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A Review of the Effects of Exercise Intervention on Brain and Behavior in Children with Autism Spectrum Disorder

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Abstract. Autism spectrum disorder (ASD) is a neurodevelopmental condition characterized by persistent social communication deficits, restricted repetitive behaviors, and motor impairments. Current interventions primarily target cognitive and behavioral symptoms, yet systematic, cost-effective, and broadly accessible programs remain insufficient. Physical exercise has shown potential as a practical supplementary strategy. Using a literature review methodology, this paper synthesizes existing evidence on how exercise interventions affect brain structures and networks—specifically the prefrontal cortex, mirror neuron system, cerebellum, and large-scale functional connectivity—and how these neural changes relate to behavioral outcomes in children with ASD. The review finds that structured physical activity may enhance prefrontal executive control, improve sensorimotor integration, and facilitate social-cognitive processing, thereby reducing stereotyped behaviors, improving social skills, and promoting motor development. The paper concludes that exercise intervention should be regarded not merely as physical training, but as a comprehensive, low-cost, and feasible approach that supports brain plasticity and functional improvement, offering valuable implications for schools, families, and rehabilitation settings.

Keywords: autism spectrum disorder, exercise intervention, brain connectivity, behavioral improvement

1. Introduction

Autism spectrum disorder(ASD) is a developmental disorder that affects many aspects of a child's growth, especially social communication, behavior, and movement. People with autism and other special needs often find themselves on the margins of society. Although they may appear no different from others on the surface, many children with ASD may experience barriers to social participation and daily functioning. Currently, interventions for children with ASD tend to focus on cognitive and behavioral remediation, but there remains a shortage of systematic, structured, and cost-effective intervention programs. Physical activity interventions have played a pivotal role in this regard. For example, some studies have shown that exercise can provide short-term reductions in stereotypic behaviours in children with ASD [1]. Exercise interventions are also associated with improvements in social skills, repetitive stereotyped behaviors, and motor skills in children and adolescents with ASD [2]. Furthermore, given the low cost involved and children's natural love of

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physical activity, exercise interventions are likely to significantly enhance the therapeutic outcomes for children with autism.

This paper focuses on how exercise intervention may affect the brain and behavior of children with autism. It mainly discusses changes in brain areas related to attention, imitation, movement, and social interaction, and explains how these changes may help reduce repetitive behaviors and improve social and motor skills.

This topic is important because exercise is a practical and low-cost intervention. Understanding its effects may help schools, families, and rehabilitation centers design more appropriate activities for children with autism.

2. The link of brain and behavior

2.1. Core pathways

A core pathway through which the brain influences behavior is that the prefrontal cortex maintains goals and rules, sends bias signals to other brain systems, and guides goal-directed behavior. Miller and Cohen argue that the prefrontal cortex does not simply produce actions directly. Instead, it keeps task-relevant information active, such as what goal a person wants to achieve, and then regulates sensory, motor, and cognitive systems to support the appropriate response. Through this process, the brain can strengthen relevant information, suppress distractions, and select behaviors that match the current goal. For example, when a child is trying to finish homework, the prefrontal cortex helps maintain attention on the task and inhibit distractions [3]. In addition, dopamine modulates neural activity within these prefrontal circuits. The intensity of biased signals within the prefrontal cortex depends on dopamine levels. Dopamine deficiency results in signal attenuation; consequently, executive capacity deteriorates when individuals experience fatigue or stress.

2.2. Case analysis

The monkey experiments illustrate how the prefrontal cortex influences behavior through top-down control. In visual search tasks, monkeys were required to identify a target among distracting stimuli. Activity in the prefrontal cortex, especially the frontal eye field, helped direct attention toward the relevant target and reduce interference from distractors. Stimulation of this region improved target detection, whereas inactivation impaired visual search performance. In paired association tasks, monkeys used a cue stimulus to retrieve its associated target from long-term memory. These findings suggest that the prefrontal cortex sends top-down signals to posterior brain regions, supporting attention, memory retrieval, and appropriate behavioral responses [4]. These mechanisms are important for understanding why exercise-based activities that require attention, rule-following, and response inhibition may support behavioral improvement in children with ASD.

Overall, the three functions (attentional orienting, memory retrieval, and response selection) are not independent of one another. Instead, the prefrontal cortex coordinates multiple posterior systems via top-down signaling, translating internal goals into overt action choices.

3. Effects of exercise interventions on the brain

3.1. Key brain regions affected

The prefrontal cortex (PFC) is closely related to attention, planning, executive control, working memory and emotional regulation. In children with ASD, weaker prefrontal functional connectivity

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and poorer network integration may partly explain difficulties in sustained attention and self-regulation. Existing exercise studies suggest that single-session or short-term moderate-intensity aerobic exercise, such as walking, can improve attentional cognitive control in children. Therefore, exercise intervention may help activate prefrontal-related cognitive control processes and support more organized goal-directed behavior [5, 6].

The mirror neuron system (MNS) supports action observation, imitation and the understanding of others' intentions, which are important foundations for social learning. Research shows that ASD is associated with atypical MNS connectivity, especially reduced intra-network connectivity in the bilateral inferior parietal lobules and abnormal coupling with theory-of-mind regions. Although direct evidence that exercise changes the MNS remains limited, movement activities involving imitation, physical synchrony and peer interaction may indirectly stimulate action-social cognitive networks and improve children's ability to understand and respond to others [7].

The cerebellum is not only responsible for balance and motor coordination, but also participates in sensory integration, timing, learning and social development. ASD is often associated with abnormalities in the cerebellar vermis, posterior cerebellum and Purkinje cells, which may contribute to sensorimotor and social communication difficulties. Although neuroimaging evidence on exercise-induced cerebellar change in ASD is still limited, aquatic exercise, horseback riding and simulated riding training have been reported to improve motor skills, balance control and social behavior. These findings suggest that exercise may indirectly support cerebellum-related functional systems through repeated coordination and sensorimotor integration [8-10].

3.2. Improvement of brain connectivity

The difficulties encountered by children with autism are not merely attributed to functional deficits of individual brain regions, but also closely associated with abnormal connectivity patterns across large-scale brain networks. Kennedy and Courchesne conducted resting-state functional magnetic resonance imaging (rs-fMRI) and found that individuals with ASD exhibited aberrant functional organization within the task-negative network (TNN) responsible for social and emotional processing. In contrast, no significant intergroup differences were observed in the task-positive network (TPN) that subserves sustained attention and goal-directed cognition. These findings demonstrate that social impairments in children with ASD originate from atypical intrinsic brain connectivity patterns, particularly the inefficient interregional coordination of social-emotional processing networks compared with typically developing peers.

Exercise intervention can improve attentional control, sensory integration and social participation via rhythmic physical activities, peer interaction, rule switching and goal-directed tasks, thereby regulating abnormal brain network connectivity in populations with ASD. In short, physical exercise is not merely a workout for skeletal muscles; instead, it delivers repetitive, predictable and socially meaningful neural stimuli to the brain. Such stimuli help optimize and flexibly adjust the disrupted brain connectivity patterns of children with autism [11].

3.3. Summary

Overall, the benefits of exercise intervention for children with autism extend far beyond physical fitness and improvement in motor performance. More importantly, physical activity may facilitate the overall coordination of whole-brain functions. By means of repetitive motor practice, rule shifting, rhythm adjustment, peer cooperation and physical interaction, exercise intervention provides stable and abundant sensorimotor stimuli for the brain, which promotes information

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communication across different brain regions. Accordingly, exercise can be regarded as a comprehensive intervention approach. It may help transform the rigid and inefficient brain connectivity patterns of children with ASD into coordinated, flexible neural circuits that are more consistent with the functional characteristics of typically developing individuals.

4. Improvement of behaviors through exercise interventions

4.1. Social behavior

Exercise intervention produces significant enhancements in social functioning for children with ASD. A meta-analysis assessed the impact of physical exercise interventions on the social skills of children with ASD. This meta-analysis of 16 studies confirms exercise interventions significantly improve social skills in children with ASD (SMD = −0.54, 95% CI = [−0.63, −0.44]). Age moderates intervention effects, and programs over 12 weeks produce better outcomes, providing strong evidence for physical exercise as an effective social intervention for children with ASD [12].

4.2. Stereotyped and repetitive behaviors

One meta-analysis covering 22 trials with 274 children with ASD found that physical exercise exerts a significant reducing effect on maladaptive stereotyped motor behaviours (SMB) among children with ASD. After standardized model adjustment, the pooled effect size reached g = 0.51, and moderator analysis indicated that elevated exercise intensity served as a stable positive predictor of intervention efficacy, whereas age, exercise duration and intervention settings produced no consistent moderating impacts [13].

Exercise may reduce stereotyped and repetitive behaviors in children with ASD through sensory, physiological, and cognitive mechanisms. Structured movement provides vestibular and proprioceptive input, potentially reducing the need for self-stimulatory actions. It may also regulate arousal and anxiety while improving inhibitory control and cognitive flexibility. Movements that biomechanically compete with stereotypy may temporarily replace repetitive responses. Exercise-related changes in dopamine, serotonin, and neuroplasticity are also proposed. However, these mechanisms remain hypothetical, and excessive intensity may increase arousal and worsen stereotypy.

4.3. Sports skills and daily life

One systematic review and meta-analysis examined randomized controlled trials of exercise interventions for fundamental motor skills in children with ASD. Thirteen studies involving 541 participants were reviewed, and ten studies with 297 participants were meta-analyzed. Exercise significantly improved locomotor skills (SMD = 1.07), object-control skills (SMD = 0.79), and stability skills (SMD = 0.72). The largest benefit was observed for locomotor abilities, while object-control and stability gains were moderate. The authors conclude that exercise effectively supports motor development in children with ASD [14].

Exercise may improve fundamental motor skills in children with ASD because structured, guided programs provide repeated opportunities to practice correct movement patterns. This targeted instruction may compensate for limited physical activity and insufficient opportunities for motor learning. Object-control activities strengthen coordination, attention, information processing, and visual-motor integration. Balance-focused exercises train the ankle and knee joints while improving

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neuromuscular and sensorimotor integration required for postural control. Aquatic exercise may offer additional benefits through vestibular stimulation, reduced body weight, postural support, and greater freedom to practice movements at an appropriate difficulty level.

5. Conclusion

This review aimed to summarize how exercise intervention may influence the brain and behavior of children with autism spectrum disorder. Based on previous literature, exercise may support children with ASD's development through multiple pathways, including improved prefrontal executive control, enhanced motor and sensory integration, possible activation of imitation-related neural systems, and better coordination of large-scale brain networks. These brain-related changes may help explain improvements in social interaction, repetitive behaviors, motor skills, and daily functioning.

This review contributes to the existing literature by linking exercise intervention with both neural mechanisms and behavioral outcomes. It suggests that physical activity should not be understood only as a way to improve fitness, but also as a structured intervention that provides repeated sensory, cognitive, motor, and social stimulation. Therefore, exercise programs may have practical value for schools, families, and rehabilitation centers because they are relatively low-cost, accessible, and acceptable for many children.

However, this review also has limitations. Some conclusions are based on indirect evidence, especially regarding the mirror neuron system, cerebellum, and exercise-induced brain connectivity changes in children with ASD. Future research should include more longitudinal studies, larger samples, and neuroimaging evidence to clarify how different types, intensities, and durations of exercise affect neural and behavioral outcomes. Overall, this review suggests exercise intervention as a potentially effective approach for promoting brain flexibility and behavioral development in children with ASD.

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