple absence of studies combining nutrition, EEG, and culturally based music. Nutrition-focused interventions have largely emphasized dietary intake, anthropometric status, feeding behavior, or caregiver education without examining neurophysiological regulation and cultural engagement (Pancheva et al., 2024; Ren et al., 2025). Neurofeedback and music-based interventions have primarily investigated cognitive, behavioral, or EEG outcomes without considering nutritional readiness, while culturally responsive interventions rarely position cultural familiarity as a mechanism supporting participation in neuro-educational stimulation (Lee et al., 2025; Ölcüoğlu et al., 2024). A theoretical gap therefore remains in explaining how nutritional readiness, neuroregulatory support, and culturally mediated engagement may operate as complementary pathways. A related methodological gap concerns the limited mixed-methods pilot evidence simultaneously examining preliminary nutritional, cognitive, and neurophysiological outcomes alongside feasibility and cultural acceptability in children with cognitive disabilities.

Accordingly, the present study aimed to examine the preliminary outcomes and acceptability of an integrated Neuro-Nutrition Biofeedback and Balinese Gamelan Sensorimotor-Rhythm stimulation program for children with cognitive disabilities using a mixed-methods one-group pilot design. Rather than testing causal effectiveness, the study examined within-participant changes and stakeholder experiences during the eight-week intervention. Specifically, the study addressed three questions: 1) What pretest-to-posttest changes are observed in BMI-for-age z-score, sustained attention, working memory, and SMR amplitude?; 2) How do parents and teachers describe changes in children's food acceptance, learning focus, behavioral regulation, and their acceptance of Balinese gamelan as part of the intervention?; 3) How do the quantitative and qualitative findings converge in explaining the preliminary outcomes and acceptability of the integrated intervention?

METHODS

This study employed a mixed-methods one-group pretest–posttest pilot design integrating quantitative assessments with qualitative interviews, behavioral observations, and field notes. The one-group design was selected because this study represented an early-stage evaluation of an integrated intervention and its measurement procedures rather than a definitive efficacy trial; accordingly, the objectives were to characterize

participant and stakeholder experiences, assess the acceptability of the intervention and measurement procedures, and identify preliminary outcome signals to inform a subsequent controlled trial. Mixed-methods pilot studies are particularly appropriate at this developmental stage because quantitative patterns can be interpreted alongside qualitative evidence concerning acceptability, usability, and contextual influences (Aschbrenner et al., 2022). Therefore, pretest–posttest differences were interpreted as observed within-participant changes temporally associated with the intervention period, not as estimates of causal treatment effects, because the absence of a comparison group means that alternative explanations, including maturation, repeated testing, regression to the mean, changes in routine, caregiver attention, and other time-related influences, cannot be excluded (Capili & Anastasi, 2024). The findings are consequently intended to guide the refinement of the intervention, outcome selection, implementation procedures, and sample-size planning for a subsequent controlled investigation.

The study included 20 children aged 6–12 years with mild-to-moderate cognitive disabilities who attended special education schools in Bali, Indonesia. Participants were recruited using purposive sampling based on their eligibility for the intervention and ability to complete the assessment and stimulation procedures. Eligible participants had a documented mild-to-moderate cognitive disability, could participate in structured auditory and digitally supported activities with assistance, and had written informed consent from a parent or legal guardian; children with severe hearing impairment or conditions preventing EEG recording or auditory stimulation were excluded. The sample size was selected for an exploratory, early-stage pilot study rather than confirmatory efficacy testing, consistent with guidance that pilot studies may use approximately 10–40 participants to estimate preliminary variability, intervention responses, and procedural feasibility (Hertzog, 2008). Thus, the 20 participants were considered adequate for identifying preliminary within-participant outcome patterns, evaluating study procedures, and informing a future adequately powered controlled study, while the findings were interpreted as preliminary and accompanied by effect-size estimates. Participant characteristics are summarized in Table 1.

Table 1. Participant Characteristics

Characteristic	n (%) / M (SD)
Gender	
Male	12 (60.0%)
Female	8 (40.0%)
Cognitive disability	
Mild cognitive disability	12 (60.0%)
Moderate cognitive disability	8 (40.0%)
Baseline	
BMI-for-age z-score	−1.45 (0.62)
Attention score	52.30 (8.50)
Working-memory score	3.80 (0.90)
SMR amplitude (μV)	5.36 (1.10)

The baseline assessment included anthropometric measurements, dietary recording, cognitive testing, behavioral observation, and EEG recording. The Neuro-Nutrition Smart System recorded children’s eating patterns, estimated nutritional intake, displayed food-related information, and provided menu recommendations adapted to their nutritional needs. Balinese gamelan stimulation was delivered three times per week for approximately 30–45 minutes per session, using digitally recorded rhythmic patterns selected to support calm alertness and sensorimotor engagement. Selected sessions included simultaneous EEG monitoring to document children’s SMR responses in the 12–15 Hz frequency range during gamelan stimulus presentation. Post-intervention assessment repeated the nutritional, cognitive, behavioral, and EEG measurements using procedures consistent with those administered at baseline. Table 2 summarizes the variables, aspects, and indicators used throughout the study.

Table 2. Research variable framework

Variable	Aspect	Indicator
Nutritional status	Anthropometric condition	Body weight, height, and BMI-for-age z-score
	Nutritional intake	Daily energy intake, dietary diversity, and nutrient adequacy
Eating behavior	Eating patterns	Frequency of main meals and snacks
	Food preferences	Acceptance of vegetables, fruits, protein sources, and unfamiliar foods
	Feeding difficulties	Food refusal, selective eating, and difficulty chewing or swallowing
Cognitive function	Attention	Sustained attention, response consistency, and ability to remain focused
	Working memory	Immediate recall, information retention, and Digit Span performance
Neurophysiological response	Sensorimotor-rhythm activity	SMR amplitude within the 12–15 Hz frequency range
	Response stability	Consistency and duration of SMR activity during Balinese gamelan stimulation
Learning behavior	Learning engagement	Participation, persistence, and responsiveness to instructions
	Behavioral regulation	Calmness, reduced distraction, and ability to remain engaged during learning
Intervention usability	Ease of use	Clarity of the interface, ease of operation, and time efficiency
	Child responsiveness	Interest, comfort, and engagement while using the system
Cultural acceptance	Cultural familiarity	Familiarity and emotional comfort associated with Balinese gamelan
	Stakeholder acceptance	Perceived relevance, willingness to continue use, and perceived benefits reported by parents and teachers

Instrument quality was examined before the main pilot through expert review, preliminary testing, and reliability assessment. Content validation involved specialists in nutrition, developmental psychology, special education, information technology, and Balinese music. The nutritional-status instrument achieved an I-CVI of 1.00 and an S-CVI/Ave of 0.95, with inter-rater reliability of Cohen's $\kappa = 0.82$. The eating-behavior questionnaire demonstrated satisfactory internal consistency (Cronbach's $\alpha = 0.84$), although three items with item-total correlations below 0.35 were revised. The EEG-SMR measurement demonstrated strong convergent validity with a standard EEG reference, $r = 0.87$, $p < 0.001$, and satisfactory test-retest reliability, ICC = 0.81. The usability questionnaire achieved Cronbach's $\alpha = 0.86$, whereas the Balinese gamelan content instrument obtained an S-CVI/Ave of 0.97 and an inter-rater reliability coefficient of 0.79. Overall, these results supported the use of the instruments for preliminary assessment in the pilot study.

Quantitative analysis began with descriptive statistics, including means and standard deviations, to summarize BMI-for-age z-score, sustained attention, working memory, and SMR amplitude at pretest and posttest. Because the study involved four conceptually related primary outcomes measured repeatedly in the same participants, the overall pretest–posttest pattern was examined using a one-way repeated-measures multivariate analysis of variance (MANOVA), with Time (pretest vs. posttest) as the within-participant factor and BMI-for-age z-score, attention, working memory, and SMR amplitude as the dependent variables. Prior to the multivariate analysis, the data were examined for missing values, extreme observations, univariate and multivariate normality, and excessive correlations among the dependent variables. When the multivariate Time effect was statistically significant, follow-up paired-samples t-tests were conducted for the individual outcomes, and the Holm procedure was applied to adjust p-values for multiple comparisons and control the family-wise Type I error rate. Statistical significance was established at $p < 0.05$. Because the study employed a one-group pretest–posttest pilot design, the observed differences were interpreted as preliminary within-participant changes across the intervention period rather than causal treatment effects.

Effect sizes were reported to complement statistical significance and to indicate the magnitude of the observed pretest–posttest changes. Standardized within-participant effects were expressed using Cohen's d_z . Following Cohen's conventional criteria, values of approximately 0.20, 0.50, and 0.80 were interpreted as small, medium, and large effects, respectively. Based on the reported paired-comparison statistics, the preliminary standardized changes were approximately $d_z = 0.52$ for BMI-for-age, 0.66 for attention, 0.73 for working memory, and 0.49 for SMR amplitude. These effect sizes were interpreted together with probability values and

the limitations of the small pilot sample.

Qualitative interview material, observational records, and field notes were analyzed thematically to identify recurring patterns concerning nutritional challenges, changes in learning behavior, neurophysiological responses, and cultural acceptance. Methodological triangulation compared the qualitative themes with the quantitative outcome patterns to determine whether parents' and teachers' experiences converged with measured nutritional, cognitive, and EEG changes. The pilot nature of the study required the findings to be interpreted as preliminary evidence rather than definitive confirmation of intervention effectiveness.

RESULT AND DISCUSSION

Twenty children with cognitive disabilities completed the pretest and posttest assessments and were included in the quantitative analysis. A one-way repeated-measures MANOVA examined the combined pattern of change across BMI-for-age z-score, attention, working memory, and EEG SMR amplitude. The analysis indicated a significant multivariate effect of Time, Wilks' $\Lambda = 0.423$, $F = 5.45$, $p = 0.006$, partial $\eta^2 = 0.577$. Follow-up paired comparisons were conducted for each outcome, with Holm adjustment applied to control the family-wise error rate. Table 3 presents the outcomes.

Table 3. Pretest–Posttest Nutritional, Cognitive, and Neurophysiological Outcomes

Outcome	Pretest, M (SD)	Posttest, M (SD)	Mean Change	Raw p	Holm-adjusted p	Cohen's dz	Magnitude
BMI-for-age z-score	–1.45 (0.62)	–0.85 (0.58)	0.60	0.032	0.064	0.52	Medium
Attention (Continuous Performance Test)	52.30 (8.50)	67.80 (7.90)	15.50	0.008	0.024	0.66	Medium
Working memory (Digit Span Test)	3.80 (0.90)	5.10 (1.20)	1.30	0.004	0.016	0.73	Medium
EEG SMR amplitude (μ V)	5.36 (1.10)	6.36 (1.00)	1.00	0.041	0.064	0.50	Medium

Note. $N = 20$. SMR = sensorimotor rhythm.

As reported in Table 3, the adjusted comparisons indicated statistically significant changes in working memory and attention, whereas the changes in BMI-for-age z-score and SMR amplitude did not remain significant after correction for multiple comparisons. Nevertheless, all four outcomes showed small-to-medium standardized within-participant changes, with Cohen's d_z ranging from 0.49 to 0.73. The largest effect was observed for attention, followed by working memory, BMI-for-age z-score, and SMR amplitude. The thematic analysis generated four interrelated themes: gradual food acceptance, improved learning focus, behavioral and neurophysiological regulation, and cultural acceptance of Balinese gamelan. These themes provided contextual information for interpreting the quantitative findings and the experiences of parents and teachers during the intervention. Table 4 presents representative evidence and analytical meaning for each theme.

Table 4. Themes derived from interviews, observations, and field notes

Theme	Evidence pattern	Representative excerpt	Analytical meaning
Gradual food acceptance	Parents reported restricted food preferences before the intervention and gradual acceptance of healthier foods during the program.	"My child would not eat any vegetables, only instant noodles. After intervention, he slowly started to try spinach." (Parent 5)	Nutritional feedback helped caregivers gradually introduce healthier foods.
Improved learning focus	Teachers observed longer task engagement, greater responsiveness to instructions, and calmer classroom participation.	"Children are more able to sit quietly during lessons, especially after listening to gamelan music." (Grade 3 Teacher)	Classroom observations converged with increases in attention and working memory.
Behavioral and neurophysiological regulation	Field notes documented increases in SMR activity during gamelan exposure, while parents described calmer behavior after listening sessions.	"EEG results show a consistent increase in SMR when gamelan is played." (Researcher field notes)	EEG and behavioral patterns suggested a possible neuroregulatory response, although mediation was not established.
Cultural acceptance	Parents and teachers perceived gamelan as familiar and emotionally comfortable for the participating children.	"I feel happy because gamelan music can be used for therapy, not just for ceremonies." (Parent 2)	Cultural familiarity appeared to support intervention acceptance and continued participation.

The quantitative and qualitative findings showed complementary patterns across the nutritional, cognitive, neurophysiological, and cultural domains. Reports of greater dietary variety and gradual food acceptance corresponded with the positive direction of the BMI-for-age findings, although the adjusted comparison did not reach statistical significance. The strongest convergence occurred in the cognitive domain. The statistically significant changes in attention and working memory were accompanied by teacher reports of longer task engagement, improved responsiveness to instructions, and reduced disengagement. This convergence suggests that cognitive and classroom-related changes represented the clearest preliminary outcome pattern in the pilot study. The neurophysiological findings were more tentative. Increased SMR amplitude was accompanied by reports of greater calmness and focus following gamelan exposure, but the adjusted comparison was not statistically significant. Accordingly, SMR should be regarded as a candidate neurophysiological indicator of regulatory change rather than a demonstrated mediator of cognitive improvement. Cultural acceptance was consistently reported by parents and teachers, who viewed Balinese gamelan as familiar, comfortable, and contextually relevant. This acceptance may have facilitated participation and supported the feasibility of integrating culturally familiar music into the intervention.

The findings provide preliminary support for an integrated approach in which nutritional guidance, culturally familiar rhythmic stimulation, and caregiver involvement may contribute to conditions that support children's learning and behavioral participation. Importantly, the findings should not be interpreted simply as parallel improvements across several outcomes. The strongest convergence occurred in the cognitive domain, where quantitative changes in attention and working memory were accompanied by teachers' observations of greater task persistence, responsiveness to instructions, and learning focus. In contrast, the nutritional and SMR findings were less definitive after adjustment for multiple comparisons and are therefore better interpreted as preliminary signals requiring further investigation. This pattern is consistent with the study's pilot purpose, which was to identify promising outcome patterns and participant experiences rather than to establish causal effectiveness.

The nutritional component may operate primarily through a nutritional-readiness pathway. Children with developmental disabilities frequently experience food selectivity, feeding difficulties, and restricted dietary variety that may compromise nutritional adequacy and participation in everyday activities (Lim et al., 2024; Soares et al., 2024; Verma et al., 2025). The Neuro-Nutrition Smart System provided caregivers with structured dietary information and practical recommendations that could be translated into gradual changes in household food practices. Parent accounts of introducing more varied and locally available foods suggest that the value of nutritional biofeedback may lie partly in strengthening caregiver decision-making and practical food literacy. Because nutritional status is influenced by multiple physiological, behavioral, and family factors, the observed

nutritional pattern should not be interpreted as rapid nutritional recovery, but as an early indication that caregiver-supported dietary monitoring may improve the conditions underlying children's readiness to participate in learning (Athaide et al., 2025; Magidigidi-Mathiso et al., 2025). The cognitive findings can be interpreted through a complementary neuroregulatory pathway. Predictable rhythmic stimulation may help organize arousal and temporal attention, creating a calmer state in which children are better able to sustain focus and process information. Rhythm- and music-based interventions have been associated with attentional regulation, communication, and cognitive engagement, although outcomes vary according to stimulus characteristics, individual responsiveness, and intervention context (Martin-Moratinos et al., 2023; Shi et al., 2024). In the present intervention, Balinese gamelan provided repetitive, structured auditory patterns that remained familiar to the participating children. Its potential contribution may therefore arise from the interaction between rhythmic organization and the child's willingness to remain engaged with the stimulus rather than from an isolated acoustic effect. This interpretation is consistent with teacher reports of calmer, more sustained classroom participation and avoids attributing the observed cognitive changes solely to gamelan stimulation.

The role of SMR requires particularly cautious interpretation. Although the direction of the EEG findings and behavioral observations is compatible with a neuroregulatory response, the present study does not establish SMR as a mediator of the relationship between gamelan stimulation and cognitive change. Demonstrating mediation would require evidence that the intervention first produces a change in SMR, that this neurophysiological change temporally precedes and predicts subsequent changes in attention or working memory, and that a statistically supported indirect intervention–SMR–cognition pathway is present. The current pretest–posttest design provides only two principal measurement occasions and therefore cannot establish this temporal sequence. SMR should consequently be regarded as a candidate neurophysiological indicator of regulatory change, rather than a demonstrated causal mechanism. This cautious interpretation is also consistent with neurofeedback literature showing that changes in behavioral outcomes cannot automatically be attributed to the targeted EEG activity because practice, engagement, expectancy, and contextual support may also contribute to observed change (Ölçüoğlu et al., 2024; Westwood et al., 2025; Wu et al., 2024). Future studies should incorporate repeated or session-level EEG measurements and adequately powered mediation models to determine whether SMR carries part of the relationship between rhythmic stimulation and cognitive outcomes.

Cultural familiarity provides a third mechanism that may help explain the intervention's acceptability. Parents and teachers consistently described Balinese gamelan as recognizable, comfortable, and appropriate within the children's social environment. Cultural responsiveness is important because interventions are more likely to be accepted and sustained when they reflect familiar values, practices, and experiences rather than when they introduce culturally neutral content without contextual adaptation (Davis et al., 2025; Lee et al., 2025). In this study, gamelan therefore served more than an auditory stimulus; it provided a culturally congruent context that may have reduced resistance, supported repeated participation, and strengthened parent and teacher acceptance. This interpretation is consistent with research emphasizing that cultural and contextual adaptation can shape accessibility, usability, engagement, and sustained participation in educational and digital interventions (Naderbagi et al., 2024; Reichenberger et al., 2025).

The principal theoretical contribution of the study is the proposal of a culturally responsive neuro-educational intervention framework. Rather than treating Neuro-Nutrition Biofeedback, SMR monitoring, and Balinese gamelan as a simple combination of intervention components, the framework specifies three complementary pathways through which they may operate. The first is nutritional readiness, in which dietary monitoring and caregiver guidance support the physiological and behavioral conditions needed for learning. The second is neuroregulatory support, in which structured rhythmic stimulation may assist arousal and attentional regulation, with SMR serving as a candidate physiological indicator. The third is culturally mediated engagement, in which familiarity with Balinese gamelan supports comfort, participation, acceptability, and repeated exposure. These pathways may converge on educationally relevant outcomes such as attention, working memory, behavioral regulation, and learning engagement. The theoretical contribution therefore lies not in combining technology, nutrition, EEG, and local music per se, but in explaining why these components may complement one another within a culturally responsive intervention system.

This framework also has practical implications for special education and family-supported intervention. Nutritional guidance can be connected with everyday caregiver practices, while culturally familiar auditory stimulation may provide a feasible means of supporting children's engagement in structured activities. EEG monitoring may complement cognitive and behavioral assessment by providing an additional physiological perspective, but it should not be treated as proof of mechanism without stronger longitudinal evidence. The integration of parent, teacher, behavioral, cognitive, and neurophysiological information may therefore be particularly useful in early-stage intervention development, where feasibility, acceptability, and convergence across different sources of evidence are important considerations.

Several limitations should guide interpretation. The small sample and one-group pretest–posttest design prevent causal attribution and leave open alternative explanations including maturation, repeated testing, caregiver attention, changes in routine, and expectancy effects. The relatively short intervention period also

limits conclusions regarding sustained nutritional, cognitive, and neurophysiological change. In addition, SMR was assessed as a preliminary neurophysiological outcome rather than through a temporally ordered mediation design, and qualitative evidence primarily represented adult perspectives. Future research should employ larger controlled or randomized designs, include longer follow-up periods, collect repeated EEG measurements across the intervention, and compare nutritional biofeedback, gamelan stimulation, and combined conditions. Such studies would allow the proposed culturally responsive neuro-educational framework to be tested more directly and clarify the independent, interactive, and potentially mediating pathways underlying the observed outcomes.

CONCLUSION

This mixed-methods one-group pilot study provides preliminary evidence regarding the outcomes and acceptability of an integrated Neuro-Nutrition Biofeedback and Balinese Gamelan Sensorimotor Rhythm stimulation program for children with cognitive disabilities. The clearest quantitative changes were observed in attention and working memory, which remained statistically significant after adjustment for multiple comparisons and were supported by teachers' reports of improved learning focus, task engagement, and responsiveness to instructions. BMI-for-age z-score and SMR amplitude also increased, although these differences did not remain statistically significant after Holm adjustment and should therefore be interpreted as preliminary nutritional and neurophysiological signals rather than evidence of intervention efficacy. Qualitative findings further indicated gradual food acceptance, calmer behavioral responses, and favorable acceptance of Balinese gamelan among parents and teachers. Overall, the findings support the preliminary plausibility of a culturally responsive neuro-educational framework involving nutritional readiness, neuroregulatory support, and culturally mediated engagement, while positioning SMR as a candidate indicator of regulatory change rather than a demonstrated mediator of cognitive improvement. However, the small sample, absence of a comparison group, short intervention period, and limited temporal assessment of SMR preclude causal conclusions; therefore, future studies should use larger controlled or randomized designs, longer follow-up periods, and repeated or session-level EEG assessments to evaluate intervention efficacy, durability, and the proposed relationships among nutritional readiness, neuroregulation, cultural engagement, and cognitive outcomes.

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