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Review

Research progress on the impact of exercise intervention on sleep disorders in children with autism

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Abstract: Autism Spectrum Disorder (ASD) is a neurodevelopmental disorder that emerges in early childhood. Sleep disorders are a common comorbidity among children and adolescents with ASD, which can exacerbate the core symptoms of the disorder and impact the growth and development of affected individuals. As a safe and repeatable non-pharmacological treatment, exercise intervention has shown positive effects on the early treatment of ASD and the management of sleep disorders, achieving certain success in the treatment of sleep disorders. This article reviews the potential mechanisms and intervention methods by which exercise can improve sleep disturbances in children with ASD. It aims to provide a theoretical foundation for optimizing exercise intervention programs aimed at alleviating sleep disorders in children and adolescents with ASD.

Keyword: exercise; intervention; autism spectrum disorder; sleep disorders; children

1 Introduction

Autism spectrum disorder (ASD) is a neurodevelopmental disorder that manifests itself in social impairments, language disorders, and abnormal behaviors[1]. In addition to the core symptoms, there are often a series of coexisting symptoms, such as cognitive dysfunction, narrow interests, epilepsy, attention deficits, anxiety and sleep disorders, of which sleep disorders are particularly common[2]. Among ASD patients, about 50%-80% of individuals have different types of and different degrees of sleep disorders[3], of which insomnia incidence is as high as 60-86%[4]. Sleep problems can trigger daytime sleepiness and physical fatigue, and may even exacerbate core symptoms. Without timely intervention, persistent sleep disturbances could potentially create a vicious cycle with the core symptoms of ASD, leading to further deterioration of the condition[5]. Current treatment options for ASD sleep disorders include pharmacologic and non-pharmacologic treatments. The effectiveness of pharmacological interventions in the treatment of sleep disorders in ASD patients has been confirmed, but there is a lack of standardized dosage,

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formulations, and efficacy of in the treatment of children with ASD, and the safety of long-term use of is controversial[3,6]. Therefore, non-pharmacological treatments are often used as a first-line program to improve sleep in children with ASD[7]. Exercise intervention, as a non-pharmacological treatment, has shown great potential in improving sleep disorders in children with ASD. The mechanisms and applications of exercise interventions for the treatment of sleep disorders in children with ASD are now reviewed, with the aim of providing a reference for the improvement of sleep disorders in children with ASD by exercise.

2 Mechanisms associated with exercise to improve sleep disorders in children and adolescents with ADS

The pathogenesis of sleep disorders in children with ASD is extremely complex and involves many factors, including sleep structure disorders, sleep regulation disorders, and co-morbidities[6]. The mechanism of sleep disorders in children with ASD has not been fully understood yet. At present, the mechanism of exercise intervention to improve sleep disorders in children with ASD is not yet completely clear, but summarizing the existing reports, it mainly includes the following aspects.

2.1 Promote melatonin release and maintain circadian rhythm balance

Melatonin synthesis dysfunction is observed in patients with ASD. Post-mortem examinations of the pineal gland, small intestine, and blood samples from ASD patients reveal reduced activity of Aralkylamine N-acetyltransferase (AANAT) and Acetylserotonin O-methyltransferase (ASMT) in the pineal gland, gut, and platelets, which hinders the melatonin synthesis pathway, leading to decreased melatonin production[8]. A reduction in melatonin levels can lead to a lower peak in melatonin secretion, delayed circadian rhythms, and an increased risk of sleep-wake disorders, manifesting as difficulty falling asleep, early waking, and nighttime awakenings[9]. Exercise of appropriate intensity and duration can regulate the secretion of melatonin and thus maintain the balance of sleep-wake cycle[10]. Research shows that moderate aerobic exercise can regulate melatonin secretion, thus maintaining the balance of sleep-wake cycle. Studies have shown that moderate aerobic exercise can improve melatonin deficiency in children with ASD, increase melatonin levels, and gradually maintain normal sleep patterns[11].

2.2 Regulate cytokine balance, Optimize sleep architecture

Children with ASD experience sleep disturbances due to elevated levels of interleukin (IL)-1β and tumor necrosis factor (TNF)-α in both the periphery and the brain[12]. Studies have shown that exercise is an effective non-pharmacological intervention that can alleviate chronic low-grade inflammation in the periphery and brain, promoting increased levels of anti-inflammatory factors such as IL-6, IL-1ra, and IL-10, while suppressing the production of TNF and IL-1[13,14]. Ansari, in a study involving children with ASD, found that after 10 weeks of aquatic exercise, the concentrations of IL-1β and TNF-α decreased, reducing the inflammatory response, improving the inflammatory environment, and enhancing sleep continuity, which led to a significant improvement in the sleep structure of children with ASD-related sleep disorders[15].

2.3 Relieve emotional co-morbidity and improve sleep quality

Emotional and behavioral problems comorbid with ASD can stimulate excessive secretion of cortisol (COR) through abnormal activity of the hypothalamic-pituitary-adrenal axis[16]. Elevated COR levels disrupt the normal stress sensitivity threshold, leading to social withdrawal behaviors in children with ASD, which hinder communication and emotional exchange with others, thereby triggering and exacerbating anxiety[17,18]. Study has shown that anxiety makes it difficult for individuals to transition from an excited state during activities to a calm state necessary for sleep[19]. Physical exercise can enhance the functional connectivity between the amygdala and the orbitofrontal cortex, helping individuals better regulate their emotions[20]. Tanksale et al. found that yoga can alleviate pre-sleep anxiety, shorten sleep latency, and improve sleep quality[21].

3 Exercise intervention for sleep disorders in children with ASD

3.1 Sleep Disorder Assessment Tools

Sleep disorders are a common comorbidity in children with ASD, primarily manifesting as difficulties in sleep initiation and maintenance, abnormal sleep patterns, sleep-related breathing disorders, and sleep-related movement disorders—issues that persist with age[22]. Assessing sleep problems in children with ASD provides a basis for evaluating the effectiveness of interventions. Currently, the main tools for assessing sleep issues in children with ASD include objective measures and subjective tools. To reduce subjective bias in the assessment process, researchers should adopt a combination of both subjective and objective tools when investigating sleep problems in children with ASD.

3.1.1 Subjective Assessment Tools

(1) Sleep Diary: A sleep diary is a tool used to record an individual's sleep patterns and habits. It includes details such as bedtime, sleep onset time, number and duration of night awakenings, time to fall back asleep, wake-up time, total sleep duration, daytime naps, and satisfaction with sleep quality[23]. (2) Insomnia Severity Index (ISI): The ISI, developed by Morin, is a key tool used to assess insomnia over the past two weeks[24]. It consists of 7 items that evaluate difficulties in falling asleep, difficulties maintaining sleep, increased daytime fatigue, and concerns about sleep. Responses are scored on a 5-point Likert scale, ranging from 0 to 4, with higher scores indicating more severe insomnia. Based on the total score, insomnia severity can be categorized as: no clinically significant insomnia (0-7 points), subthreshold insomnia (8-14 points), moderate insomnia (15-21 points), and severe insomnia (22-28 points). The ISI has been translated into multiple languages and is widely used in clinical assessments. (3) Children’s Sleep Habits Questionnaire (CSHQ): The CSHQ, developed by Owens et al., is used to assess sleep behavior problems and sleep disorders in children aged 3 to 12 over the past four weeks[25]. The questionnaire covers eight dimensions: bedtime resistance, sleep onset delay, sleep duration, sleep anxiety, night wakings, parasomnias, sleep-disordered breathing, and daytime sleepiness, with a total of 33 items. A 3-point scale is used for scoring, with higher scores indicating more sleep problems. Due to its ability to comprehensively reflect children's sleep issues, the CSHQ is widely used in research studies. (4) Mini-Sleep Questionnaire: The Mini-Sleep Questionnaire, developed by Zomer et al., assesses aspects of nighttime sleep[26]. It includes two dimensions: daytime sleepiness and sleep quality, with a total of 9 items. This scale uses a 7-point scoring system, where higher scores indicate poorer sleep-wake quality. Sleep quality is categorized as follows: 10–24 points for good sleep-wake quality, 25–27 points for mild

sleep-wake difficulties, 28–30 points for moderate sleep-wake difficulties, and >30 points for severe sleep-wake difficulties.

3.1.2 Objective Assessment Tools

(1) Sleep-EEG Device: The Sleep-EEG device is a precise sleep monitoring instrument specifically designed to track and record brain activity during sleep. By analyzing brainwave patterns, it assesses an individual's sleep stages, cycles, and overall sleep architecture, aiding in the identification of sleep disorders[27]. (2) Accelerometer Device: Actigraphy devices are considered standardized tools for recording sleep parameters. Worn on the patient's limbs, the devices objectively track sleep and wake states by measuring limb movement frequency, providing data on sleep patterns and duration. Compared to the Sleep-EEG device, actigraphy is smaller, portable, easy to wear, and more readily accepted by children with ASD. Additionally, it offers accurate assessments of various sleep disorders[28].

3.2 Current Status of Exercise Interventions

Current treatments for sleep disorders in children with autism primarily include medication, cognitive behavioral therapy, and sleep education [3]. Given the complexity of the pathogenesis of sleep disorders in children with autism and the uniqueness of this population, there is an urgent need to explore more diverse and effective prevention and treatment strategies. According to the Expert Consensus on Exercise Prescription in China, it is recommended that children with disabilities engage in aerobic exercise, resistance training, and bone-strengthening activities at least three times per week, with each session lasting over 60 minutes, and the intensity ranging from moderate to vigorous[29]. The exercise dosage should start low and gradually increase to normal levels. Existing research shows that children and adolescents with ASD tend to have low levels of exercise frequency, intensity, and participation[30]. This low level of physical activity not only hinders the development of physical health in individuals with ASD but also increases the risk of chronic diseases[17,31]. During exercise, children experience a synergistic effect between physiological functions, sleep structure, and the musculoskeletal system, which collectively contributes to overall health[32].

In recent years, scholars have found that exercise training has a positive effect on improving sleep disorders in children with autism. Jackson et al. found that physical exercise can regulate BMI, psychological state, and social communication, offering a bio-psycho-social intervention approach that is effective in preventing and treating sleep disorders in children with ASD[33]. Rosa et al. conducted a training intervention involving judo and ball sports for children with ASD who had sleep disorders[34]. After three months of intervention, there was a reduction in Mini-Sleep Questionnaire scores and an increase in quality of life scores (KIDSCREEN-52 questionnaire). However, existing research on the effective dosage of exercise for treating sleep disorders in children with ASD remains inconsistent, with variations in exercise intensity, duration, and frequency across studies. Future research needs to further explore and determine the optimal dosage of exercise for effectively treating sleep disorders in children with autism. The effectiveness of different types of physical activity in improving sleep disorders in children with autism is discussed in detail below, with relevant information from the literature categorized and summarized in Table 1.

3.3 The effects of different types of exercise on sleep improvement in children with ASD

3.3.1 Aerobic Exercise

Aerobic exercise refers to physical activities powered by aerobic metabolism, which not only promotes cardiovascular health but also supports neural development and brain plasticity. For children with ASD, common aerobic exercises in the prevention and treatment of sleep disorders include basketball, jogging, cycling, and aquatic activities. Basketball and cycling have a strong element of structure, and are often combined with skill training during interventions. Brand et al. found that cycling training helped improve sleep disorders in children with ASD[35]. After three weeks of aerobic exercise, sleep efficiency increased, sleep latency was reduced, and the time spent awake after sleep onset decreased. These findings were confirmed by Tse et al., who designed a basketball intervention program with a coach-to-participant ratio of 1:2 or 1:3[36]. The regimen included 10 minutes of warm-up, 30 minutes of basketball skill training, and 5 minutes of cool-down relaxation. After 12 weeks of intervention, results showed improvements in sleep efficiency, with reduced sleep latency, longer sleep duration, and decreased time spent awake after sleep onset.

Aquatic exercise refers to physical activities performed in water, utilizing buoyancy and resistance for movement and training. In exercise interventions for sleep disorders in children with ASD, in addition to swimming, activities such as water walking, limb movements, and games are often included to enhance both the enjoyment and effectiveness of the program[15,37]. Oriel et al. explored the effects of aquatic exercise on improving sleep in children with ASD using an A-B-A withdrawal design[38]. During the intervention phase, the aquatic program included warm-up exercises, upper and lower limb movements, jumping, jogging, kickboard relays, games, free swimming, and cool-down exercises (conducted twice a week, 60 minutes per session, for four weeks). The results showed improvements in sleep latency, total sleep time, and the number of nighttime awakenings compared to pre-intervention levels.

3.3.2 Mind-Body Exercises

Mind-body exercises combine physical activity with psychological adjustment, integrating bodily movements, breathing, and mental focus. This approach stimulates parasympathetic nerve activity, helping to release emotions, which in turn aids children with ASD in relaxing and falling asleep more easily at night[39]. Based on the nature of the movements, mind-body exercises can be divided into martial arts and yoga. Martial arts emphasize the combination of explosiveness, speed, and strength, including disciplines like judo and karate, while yoga focuses on coordinating breathing with controlled, slow postural transitions. Scholars worldwide have increasingly recognized the impact of mind-body exercises on the psychological and behavioral outcomes of special-needs children. Wei et al. reviewed existing evidence and found that yoga can enhance emotional regulation and awareness in children with ASD, reducing anxiety[40]. AdibSaber et al. conducted karate training for children with ASD aged 8-14, and the results showed that karate improved pre-sleep anxiety, reduced sleep resistance, and alleviated daytime sleepiness[41]. Tanksale et al. designed a yoga program combined with third-wave cognitive behavioral therapy (CBT), which included one 60-minute group yoga session per week for six weeks, at least three 10-minute home yoga sessions per week, and 10 minutes of progressive muscle relaxation audio exercises before bed[21]. The results indicated that the combination of yoga and third-wave CBT led to a reduction in anxiety and sleep problems in children with ASD.

Table 1: The effect of different types of exercise interventions on improving sleep quality in

children with ASD

References	Age (years）	Participants number	Intervention protocol	Intervention effect
Brandet et al.[35] (2015)	7-13	10 Pre-post test design	**Frequency:** 3 days/week. **Duration:** 60 minutes/session **Circle**: 3 weeks **Exercise Programs:** 30 minutes of cycling, 30 minutes of coordination and balance training	Sleep-EEG: Increased sleep efficiency, shorter sleep latency, fewer post-sleep awakenings, increased deep sleep, slow wave sleep; Insomnia Severity Index (ISI) questionnaire: no significant change
Tse et al [36] (2019)	8-12	Intervention group:19 Control group:21	**Frequency:** 2 days/week **Duration:** 45 minutes/session **Circle**: 12 weeks **Exercise Programs:** Basketball	Accelerometer Devices: increased sleep efficiency, fewer post-sleep awakenings Sleep logs: sleep efficiency, sleep latency, sleep duration improvement
Tse et al.[11] (2022)	8-12	Intervention group:23 Control group:32	**Frequency:** 2 days/week **Duration**: 30 minutes/session： **Circle:** 12 weeks **Exercise Programs:** Jogging (5 min warm-up, 20 min running and 5 min cool-down).	Accelerometer Devices: Sleep efficiency increased during the intervention, awakenings after sleep decreased, sleep duration increased, and decreased at the end of the intervention Sleep log: no significant change
Ansari et al.[15] (2021)	6-14	Intervention group:20 Control group:20	**Frequency**：2 days/week **Duration**：60 minutes/session **Circle**：10 weeks **Exercise Programs**：Aquatic exercise (5 min warm-up, 15 min orientation, 20 min basic swimming skills, 15 min free swimming and 5 min cool-down)	CSHQ: Improvement in sleep resistance, sleep duration, nighttime awakenings

Oriel et al.[38] （2014）	6-11	8 A-B-A withdrawal design	**Frequency**：2 days/week **Duration**：60 minutes/session **Circle**：4 weeks **Exercise Programs**：Aquatic exercise (warm-up, upper and lower body exercises, jumping, jogging, kickboard relay, games, free swimming, cool down)	CSHQ: Shortened sleep latency, increased sleep duration
Lawson and Little[42] (2017)	5-12	10 Pre-post test design	**Frequency**：1 days/week **Duration**：30 minutes/session **Circle**：8 weeks **Exercise Programs**：Swimming	CSHQ: 4 children with ASD had improved sleep quality, 1 had no change, and 5 had exacerbated sleep disturbances
AdibSaber et al.[41] (2021)	8-14	Intervention group:10 Control group:10	**Frequency**：5 days/week **Duration**：60 minutes/session **Circle**：10 weeks **Exercise Programs**：Karate	CSHQ: Decreased bedtime resistance, sleep anxiety, number of nighttime awakenings, abnormal sleep-related behaviors, daytime sleepiness; increased sleep duration
Garcia et al. [43] (2024)	Average 13.17	18 Pre-post test design	**Frequency**：1 days/week **Duration**：45 minutes/session **Circle**：14 weeks **Exercise Programs**：Judo	Accelerometer Devices: Increased sleep efficiency, reduced sleep latency, post-sleep awakening time

Chittaluru et al.[44] (2023)	8-17	20 Pre-post test design	**Frequency**：1 days/week **Duration**：45 minutes/session **Circle**：16 weeks **Exercise Programs**：Judo (5min warm-up, 5min fall/landing exercises, 5min balance training, 15min judo techniques, 10 sets of partner practice techniques, 5min deep breathing, stretching)	Accelerometer Devices: Increased sleep efficiency, reduced sleep latency, post-sleep awakening time
Tanksale et al.[21] (2020)	8-17	Intervention group:31 Control group:30	**Frequency**：1 days/week **Duration**：60 minutes/session **Circle**：6 weeks **Exercise Programs**：Team training yoga combined with third wave cognitive behavioral therapy. Home training at least 3 times a week, each 10 minutes of yoga practice, and 10 minutes of bedtime progressive muscle relaxation audio	CSHQ：Improvement in sleep resistance, delayed sleep onset, and sleep anxiety
Narasingharao et al.[45] (2017)	5-16	64 Pre-post test design	**Frequency**：5 days/week **Duration**：75 minutes/session **Circle**：12 weeks **Exercise Programs**：Yoga	15-Question Sleep Questionnaire (SQ1-SQ15) : Improved sleep duration, quality, habits
Rosa et al. [34] (2021)	6-15	Judo group:29 Baal group:36	**Frequency**：2 days/week **Duration**：60 minutes/session **Circle**：12 weeks **Exercise Programs**：Judo (warm-up, stretching, impact, fall cushioning, immobilization techniques, throwing, confrontation simulation and relaxation)	Mini-Sleep Questionnaire：Sleep quality improvement

	Ball sports: soccer, volleyball, basketball and handball (warm-up, stretching, basic motor skill exercises, ball sport specific exercises, games, relaxation)

4 Conclusion

As a non-pharmacological intervention, exercise has shown great potential in improving sleep disorders in children with autism. This study summarized the mechanisms by which exercise interventions improve sleep disorders in children with ASD, as well as the effects of different types of exercise. Exercise can help maintain normal sleep patterns by regulating the balance of cytokine secretion, promoting neurotransmitter release, and improving negative emotional issues and social functioning. Different types of physical activity exhibit distinct characteristics in improving the distribution and duration of various sleep stages in children and adolescents with ASD. Summarizing the previous discussion, exercise has shown positive effects on increasing sleep depth, shortening sleep onset latency, reducing nighttime awakenings, and extending total sleep duration. Additionally, mind-body exercises, which integrate physical activity with psychological regulation, are effective in alleviating pre-sleep anxiety and resistance to sleep. The positive impact of exercise on sleep disorders in children with ASD has become increasingly evident and should receive adequate attention and focus. However, in China, there is still relatively little attention given to exercise interventions for sleep disorders in children with autism. Moreover, existing intervention programs are developed by researchers, leading to variability in the protocols, and the optimal dose of exercise therapy remains unclear. Future research should continue to explore the impact of different exercise modalities and dosages on sleep disorders in children with autism, particularly investigating the effectiveness of home and community-based exercise interventions. Given the individual differences among children with autism, future studies should also consider developing personalized exercise intervention plans to enhance treatment outcomes. Additionally, establishing an interdisciplinary intervention team will facilitate the provision of more comprehensive therapeutic services.

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