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Effect of Median Nerve Stimulation with High-Intensity Interval Training on Neurobehavioral Outcomes and Stress Biomarkers in Children with Attention Deficit Hyperactivity Disorder: A Pilot Study

Iswarya Suresh[1*], Anitha Arul[2], Shenbaga Sundaram Subramanian[3], Padmavathi Venkatesalu[4], Meenakshi Sivakumar[5], Kavitha Ramanathan[6], Abeer Samir Ali Jamal[7], Ghadeer Ghazi Alahmadi[8], Nour Gazzaz[9], Maha Bamehrez[10] and Riziq Allah Mustafa Gaowgzeh[11]

[1-3]Saveetha College of Physiotherapy, Saveetha Institute of Medical and Technical Sciences (SIMATS), Thandalam, Chennai, Tamil Nadu, 602105, India
[4]Faculty of Physiotherapy, Sree Balaji Medical College and Hospital, Bharath Institute of Higher Education and Research, Chromepet, Chennai, India
[5]Mohamed Sathak AJ College of Physiotherapy, Dr MGR University, Chennai, India
[6]Department of Nursing, College of Medicine and Health Sciences, Arabian Gulf University, Bahrain
[7,8,11]Department of Physical Therapy, Faculty of Medical Rehabilitation Sciences, King Abdulaziz University, Jeddah, Saudi Arabia
[9,10]Department of Paediatrics, Faculty of Medicine, King Abdulaziz University, Jeddah. Saudi Arabia

*Corresponding author: Iswarya Suresh (e-mail: iswarya.scpt@saveetha.com).

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Abstract **Background:** Attention Deficit Hyperactivity Disorder (ADHD) is a common childhood neurodevelopmental disorder characterised by inattention, motor hyperactivity and impulsivity, with significant subsequent impact on behavioural, emotional, cognitive, academic and social functioning. Executive function deficits and altered stress response are also associated with ADHD. While High-Intensity Interval Training (HIIT) may enhance neurobehavioral functioning and Median Nerve Stimulation (MNS) may alter neural activity, research on their integrated effects on neurobehavioral outcomes and salivary cortisol levels among children with ADHD is limited. **Objective:** This study aimed to determine the effects of MNS combined with HIIT on neurobehavioral outcomes and salivary cortisol levels among children with ADHD. **Materials and Method:** This pilot randomised study recruited 20 children with ADHD, with combined presentation, aged 8 to 12 years and randomly allocated them into two Groups. Group A received MNS with HIIT (n = 10), whereas Group B received Sham stimulation with HIIT (n = 10). The intervention was administered for 50 minutes, 5 sessions per week, for a total span of 8 weeks. Neurobehavioral outcomes were assessed using the parent-reported Vanderbilt ADHD Rating Scale and the Childhood Executive Functioning Inventory. Salivary cortisol was assessed as a stress biomarker. Data were analysed using paired and independent t tests. **Results:** Group A had significantly lower post test scores than Group B for inattention (10.50±1.080 vs. 19.80±2.098), hyperactivity (10.70±1.160 vs. 21.00±2.494), total ADHD symptoms (21.20±1.751 vs. 40.80±2.860), inhibitory factor (32.80±2.150 vs. 42.50±1.581) and working memory (33.50±2.461 vs. 51.00±3.162). Salivary cortisol levels increased more in Group A than in Group B (2.454±0.166 vs. 1.187±0.090). All between-group differences were statistically significant ($p<0.001$). **Conclusion:** This study concluded that MNS with HIIT may be more beneficial than Sham stimulation with HIIT in reducing neurobehavioral outcomes and improving salivary cortisol levels among children with ADHD.

Key Words Attention Deficit Hyperactivity Disorder, Child, Cortisol, Good Health and Well-Being, Electrical Stimulation, High-Intensity Interval Training

INTRODUCTION

Attention Deficit Hyperactivity Disorder (ADHD) is among the most prevalent neurodevelopmental disorders in childhood psychiatry and is recognised for its high prevalence and notable clinical diversity [1]. The disorder is characterised by developmentally inappropriate levels of inattention and hyperactivity-impulsivity before age 12 in children of average intelligence. These symptoms are wide-ranging and may affect normal functioning at home, at school and in social settings [2,3].

Epidemiological syntheses reveal a pooled prevalence of 8% of ADHD among children and adolescents. Boys are diagnosed with ADHD at approximately twice the rate of girls. It is most common in primary school-aged children (7.6% among those aged 3-12 years) and declines substantially in adolescence (5.6% in 12-18 years) [4,5].

The neurobehavioral hallmarks of ADHD are closely associated with variations in the brain networks that control cognitive and behavioural regulation [6]. For instance, impaired sustained attention, executive functioning, inhibitory control and reward processing have been associated with dysfunction of the prefrontal cortex, striatum and anterior cingulate cortex and altered dopaminergic and noradrenergic signalling [7,8].

In addition to these neural networks and neurotransmitter pathways, growing evidence suggests that stress-regulatory systems may play an important part in the neurobiology of ADHD [9]. The Hypothalamic-Pituitary-Adrenal (HPA) axis is a key physiological system involved in stress regulation and cortisol is the primary glucocorticoid effector. Cortisol, a glucocorticoid hormone produced by the adrenal glands, is released during activation of the HPA axis and is an important physiological measure of stress regulation [10]. Children and adolescents with ADHD have demonstrated altered HPA-axis activity, with some studies reporting lower baseline or morning cortisol levels and slower cortisol responses to stress, although results are inconsistent. Dysregulated cortisol levels in the morning have been associated with ADHD symptoms, hyperactivity, weariness and anxiety. Considering the close association between cortisol regulation and brain circuits supporting attention, executive functioning and behavioural control, changes in HPA-axis activity may contribute to the neurobehavioral symptoms of ADHD [11,12].

Traditional approaches to ADHD treatment include stimulant medications. However, these medications may cause adverse effects in children and adolescents, including decreased appetite, sleep difficulties and mood changes. Recent systematic reviews reveal that early discontinuation of medication among individuals with ADHD is prevalent worldwide and is commonly associated with side effects, lack of response, dosing difficulties, stigma and patient attitudes, which may interfere with favourable treatment outcomes [13,14].

Given the limitations of pharmacological treatment, interest has grown in non-pharmacological therapies such as neurofeedback, cognitive behavioural therapy, mindfulness techniques and Physical Exercise (PE) [15]. Recent research has explored culturally adapted, play-based behavioural interventions for children with neurodevelopmental conditions, including autism spectrum disorder [16]. Among these techniques, considerable attention has been given to physical exercise in recent years. Physical exercise is a planned, structured and repetitive activity performed with a specific objective. High-Intensity Interval Training (HIIT) consists of repeated bouts of high-intensity exercise interspersed with recovery periods [17,18].

With advances in non-invasive neuromodulation, interest has grown in peripheral stimulation as an alternative to commonly used brain stimulation techniques, such as transcranial Direct Current Stimulation (tDCS) and Transcranial Magnetic Stimulation (TMS). Median Nerve Stimulation (MNS) is a non-invasive peripheral neuromodulation treatment that uses electrical stimulation of the median nerve at the wrist. It stimulates ascending neuronal pathways and may influence brainstem, thalamocortical and sensorimotor networks, potentially influencing cortical excitability and neurobehavioral regulation. These pathways may also be associated with autonomic control, which is closely associated with the Hypothalamic-Pituitary-Adrenal (HPA) axis and cortisol-mediated stress responses [19-21].

Prior research has examined the effects of physical activity on salivary cortisol levels and neurobehavioral outcomes in children with ADHD. Similarly, the potential neurobehavioral effects of MNS have been investigated; however, its effects on cortisol regulation in children with ADHD remain unclear. Furthermore, the combined effects of MNS and HIIT on these outcomes remain insufficiently investigated. The primary hypothesis was that the combination of MNS and HIIT would produce greater improvements in VADRS and CHEXI scores than HIIT combined with sham stimulation. VADRS and CHEXI scores were the primary outcomes, while salivary cortisol levels were the secondary outcome. The second hypothesis was that the groups would differ in salivary cortisol levels following the intervention. The novelty of the present study lies in whether adding MNS to HIIT provides additional benefits for neurobehavioral outcomes and salivary cortisol levels compared with HIIT with sham stimulation in children with ADHD.

METHODS

Study Design and Sample Size Estimation

This pilot randomised controlled trial was conducted in a private setting among children with ADHD from 1 May to 1 August 2026, representing the overall study period. Because this was a preliminary pilot study, we did not perform a formal sample size estimation using G*Power. Instead, we included 10 participants based on a rule of thumb, for a total sample of 20. This study aimed to assess the feasibility of implementing the intervention protocol and obtain preliminary estimates of changes in ADHD symptoms, executive functioning and salivary cortisol to inform the design of a future definitive trial. We selected participants according to predefined inclusion and exclusion criteria, as shown in Figure 1. We randomly assigned eligible participants to one of two groups, Group A or Group B, using the sealed envelope method. Group A received (MNS+HIIT) while Group B received (Sham Stimulation+HIIT). The allocation sequence was computer-generated by an independent individual who was not involved in participant recruitment, intervention delivery or outcome evaluation and who also prepared the opaque, sealed, sequentially

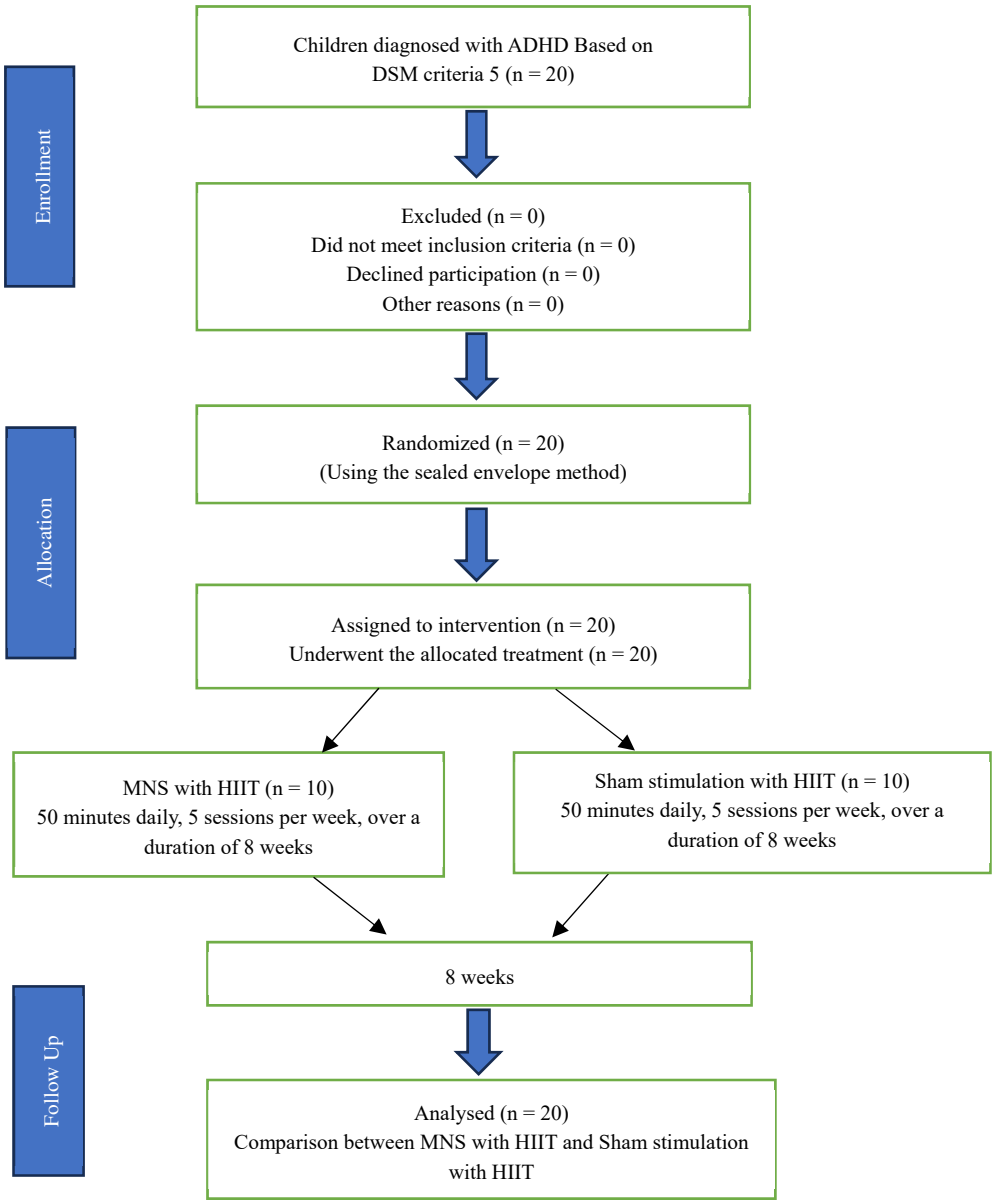


Figure 1: Participant Recruitment Flow Chart

Table 1: Baseline Characteristics of Group A and B

Variable	Group A (Mean±SD)	Group B (Mean±SD)	p-value
Age (years)	10.00±1.333	10.10±1.197	0.862
Height (cm)	139.60±7.321	141.50±7.044	0.562
Weight (kg)	37.410±5.152	39.090±4.690	0.456
BMI (kg/m²)	19.092±0.621	19.445±0.554	0.196
Gender (n%)	Frequency (Percentage)		
Male	3 (30.0%)	4 (40.0%)	1.000
Female	7 (70.0%)	6 (60.0%)	

numbered envelopes, which were opened by the physiotherapist only after the participant's eligibility was confirmed and enrolment details were recorded. All participants were informed about the study protocol before the intervention and written informed consent was obtained from their parents or legal guardians. The intervention was administered by a physiotherapist who was not blinded to group allocation and administered the intervention. Participants were blinded to group allocation and the outcome assessor was blinded to treatment allocation to minimise assessment bias. The outcome assessor was blinded to group allocation, reducing the risk of assessment bias. Baseline anthropometric and demographic data (age, gender, height, weight and BMI) were collected from all participants. No significant differences were observed across groups ($p>0.05$) (Table 1). Participants underwent the

intervention for 50 minutes daily, 5 times per week, for 8 weeks. Outcome measures were assessed using the Vanderbilt ADHD Rating Scale (VADRS), the Childhood Executive Functioning Inventory (CHEXI) and Salivary Cortisol. We monitored adverse events, including headache, dizziness, fatigue and discomfort associated with MNS or HIIT, throughout the intervention. No adverse events or unexpected outcomes were reported.

Inclusion Criteria

Children aged 8-12 years with a diagnosis of ADHD, combined presentation based on the Diagnostic and Statistical Manual of Mental Disorders 5 criteria, as established by a behavioural paediatrician, were eligible to participate; both genders were included. Participants had to follow verbal directions and demonstrate adequate cognitive functioning. Children receiving medication for ADHD were eligible for inclusion if their medication type and dosage had remained stable for at least three months before enrolment.

Exclusion Criteria

Children with a history of neurological diseases, epilepsy, seizures, musculoskeletal illnesses or cardiovascular problems were excluded from the study.

Treatment Procedure

A structured 8 week rehabilitation programme combining HIIT and MNS was administered under physiotherapist supervision. The intervention was conducted five days per week, with each session lasting 50 minutes. Each session consisted of a 5-minute warm-up, 30 minutes of HIIT, 10 minutes of median nerve stimulation and a 5-minute cool-down.

HIIT Protocol

Exercise intensity was determined based on age-predicted maximal heart rate (HRmax), calculated using the formula 208.609-(0.716×age). Heart rate was continuously monitored during the sessions using a Polar H10 heart rate monitor, while perceived exertion was assessed using the Borg Rating of Perceived Exertion (RPE) scale (6-20). Each session began with a 5 minute warm-up, followed by a HIIT protocol comprising shuttle runs, jumping jacks, burpees, mountain climbers, frog leaps and bear crawls, as detailed in Table 2. The HIIT protocol consisted of six 4 minute high-intensity intervals, interspersed with 1-min active recovery periods at 50% HRmax , followed by a 5 minute cool-down [22,23].

Median Nerve Stimulation

The child was seated comfortably with the forearm supported and surface electrodes were connected to a portable electrical stimulator placed over the median nerve at the wrist. The anode was placed at the wrist crease and the cathode was placed proximally along the forearm. Stimulation was delivered for 10 minutes at a pulse width of 200 μs, an intensity of 2 mA and a frequency of 12 Hz based on previously published protocols. The sham group electrodes were positioned the same way as those in the intervention group. A brief, low-intensity electrical current was delivered during the initial part of the 10-minute session to produce a comparable sensation, after which the intensity was lowered to zero for the remainder of the session. The intervention was carried out in a peaceful, comfortable environment to improve the participant's relaxation, comfort and cooperation [24].

Attendance, Adherence and Treatment Fidelity

Participants' attendance and adherence were monitored throughout the intervention period. No protocol deviations or co-interventions occurred. The same physiotherapist delivered the interventions in both groups and consistently followed the prescribed treatment procedures and parameters across sessions to maintain treatment fidelity.

Outcome Variables

Primary Outcome: The parent versions of the Childhood Executive Functioning Inventory (CHEXI) and the Vanderbilt ADHD Rating Scales (VADRS) were used to assess the outcome variables at baseline and follow-up. To ensure consistent assessment of executive functioning and ADHD symptoms, the same parent completed both questionnaires at both time points. Higher VADRS scores indicate greater inattention, hyperactivity and impulsivity, whereas higher CHEXI levels indicate greater executive functioning difficulties. Conversely, lower scores on both scales indicate less severe ADHD symptoms and fewer executive functioning difficulties, respectively.

VADRS

The Vanderbilt ADHD Rating Scales (VADRS) is a validated instrument for assessing ADHD symptoms in children and

Table 2: HIIT Protocol

Exercise Component	Week 1-2	Week 3-5	Week 6-8
Shuttle run	2-3 rounds	3-4 rounds	4-5 rounds
Jumping Jacks	10-12 reps	12-15 reps	15-18 reps
Burpees	5-6 reps	7-8 reps	9-10 reps
Mountain Climbers	12-15 reps	18-22 reps	25-30 reps
Frog Jumps	6-8 reps	8-10 reps	10-12 reps
Bear Crawl	8-10 rounds	12-15 rounds	18-20 rounds
Exercise Parameters			
Sets	3 sets	3 sets	3 sets
Work Interval	4 minute	4 minute	4 minute
Active Recovery	1 minute	1 minute	1 minute
Exercise Intensity HRmax	80-85%	85-95%	95-100%

adolescents. It demonstrates excellent internal consistency, with Cronbach's alpha values ranging from 0.91 to 0.94 and good test-retest reliability (>0.80). The scale also exhibits a reliable four-factor structure consistent with ADHD symptom domains and has shown 80% sensitivity and 75% specificity for identifying children with ADHD [25].

CHEXI

CHEXI is a tool teachers and parents use to evaluate children's executive functioning. The CHEXI can accurately and validly measure children's executive function. The CHEXI has adequate test-retest reliability and good internal consistency (α = 0.86-0.91). It provides a stable two-factor structure of working memory and inhibition, along with strong construct and convergent validity [26].

Secondary Outcome

Salivary Cortisol: Saliva samples were collected between 8.00 and 10.00 a.m. to control for diurnal change in cortisol secretion. Participants were instructed to abstain from eating, drinking coffee and undergoing any dental hygiene treatments for at least 1 hour before sample collection. Unstimulated saliva was collected using a standard passive drool method. Participants were instructed to allow saliva to accumulate naturally in the mouth without chewing or using any salivary stimulants and to gently drool or expectorate the saliva into sterile, labelled saliva collection containers under aseptic conditions. The samples were transported and stored at 2-8°C immediately after collection to preserve sample integrity and were delivered to a recognised diagnostic laboratory within 2 hours of collection. Upon arrival, we processed the samples and prepared them for salivary cortisol analysis using an Enzyme-Linked Immunosorbent Assay (ELISA) according to the manufacturer's instructions. Appropriate procedures were followed to prevent contamination and repeated freeze-thaw cycles. Salivary cortisol concentrations were measured using ELISA. All laboratory procedures were performed by trained laboratory professionals who were blinded to the aims of the study and participant information, to minimise potential measurement and observer bias [27].

Data Analysis

Statistical analyses were performed using IBM SPSS software version 30.0.0.0. Normality of the data was assessed using the Shapiro-Wilk test before conducting inferential analyses. As the data were normally distributed, parametric tests were used. A paired t-test was performed to compare pre-test and post-test values within each group, while an independent t-test was used to compare between the two groups. We considered $p<0.05$ statistically significant.

RESULTS

Both groups had statistically significant improvements in ADHD symptoms following the intervention ($p<0.001$). In Group A, inattention score decreased from 21.30±2.406 to 10.50±1.080 (t = 17.172), hyperactivity reduced from 22.40±2.319 to 10.70±1.160 (t = 15.682) and total ADHD symptoms decreased from 43.70±2.312 to 21.20±1.751 (t = 33.541). Likewise, in Group B inattentiveness reduced from 21.10±2.331 to 19.80±2.098 (t = 8.510), hyperactivity reduced from 22.10±2.514to 21.00±2.494 (t = 11.000) and total ADHD symptoms reduced from 43.20±3.155 to 40.80±2.860 (t = 10.854) which were statistically significant ($p<0.001$). However, in all three domains, mean reductions were more significant in Group A than in Group B, indicating a greater reduction in ADHD symptoms in Group A, as shown in Table 3.

Comparison of CHEXI scores showed significant changes in executive function domains in both groups following the intervention ($p<0.001$). In Group A, the inhibitory factor score decreased from 44.10±2.601 to 32.80±2.150 (t = 30.818) and working memory decreased from 53.10±3.843 to 33.50±2.461 (t = 18.198). Similarly, in Group B, the inhibitory factor score decreased from 44.70±1.947 to 42.50±1.581 (t = 11.000) and working memory decreased from 53.30±3.592 to 51.00±3.162 (t = 10.776), with all changes statistically significant ($p<0.001$). Group A showed greater reductions in both domains than Group B, indicating greater inhibitory control and working memory difficulties in Group A, as shown in Table 4.

Both groups showed a statistically significant change in salivary cortisol levels ($p<0.001$). The mean cortisol level in Group A considerably increased from pre-test (0.875±0.131) ng/ml to post-test (2.454±0.166) ng/ml (t = -87.828). In Group B, mean cortisol level increased from (0.848±0.089 to 1.187±0.090) ng/ml (t = -11.863). Following the intervention, salivary cortisol levels increased more in Group A than in Group B, as shown in Table 5.

The post-test comparison showed statistically significant differences between Group A and Group B across all outcome variables ($p<0.001$). The inattention scores for Group A and B were 10.50±1.080 and 19.80±2.098, respectively (t = -12.465). Hyperactivity scores were 10.70±1.160 and 21.00±2.494 in Groups A and B, respectively (t = -11.841). Total ADHD symptoms were 21.20±1.751 in Group A and 40.80±2.860 in Group B (t = -18.484). In Groups A and B, inhibitory factor scores were 32.80±2.150 and 42.50±1.581, respectively (t = -11.494). The working memory scores were 33.50±2.461 in Group A and 51.00±3.162 in Group B (t = -13.811). Salivary cortisol levels were 2.454±0.166 ng/ml in Group A and 1.187±0.090 ng/ml in Group B

Table 3: Comparison of Pre- and Post-Test Values of Group A and B using VADRS

Domain	Group	Pre-test (Mean±SD)	Post-test (Mean±SD)	Mean Difference (95% CI)	t-value	p-value	Cohen's d
Inattention	Group A	21.30±2.406	10.50±1.080	10.800 (9.377 to 12.223)	17.172	<0.001	5.430
	Group B	21.10±2.331	19.80±2.098	1.300 (0.954 to 1.646)	8.510	<0.001	2.691
Hyperactivity	Group A	22.40±2.319	10.70±1.160	11.700 (10.012 to 13.388)	15.682	<0.001	4.959
	Group B	22.10±2.514	21.00±2.494	1.100 (0.874 to 1.326)	11.000	<0.001	3.479
Total ADHD symptoms	Group A	43.70±2.312	21.20±1.751	22.500 (20.982 to 24.018)	33.541	<0.001	10.607
	Group B	43.20±3.155	40.80±2.860	2.400 (1.900 to 2.900)	10.854	<0.001	3.432

Table 4: Comparison of Pre- and Post-Test Values of Group A and B using CHEXI

Domain	Group	Pre-test (Mean±SD)	Post-test (Mean±SD)	Mean Difference (95% CI)	t-value	p-value	Cohen's d
Inhibitory Factor	Group A	44.10±2.601	32.80±2.150	11.300 (10.471 to 12.129)	30.818	<0.001	9.746
	Group B	44.70±1.947	42.50±1.581	2.200 (1.748 to 2.652)	11.000	<0.001	3.479
Working Memory	Group A	53.10±3.843	33.50±2.461	19.600 (17.164 to 22.036)	18.198	<0.001	5.755
	Group B	53.30±3.592	51.00±3.162	2.300 (1.817 to 2.783)	10.776	<0.001	3.408

Table 5: Comparison of Pre- and Post-Test Values of Group A and B using Salivary Cortisol (Post-Pre)

Domain	Group	Pre-test (Mean±SD)	Post-test (Mean±SD)	Mean Difference (95% CI)	t-value	p-value	Cohen's d
Salivary Cortisol	Group A	0.875±0.131	2.454±0.166	-1.579 (-1.616 to -1.538)	- 87.828	<0.001	-27.77
	Group B	0.848±0.089	1.187±0.090	0.339 (-0.403 to -0.274)	- 11.863	<0.001	-3.752

Table 6: Post-Test Values of Group A and B using VADRS, CHEXI and Salivary Cortisol

Domain	Group A (Mean±SD)	Group B (Mean±SD)	Mean Difference	95% CI	t-value	p-value	Cohens d
Inattention	10.50±1.080	19.80±2.098	-9.300	-10.867 to -7.733	-12.465	<0.001	-5.574
Hyperactivity	10.70±1.160	21.00±2.494	-10.300	-12.128 to -8.472	-11.841	<0.001	-5.295
Total ADHD symptoms	21.20±1.751	40.80±2.860	-19.600	-21.828 to -17.372	-18.484	<0.001	-8.266
Inhibitory Factor	32.80±2.150	42.50±1.581	-9.700	-11.473 to -7.927	-11.494	<0.001	-5.140
Working Memory	33.50±2.461	51.00±3.162	-17.500	-20.162 to -14.838	-13.811	<0.001	-6.176
Salivary cortisol	2.454±0.166	1.187±0.090	1.267	1.142 to 1.392	21.240	<0.001	9.499

(t = 21.240). Overall, Group A had a larger reduction in ADHD symptoms and executive function problems and a greater increase in salivary cortisol levels, indicating a greater shift toward normalisation of salivary cortisol levels than Group B (Table 6).

DISCUSSION

This study compared the effects of MNS combined with HIIT and sham stimulation combined with HIIT in children with ADHD. The findings suggested greater reductions in core ADHD symptoms and higher salivary cortisol levels in the MNS-combined-with-HIIT group than in the sham-stimulation-combined-with-HIIT group.

The reduction in core ADHD symptoms noted in the present study aligns with Santamaría-Vázquez *et al.* [24]. They reported that MNS reduced behavioural disturbances, hyperactivity, impulsivity and anxiety. They also noted changes in theta activity, suggesting altered cortical activity. MNS might influence thalamocortical pathways by stimulating afferent pathways, thereby supporting attention and behaviour control [24]. However, these proposed neural mechanisms remain hypothetical because neural activity and thalamocortical function were not directly assessed in the present study.

Beyond the potential effects of MNS, the reduction of ADHD symptoms may also be associated with HIIT. This finding aligns with Sabaghi *et al.* [28], who documented reductions in inattention, hyperactivity and impulsivity following HIIT among children with ADHD. They also found improvements in behavioural inhibition. HIIT was more effective than MICT in improving attention deficits and selected GO/No-Go test outcomes. The authors speculated that these benefits might be mediated through altered neurotransmitter activity, increased cerebral blood flow and BDNF-related neuroplasticity. These changes may involve dopaminergic, noradrenergic and glutamatergic systems [28].

Furthermore, Sun *et al.* [29] reported that game-based HIIT can improve physical fitness while simultaneously enhancing activation of the dorsolateral prefrontal cortex, a key brain region involved in executive functioning, cognitive control and attention regulation in children with ADHD. These mechanisms may help explain the reductions in core ADHD symptoms observed in the present study, although they were not directly assessed.

In addition to the observed effects on core symptoms, the intervention may also have influenced physiological stress regulation; an increase in salivary cortisol was also detected in the present study. This finding corresponds with Fulun *et al.* [1], who observed decreased morning cortisol and stress-related cortisol levels in children with ADHD, indicating possible HPA axis hypoactivity. The increase in salivary cortisol in our study may indicate modulation of HPA axis activity, potentially arising from the combined neurophysiological effects of MNS and exercise on the autonomic and stress response system.

Corominas-Roso *et al.* [30] offered additional insights into cortisol responses in children with ADHD. The authors reported that children with ADHD had blunted cortisol responses to stress, although they experienced greater psychological stress. Although the study population differed from that in the present investigation, these findings suggest that cortisol variations should not be considered solely an indicator of subjective stress. Likewise, the observed improvement in cortisol levels following MNS paired with HIIT may mark physiological stress rather than increased subjective stress [30]. Schuurmans *et al.* [31] provided further evidence distinguishing cortisol levels from subjective stress. They observed that adolescents with trauma histories exhibited higher basal cortisol levels and a blunted cortisol response to acute stress. This pattern suggested chronic stress-induced downregulation of the HPA axis. Although the study population differed from the present population, the results suggest that increased cortisol

may reflect HPA-axis control rather than acute stress alone. Dastamooz *et al.* [32] provided further evidence from exercise-based regimens in adolescents with ADHD; their findings reported that adolescents with ADHD experienced reduced self-reported stress and increased salivary cortisol following a short bout of moderate-to-vigorous exercise. Thus, increased cortisol following exercise may reflect the body's biological response to physical activity rather than increased perceived stress.

In summary, our results showed that MNS combined with HIIT significantly improved neurobehavioral outcomes and increased salivary cortisol levels compared with sham stimulation combined with HIIT, suggesting potential improved physiological stress regulation in children with ADHD. The combined intervention may have improved attention and behavioural symptoms through MNS's influence on neural function and HIIT's influence on neural and physiological function. The observed improvements in cortisol may reflect a better modulation of the physiological stress response. These results suggest the feasibility and potential efficacy of MNS combined with HIIT as a promising non-pharmacological intervention for managing neurobehavioral symptoms and physiological stress regulation in children with ADHD.

CONCLUSIONS

The research demonstrated that 8 weeks of MNS combined with HIIT is more effective than Sham stimulation combined with HIIT in reducing neurobehavioral symptoms and normalising salivary cortisol levels in children with ADHD.

Limitations and Recommendation

As this was a pilot study involving a relatively small sample, the findings may have limited generalisability. No long-term follow-up was undertaken to determine the sustainability of the treatment. In addition, the intervention lasted a relatively short time. Salivary cortisol was measured at a single time point and may therefore not capture the complete diurnal variation in cortisol. The study relied mostly on questionnaire-based assessments and did not include objective neurophysiological markers such as EEG. Furthermore, the findings may not generalise to children with different ADHD presentations, medication regimens, comorbidities and sleep patterns.

Future research should include larger sample sizes, longer-term follow-up and multiple salivary cortisol measurements to assess treatment sustainability and diurnal cortisol changes. Researchers should also consider objective neurophysiological markers such as EEG, along with ADHD symptom severity, individual participant characteristics and sleep patterns, to provide a more comprehensive understanding of treatment outcomes.

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Ethical Approval

The Institutional Ethics Committee approved the study, which adhered to the Declaration of Helsinki (080/04/2026/FGSR/SCPT).

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