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Efficacy of Transcranial Magnetic Stimulation for Enhancing Speech Function in Children with Autism: A Controlled Trial

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Abstract: *Language dysfunction in children with autism presents a significant barrier to social integration and effective communication of their needs. Traditional interventions have demonstrated limited effectiveness in addressing these deficits. However, transcranial magnetic stimulation (TMS) shows considerable promise as a novel treatment for language disorders in children with autism. In this study, 60 children with autism and language impairments were recruited and randomly assigned to either an experimental group or a control group. The control group underwent conventional language training, while the experimental group received TMS in addition to the same language training for a duration of four weeks. The Autism Behavior Checklist (ABC), Autism Treatment Evaluation Checklist (ATEC), and Psychoeducational Profile (PEP-3) were administered to assess the children's progress before and after treatment. The results indicated that the experimental group exhibited significant improvements in verbal communication and social skills scores compared to the control group, with statistically significant differences (P<0.05). In conclusion, TMS represents a promising intervention for language deficits in children with autism spectrum disorder (ASD), with the potential to enhance functional brain connectivity, improve cortical plasticity, and lead to more effective language development outcomes.*

Keywords: *autism; transcranial magnetic stimulation; language impairments; behavioral interventions*

1. Introduction

Autism Spectrum Disorder (ASD) is a neurodevelopmental condition characterized by a wide range of social, communicative, and behavioral challenges[1]. First identified in the mid-20th century, autism has since been recognized as a spectrum disorder due to the considerable variation in the type and severity of symptoms among individuals. The prevalence of ASD has risen substantially over the past few decades, with recent estimates suggesting that approximately 1 in 54 children in the United States are diagnosed with the disorder[2]. Despite extensive research efforts, the precise etiology of autism remains elusive, with current theories suggesting a multifactorial origin involving genetic, environmental, and neurological components[3–5].

The core symptoms of autism include deficits in social communication and interaction, as well as the presence of restrictive and repetitive behaviors. Among these, speech and language impairments are particularly pervasive, with many children on the spectrum exhibiting delayed speech development, echolalia, or atypical use of language[6–8]. These impairments can significantly hinder social integration and the ability to express needs, leading to increased frustration and behavioral difficulties.

Traditional therapeutic approaches for speech and language impairments in children with autism have included speech therapy, behavioral interventions, and, more recently, the use of assistive technologies[9,10]. While these interventions have shown varying degrees of success, a significant number of children with autism continue to experience persistent speech difficulties despite prolonged and intensive therapy. This challenge underscores the need for innovative and more effective therapeutic modalities.

In recent years, transcranial magnetic stimulation (TMS) has emerged as a promising

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neuromodulatory technique with potential applications in the treatment of speech and language impairments in children with autism[11,12]. TMS involves the use of magnetic fields to stimulate specific regions of the brain, thereby modulating neural activity. Originally developed as a diagnostic tool for mapping brain function, TMS has been increasingly explored for its therapeutic potential across a range of neurological and psychiatric disorders, including depression, schizophrenia, and Parkinsons disease.

The application of TMS in the context of autism is still in its infancy, but early studies have yielded encouraging results. Research suggests that TMS may facilitate improvements in speech function by targeting regions of the brain implicated in language processing and production, such as Broca area and the left inferior frontal gyrus. These areas are often found to be underactive or misaligned in individuals with autism, contributing to their speech and language difficulties. By enhancing the connectivity and activity within these regions, TMS may help to alleviate some of the core speech impairments associated with autism[13,14]. Moreover, TMS is non-invasive and well-tolerated, making it a particularly attractive option for use in pediatric populations. The technique does not require anesthesia, and the side effects are generally mild and transient, typically including headache or scalp discomfort. This favorable safety profile, combined with the preliminary evidence of efficacy, has generated considerable interest in the potential of TMS as a novel intervention for speech impairments in children with autism[15–17].

Despite the promise shown by early studies, the use of TMS in autism remains experimental, with several critical questions yet to be answered. These include identifying the optimal stimulation parameters, understanding the long-term effects of repeated TMS sessions, and determining the specific subgroups of children with autism who are most likely to benefit from this intervention. Additionally, larger, well-controlled trials are needed to confirm the preliminary findings and to establish TMS as a standardized treatment option within the broader spectrum of autism therapies. In this study, we aim to build upon the existing body of knowledge by conducting a controlled trial to evaluate the efficacy of TMS in improving speech function in children with autism. By focusing on this specific aspect of autism intervention, we hope to contribute valuable insights into the potential role of TMS in the multidisciplinary treatment of speech and language impairments in children with autism.

2. Methods

2.1 Study design

From September 2023 to June 2024, 60 children with ASD admitted to our hospital were randomly assigned to one of two groups: the observation group (30 cases) and the control group (30 cases), using a random number table method. The study was approved by the Medical Ethics Committee of our hospital, and informed consent was obtained from all participants' guardians. The observation group consisted of 24 males and 6 females, with a mean age of months. The control group included 23 males and 7 females, with a mean age of months. There were no significant differences in the baseline characteristics between the two groups ($p>0.05$), making them comparable.

2.2 Inclusion and Exclusion Criteria

Inclusion Criteria: (1) Meet the diagnostic criteria for ASD; (2) Age 6-10 years, no gender restrictions; (3) Autism Behavioral Scale score >67, Childhood Autism Rating Scale (CARS) score >30; (4) No progressive brain lesions, acute or chronic infectious diseases, or hearing impairments; (5) No related treatments received in the past month; (6) Informed consent obtained from parents or guardians.

Exclusion Criteria: (1) Presence of childhood schizophrenia, Heller syndrome, or Rett syndrome; (2) History of epilepsy; (3) Severe organic lesions, genetic-metabolic disorders, or infectious diseases; and (4) Inability to adhere to the treatment protocol.

2.3 Intervention

The control group received speech training, which involved the following steps: (1) Organize the training environment according to the specific training activities, emphasizing visual cues through special arrangements of the site, toys, and other objects. (2) Develop a structured training program to ensure a procedural approach to the sessions. (3) Define the training content, focusing on children's speech articulation, non-verbal communication, perception, cognition, language comprehension and expression, social skills, and emotional awareness. (4) Employ a variety of teaching methods, including verbal instructions, body language, visual cues, labels, charts, and written words, to enhance the children's

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understanding of the training material. Behavioral reinforcement techniques and other behavior modification strategies are also used to improve verbal communication, social interactions, and reduce maladaptive behaviors in children with ASD. Each session was administered by professionally qualified rehabilitation therapists and last 20 minutes, conducted twice daily, six times a week, over a continuous four-week treatment period.

The experimental group received Transcranial Magnetic Stimulation (TMS) in addition to the control group's treatment: (1) Stimulation site: Broca's area, located in the left inferior frontal gyrus, corresponding to F5 in the 10-20 EEG electrode placement system. (2) Stimulation protocol: a frequency of 10 Hz with an intensity set at 70% of the motor threshold[18]. Each session involved 1,800 pulses, delivered in 20 sequences of 90 pulses each, with a 20-second interval between sequences. Treatment was administered once daily for six consecutive days each week, followed by one day of rest, for a total treatment duration of four weeks.

2.4 Measurement

Autism Behavior Checklist (ABC)[19]: This checklist includes 57 items covering sensory, behavioral, emotional, and linguistic abnormalities observed in children. It is completed by the child's parents or caregivers who have been with the child for more than two weeks. A four-point scale (0–3) is used, with higher scores indicating more pronounced and severe behaviors. The scale is divided into five domains: sensory (S), relating (R), body/movement (B), language (L), and self-help (S).

Autism Treatment Evaluation Checklist (ATEC)[20]: Developed in 1999 by the San Diego Autism Institute, this scale consists of four sections: I. Expressive/Verbal Communication (14 items), II. Socialization (20 items), III. Sensory/Cognitive Awareness (18 items), and IV. Health/Physical/ Behavioral (25 items). A three-point scale (0–2) is used, with higher scores indicating more severe behaviors.

Psychoeducational Profile – Third Edition (PEP-3)[21]: This instrument is specifically designed to assess the psychological and educational functioning of children with ASD. It consists of developmental and behavioral reports across 172 items, divided into 10 sections, including cognitive abilities, verbal expression, verbal comprehension, fine motor skills, gross motor skills, imitation, affective expression, social interaction, and behavioral traits (verbal and nonverbal). Items are scored 0, 1, or 2, where 0 represents failure, 1 indicates partial completion, and 2 indicates successful completion.

2.5 Statistical analysis

Statistical analysis was conducted using SPSS 23.0 software. Data from the two groups were compared and analyzed, with measurement data expressed as mean ± standard deviation. For normally distributed data, comparisons between the two groups were performed using the t-test. For data not conforming to normal distribution, the Welch's t-test was employed. A significance level of $\alpha = 0.05$ was used, with $\alpha = 0.01$ considered highly significant. All tests were two-sided.

3. Results

After 4 weeks of TMS combined with educational rehabilitation training, children with ASD in the observation group demonstrated a significant increase in meaningful verbal communication. Scale assessments revealed improvements in both verbal and non-verbal communication behaviors, as well as enhanced verbal comprehension, expression, and cognitive abilities.

3.1 Comparison of ABC scores between the two groups

Following treatment, the observation group showed a significant reduction in the ABC scale scores for verbal communication and social ability compared to the control group ($P<0.05$), although the total score did not significantly decrease (see Table 1). This suggests that after 4 weeks of TMS intervention, verbal communication and social skills in children with ASD improved.

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Table 1: Comparison of ABC scores between the two groups. ($\bar{x}$±s)

Group	Relating	Language	Total scores
Control group	30.3±5.2	29.1±3.2	83.5±11.9
Experimental group	26.7±6.3*	24.2±4.1*	78.2±10.8*
t	2.41	3.05	1.81
p	0.019	0.003	0.076

*p <0.05 compared to the control group.

3.2 Comparison of ATEC scores between the two groups

After the 4-week TMS intervention, the observation group showed a significant reduction in the ATEC subscale scores for verbal communication, social ability, and the total score compared to the control group, with statistically significant differences (P<0.05) (see Table 2). These findings suggest that the TMS intervention led to improvements in verbal communication and social abilities in children with ASD.

Table 2: Comparison of ATEC scores between the two groups. ($\bar{x}$±s)

Group	Expressive/Verbal Communication	Socialization	Total scores
Control group	19.20±2.89	20.61±5.03	75.53±13.61
Experimental group	16.41±2.85*	17.34±4.75*	64.11±12.23*
t	1.573	4.342	3.671
p	0.001	0.013	0.001

*p <0.05 compared to the control group.

3.3 Comparison of PEP-3 scores between the two groups

After treatment, the observation group showed significant improvements in the PEP-3 subscale scores for cognition, verbal comprehension, verbal expression, and verbal behavioral characteristics compared to the control group (P<0.05) (see Table 3). These results indicate that TMS intervention led to enhanced meaningful verbal communication and social interaction abilities in children with ASD.

Table 3: Comparison of PEP-3 scores between the two groups. ($\bar{x}$±s)

Group	cognitive abilities	verbal expression	verbal comprehension	behavioral traits (verbal)
Control group	35.62±7.43	28.62±4.67	24.76±4.91	18.66±3.89
Experimental group	45.66±7.11*	31.72±4.03*	32.56±6.10*	26.26±2.71*
t	1.489	4.542	2.126	2.701
p	0.001	0.031	0.001	0.001

*p <0.05 compared to the control group.

4. Discussion

TMS has emerged as a promising therapeutic approach for improving speech function in children with ASD[22]. Over the past few years, growing evidence has supported the efficacy of TMS in ameliorating various core symptoms of ASD, particularly language and communication deficits. Several studies have demonstrated that TMS can positively influence the neurophysiological underpinnings of ASD by modulating cortical excitability and improving functional connectivity in critical brain regions[23,24].

4.1 Summary of evidence supporting TMS in ASD treatment

TMS has been widely researched as a non-invasive neuromodulation technique with potential therapeutic benefits for children with ASD. Previous studies have focused on the impact of TMS on improving social communication, reducing repetitive behaviors, and alleviating cognitive impairments. For instance, a randomized controlled trial by Oberman et al. found that repetitive TMS (rTMS) applied to the dorsolateral prefrontal cortex (DLPFC) resulted in significant improvements in social

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responsiveness and language comprehension[16]. Another study by Sokhadze et al. reported reductions in irritability and hyperactivity, as well as improvements in language function, following rTMS applied to the anterior cingulate cortex (ACC)[25]. While the precise effects of TMS vary depending on the target brain region, stimulation protocol, and individual differences, these findings underscore the potential of TMS to alleviate speech and communication difficulties in children with ASD.

4.2 Mechanisms of TMS action: improving brain networks and cortical activation

The therapeutic effects of TMS in children with ASD are believed to stem from its ability to modulate dysfunctional neural circuits and cortical networks. In ASD, alterations in brain connectivity, particularly underconnectivity in long-range connections and hyperconnectivity in local circuits, contribute to the core symptoms, including speech deficits[26]. TMS, by inducing magnetic fields that penetrate the skull and generate electrical currents, influences the excitability of cortical neurons and the synchronization of neural networks.

One possible mechanism for the improvement in speech function is the restoration of cortical plasticity in key brain areas involved in language processing. For instance, stimulation of Broca's area—an essential region for speech production—may enhance the functional connectivity between this region and other parts of the brain[27], such as Wernicke's area, leading to improved language comprehension and verbal expression[28]. Additionally, TMS may regulate gamma oscillations[29], which are critical for language and cognitive processing, thereby improving the integration of sensory information in children with ASD.

Moreover, TMS may help to recalibrate the balance between excitation and inhibition in cortical circuits[30]. Studies have suggested that ASD is characterized by an imbalance between excitatory and inhibitory neurotransmission, particularly in regions responsible for language and social cognition. By selectively modulating the excitability of these circuits, TMS can promote more normalized patterns of brain activation, leading to better speech outcomes.

4.3 Clinical significance and considerations for TMS in autism treatment

The application of TMS in clinical settings for treating speech impairments in children with ASD holds significant promise. Its non-invasive nature, combined with the ability to target specific cortical regions, makes it an appealing alternative to more conventional therapies. TMS has the potential to be integrated into multidisciplinary treatment plans that include speech therapy, behavioral interventions, and pharmacological support.

However, there are several important considerations for its clinical use. First, TMS protocols need to be individualized, taking into account factors such as age, severity of symptoms, and neurodevelopmental stage13. Furthermore, there is a need to establish standardized guidelines regarding stimulation parameters, including intensity, frequency, and duration of treatment. Safety concerns, particularly the risk of inducing seizures, should also be carefully evaluated in vulnerable populations like children with ASD. Close monitoring for any adverse effects, such as headaches, scalp discomfort, or transient mood changes, is essential to ensure that the benefits outweigh the risks.

4.4 Future prospects and potential improvements in TMS treatment

Looking forward, the use of TMS for treating ASD-related speech deficits offers several exciting prospects. Future research should focus on optimizing stimulation protocols to maximize therapeutic effects and minimize side effects. Studies investigating the long-term efficacy of TMS and its ability to induce lasting changes in brain function are particularly needed. In addition, combining TMS with neuroimaging techniques, such as functional MRI (fMRI) or electroencephalography (EEG), could provide deeper insights into the mechanisms of action and help identify biomarkers for predicting treatment response[31].

Advances in personalized medicine may also play a crucial role in the future of TMS therapy. Tailoring stimulation parameters based on an individual's neurobiological profile could enhance treatment outcomes and reduce variability in response. Additionally, combining TMS with other interventions, such as transcranial direct current stimulation (tDCS) or cognitive behavioral therapy (CBT), could provide synergistic benefits for children with ASD[32].

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4.5 Limitations of the present study

While the results of the present clinical trial indicate significant improvements in verbal communication and social interaction abilities following TMS treatment, several limitations must be acknowledged. First, the sample size was relatively small, which may limit the generalizability of the findings. Larger, multicenter studies are needed to validate these results. Second, the study did not assess the long-term effects of TMS, and it remains unclear whether the observed improvements are sustained over time. Follow-up studies with extended monitoring periods are essential to determine the durability of the therapeutic benefits. Additionally, the study did not explore potential individual differences in treatment response, which could be influenced by factors such as age, severity of ASD, or comorbidities.

5. Conclusion

In conclusion, TMS offers a promising avenue for treating speech deficits in children with ASD, with the potential to improve functional connectivity, enhance cortical plasticity, and promote more effective language outcomes. However, further research is needed to optimize treatment protocols, assess long-term effects, and explore the integration of TMS with other therapeutic modalities.

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