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Cognitive Neural Mechanism and Intervention of Attention Deficits in Patients with Down Syndrome

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Abstract: ***Patients with Down's syndrome have attention deficits, which can exacerbate their cognitive disorder and affect their skills development and life quality. Currently, explanations for attention deficits in patients with Down's syndrome focus on neurological developmental deficits, which pose a significant challenge for subsequent improvement in cognitive function. This paper reviews relevant empirical studies, attempts to propose the hypothesis that inhibition disorder is the cognitive mechanism leading to this attention deficit, and introduces mindfulness training based on the explanation of its cognitive neural mechanism to demonstrate the possibility of mindfulness training to improve attention deficit in patients with Down's syndrome. Future studies can continue to explore the cognitive neural mechanism of attention deficit in patients with Down's syndrome, and further examine the effectiveness of mindfulness training to improve the ability of patients with Down's syndrome to suppress distracting information, improve attention deficit, and thus enhance their cognitive level and life happiness.***

Keywords: Down Syndrome, Attention deficit, Attentional inhibition, Mindfulness training.

1. Introduction

Down Syndrome(DS), or 21-trisomy syndrome, is a disorder caused by chromosome 21, in which patients suffer from significant intellectual disability, distinctive facial features, impaired growth and multiple malformations compared to the normal group. Studies have shown that DS patients exhibit severe cognitive dysfunction, with attention deficits being one of the most prominent manifestations, manifested by difficulties in attentional sustained, attentional shifting, and attentional disengagement, [1] and these attention deficits also lead to DS patients a decline in health-related life quality and well-being.

Studies of frontal, parietal and cortical function in DS patients have found that their cortical function differs from the developmental pathways of normal person, [2] and during childhood and adulthood, there is a reduction in overall brain gray and white matter, with a smaller cerebellum, frontal and temporal lobes, a reduction in sulcus depth and a narrowing of the superior temporal gyrus [3]. Researchers believe that cognitive and neurological disorders may be due to DS patients have developmental deficits in brain regions that is underdeveloped connections between the hippocampus and prefrontal cortex [4]. The neural networks associated with attention typically involve the frontal and parietal regions of the brain [5], and thus, this may partially account for the attention deficits in DS patients.

Previous research on attention deficits in DS patients have mainly focused on the underdevelopment of brain regions, a perspective that poses a greater challenge for subsequent behavioral interventions. This paper attempts to propose a cognitive perspective of inhibitory function deficits in DS patients may be due to a lack of inhibitory function during the attention process, which begins with the inhibition-activation theoretical model of attention and is based on the activation and inhibition of selective attention as well as information processing theory. The attention deficits in DS patients may exacerbate cognitive dysfunction and could also lead to prolonged response times and decreased life quality. To improve the survival skills and life quality of DS patients, it is essential to train their inhibitory abilities to enhance their cognitive functions. Therefore, this paper introduces mindful training as an intervention based on inhibitory deficits and explores its potential as a method to improve attention function and improve inhibitory abilities in DS patients, as well as further enhancing their sustained attention, attention disengagement, and attention shifting abilities.

2. Attention Deficits in DS Patients

2.1 Sustained Attention Deficits

Sustained attention refers to the ability to maintain focus or vigilance on events over time, which enables individuals to prepare to receive information for processing and to maintain attention within the time frame required to complete tasks. Sustained attention deficits may be associated with atypical development, and studies have found that the majority of DS patients suffer from attention problems such as inattention and distractibility. [6] and colleagues found that, compared to children with typical development (TD), DS children exhibit significantly shorter sustained attention duration and fewer sustained attention cycles. 6 DS children aged 3-6 perform poorly in visual sustained attention [7]. Yanxia Wang [8] found that DS children have a lower correct response rate and slower reaction speed in sustained attention tasks [8]. Brodeur [9] and colleagues used a spatially focused sustained attention task to investigate the ability of DS children and adolescents to maintain attention while identifying targets among distractors. They found that when the target was hidden among distractors in a single spatial array, the performance were similar to that of TD children matched for mental age. However, when the task became more complex and relied on other cognitive mechanisms such as working memory and executive functions, their performance was worse than that of the TD children [9]. Over time, it was also found that the

overall sustained attention their performance was lower than that of TD children. But in the latter half of the task, compared with other developmental disability controls (e.g., Williams syndrome), there was no continuous decline in attention tasks accuracy. Researchers using the Elevator Task found that the sustained attention performance of DS adults was lower than that of the mental age-matched (MA) group when the task involved additional working memory [10]. Therefore, researchers believe that DS patients may exhibit poorer sustained attention performance when it comes to complex cognitive tasks involving working memory or executive functions. Research also has found that individuals with frontal and parietal lobe functional impairments or dysfunction may have sustained attention abnormalities, [11] and since DS patients have underdeveloped frontal and parietal lobe functions, they may exhibit sustained attention deficits. Additionally, some researchers believe that sustained attention deficits may be due to a lack of attention control abilities.

2.2 Attention Deficit Disorder

Attention disengagement refers to the process of shifting attention away from a continuously focused stimulus to other stimuli. D'Souza [1] and colleagues used Eye Movement Technology and the gap-overlap paradigm to study the visual orientation of children with neurodevelopmental disorder. They found that DS children were slower in disengaging their visual attention from objects they were engaged with, indicating a deficit in attention disengagement [1]. Pejovic and others research on 5-7 month-old DS infants found that compared to TD groups, DS infants were slower in directing their visual attention to stimuli, suggesting that they require more time to begin focusing on salient visual cues in their environment [12]. This is consistent with previous research findings on attention disengagement impairment in DS infants and children [1]. Additionally, researchers found that DS children take longer to establish eye contact with others compared to the TD group, which affects their ability to shift their gaze to objects that others in the environment are looking at [13]. Further studies using visual inhibition, search tasks, the Cognitive Proficiency Index for attention, and joint feature search tasks found that DS children spend more time in experiments, make more errors, correctly identify fewer targets, and exhibit lower visual search efficiency compared to TD children and other developmental disorder children. Cornish and colleagues, using a map search task, found that DS adults detected fewer correct targets in the task than the control group, indicating a lower ability to correctly identify targets. Therefore, these studies collectively suggest that DS children are unable to inhibit distracting information during tasks and to disengage their attention from such distractions. Attention disengagement is related to the parietal cortex, [14] and Posner and Petersen [15] also found that the superior colliculus and the pulvinar in the thalamus play a role in controlling the allocation of attention [15]. The superior colliculus helps to shift spatial attention to a new location, [16] which is instrumental in moving attention away from a specific location or stimulus to a new stimulus, while the occipital lobe is important for attracting new attentional foci [14].

2.3 Attention Shifting Deficits

Attention shifting refers to the ability to switch or transition attention between different tasks, rules, or criteria as needed. Any irregularity in attention shifting may limit how people interact with their environment, thereby learning from it, and have detrimental effects. Irregularities in attention shifting have been observed in children with neurodevelopmental disorders. Studies have shown that DS children perform worse in attention shifting tasks compared to their peers of the same mental age. 8 Researchers have found that compared to the TD group matched for mental age, DS adolescents also perform poorly in switching tasks [17]. Furthermore, Tungate and Conners conducted a meta-analysis of 57 studies and found that DS patients had poorer attention shifting ability compared to the control group in studies using the card sorting task [18]. DS children exhibit abnormalities in the development of the frontal and parietal lobes, [8] with the prefrontal cortex being involved in the higher-level regulation of attention shifting [19]. Consequently, Yanxia Wang [8] posits that children with DS children who have damage to the right prefrontal cortex will display transfer attention disorders, thus showing difficulties in attention shifting.

In summary, previous studies have examined various attention deficits in DS patients, and while some researchers have analyzed the causes from the perspective of brain regional developmental deficits, [4] there has been a lack of explanation regarding the cognitive mechanisms underlying these functional impairments. This deficiency hinders the development of appropriate behavioral interventions for attentional dysfunction in DS patients, increasing the difficulty of improving cognitive functions in these patients. Therefore, this paper attempts to approach the explanation of attention deficits in DS patients from the perspective of inhibitory function, proposing a attention deficits hypothesis based on deficits in inhibitory function.

3. Cognitive and Neural Mechanisms of Attention Deficits in Down Syndrome Patients

3.1 Cognitive Mechanisms Underlying Attention Deficits in Down Syndrome Patients

Attentional bias refers to an individual's selective attention towards specific stimuli, allocating attentional resources differently to the chosen stimuli compared to others. Researchers have proposed that attention facilitation, attention disengagement, and attention avoidance are three sub-components of attentional bias. Ouimet [20] proposed the Multi-process Model of Attention, which suggests that attentional bias exists in various processes such as the orientation, interpretation, involvement, disengagement, and avoidance of attention [20]. Selective attention is a neural mechanism that processes information presented simultaneously in different ways, helping people identify what they are searching for and ignore irrelevant content, selectively processing and handling targets or information. Selective attention reduces the time required to detect target information by increasing selectivity for targets and inhibiting responses to distracting information. Tipper and colleagues [21] believe that there is an inhibitory mechanism in the process of selective attention; the activation-inhibition model of attention suggests that selective attention is characterized

by the activation of relevant information and the inhibition of irrelevant information, with inhibition being an important mechanism of selective attention [21]. Additionally, research has found that inhibition occurs early in the cognitive process, determining whether information can enter the cognitive processing stream [22]. Researcher believes that attentional bias is also manifested in the activation and inhibition processes of selective attention.

Research has also found that DS patients exhibit attentional bias, showing persistence towards previous targets in experimental tasks, [23] and due to impaired inhibitory mechanisms, they are more susceptible to interference from other distractors. The attention-activation model posits that inhibition is an important component of selective attention, which is the process of filtering out irrelevant information and searching for target information, including inhibiting the filtering of unimportant or irrelevant stimuli, allowing individuals to focus more on the present and to scan and select relevant stimuli in the environment. Early studies using the classic color-word Stroop tasks, stop signal tasks, and Go/No Go tasks found that DS children have deficits in the inhibition of stimulus interference, cognitive interference, and intentional actions compared to children of the same mental age [24]. Inhibition plays a crucial role in the attention process. In selective attention processes, it is necessary to inhibit distracting stimuli and allocate limited attention resources more effectively to target stimuli; in sustained attention processes, it is necessary to inhibit irrelevant stimuli and establish habituation responses to maintain alertness to new stimuli; and in shifting attention processes, it is necessary to switch from a successful response, inhibit habituated responses, and establish new rules [8]. [8] believes that DS children have selective impairments in attentional functions, and their performance in selective attention tasks with added distractors is worse than control group; Shalev and colleagues also believe that previous assessments of attention in DS patients may rely on the ability to use selective attention to identify relevant targets among competing distractors in a short period, without directly affecting sustained attention [25]. DS individual performed worse than TD groups in proactive interference (PI) tasks and directed forgetting tasks, recalling more off-target words and “distracting” words that should have been forgotten or inhibit. This indicates that DS individuals have difficulties in inhibiting information that is irrelevant or no longer relevant to the task goals [26]. Researchers used the Navon task to test the inhibitory abilities of DS adults, and found that they had more difficulty in processing inconsistent information and inhibiting interference compared to TD children matched for mental age (MA=6.8 years) [27].

In summary, DS patients of different ages exhibit certain difficulties in inhibition. A study by Joioa-Acosta DS adults found that inhibitory ability is related to attention and is a key factor in other cognitive functions, including attention [28]. Summarizing the above viewpoints, this paper posits that DS patients have deficits in attention functions, with poor sustained attention, attention disengagement, and shifting attention capabilities. They tend to maintain focus on distracting stimuli, fail to maintain attention on target information, and disengage from distracting stimuli and shift their attention from the current target to a new target stimulus. According to the Inhibition-Activation Model and the Attention Multiple Process Model, inhibition is a continuous process that runs through the stages of orientation, interpretation, engagement, disengagement, and avoidance. Therefore, this paper posits that due to impaired inhibitory functions in DS patients, they are unable to effectively inhibit the depletion of attention resources by distracting stimuli. When attention resources are allocated more to these distractions, there are insufficient resources to focus on the current stimulus, that is, they cannot maintain sustained attention on the current information center effectively. As a result, they exhibit a lack of sustained attention ability, leading to impairment. At the same time, the impaired inhibitory ability in DS patients also leads to deficits in disengagement and shifting. That is, when they need to disengage their attention from distracting stimuli and shift from the current stimulus to a new target stimulus, they may be unable to inhibit attention to the distracting information or the current information, resulting in difficulties with attention disengagement and shift disorders. Based on this, this paper attempts to propose the inhibitory deficit hypothesis of DS, which suggests that the sustained attention deficits, shifting attention deficits, and attention deficit disorder exhibited by DS patients are due to deficits in inhibitory functions.

3.2 The Neural Mechanisms Underlying Attention Deficits in Down Syndrome Patients

fMRI studies have revealed that DS patients exhibit atypical activation in brain regions compared to age-matched controls, and there are abnormalities in fMRI connectivity, is a general increase in synchrony between distributed brain networks, with deficiencies observed in both negative and long-range positive connectivity, which may indicate a failure in the integration of temporal lobe structures with distributed brain networks [29]. In addition, Pujol and colleagues 30 observed that, in addition to reduced within-network connectivity of the dorsal attention network, there is also abnormal practice between the anterior temporal lobe and the anterior cingulate cortex, which may lead to a decline in adaptive function test scores [30]. In a near-infrared spectroscopy study conducted on DS infants, lower average connectivity between channels was observed [31]. Anderson and colleagues [29] found that the responses of DS adolescents and adults to violent images, there was a significant reduction in the activation of the dorsal attention network, with the brain’s response to antagonists showing the greatest decrease in the dorsal attention network and the left medial temporal lobe. Additionally, activation within the dorsal attention network exhibited lower self-correlation, which may be consistent with a shortened duration of attention or an inability to maintain attention activation for extended periods [29]. They suggested that the failure to activate the distributed brain attention network may be due to fundamental impairments in visual cortical perception and DS patients may experience more severe brain dysfunction, and core perceptual abnormalities could complicate the more complex attentional and cognitive processes that rely on perception. Inattention may be a direct result of perceptual activation, as the activation of the attention network requires communication from different sites throughout the brain. The lack of synchronization in these regions may lead to an inability to maintain activation related to conscious perception [29]. ERP studies have also found that

longer latency of the mismatch negativity (MMN) in DS adults is associated with poorer attention [32].

Researchers believe that the attention network includes the visual cortex, parietal cortex, and frontal cortex as well as subcortical structures such as the superior colliculus and the pulvinar nucleus of the thalamus. DS patients exhibit underdeveloped frontal lobe functions, with a reduction in frontal lobe volume [2] and underdeveloped callosal neural projection regions that connect the frontal lobe to the brain [33]. Therefore, structural issues affecting frontal lobe connectivity, such as demyelination, may lead to impairments in attention functions, resulting in attention deficits. [32] inhibition involves selectively engaging and focusing on the task at hand while inhibiting attention to other stimuli. Research indicates that DS patients experience inhibitory deficits from childhood through adulthood. The frontal cortex is associated with attention inhibition, [34] and the frontal cortex exerts stronger inhibition on responses to distractors and inactivation of the frontal cortex is related to an increase in distractibility [35]. The interaction between the frontal eye field (FEF) and the lateral intraparietal area (LIP) within the parietal lobe, as well as the FEF is related to the inhibition of attention shifting [36]. The frontal and parietal cortices play a significant role in maintaining and controlling attention, modulating sensory processing in the visual cortex [5], and the effects of attention are greater in the frontal and parietal cortices than in the visual cortex [37]. Therefore, the insufficiency of frontal lobe function in DS patients may lead to deficits in inhibitory functions. Alternatively, the underdevelopment of frontal lobe function may result in an inadequate allocation of attention resources, thus insufficient control over the attention system, enhancing the activity of the stimulus-driven system, and reducing the activity of the goal-oriented system. The stimulus-driven system is associated with the ventral frontoparietal network, while the goal-oriented system is related to the dorsal frontoparietal network [38]. The imbalance between the two systems causes individuals to allocate more attention resources to distracting stimuli, making it difficult to inhibit attention to these distractions. This leads to difficulty in focusing attention on target information, disengaging attention from distracting stimuli, and shifting attention to other target information. Thus, future research can continue to explore the specific mechanisms of attention deficits in DS patients by combining brain regions related to attention, such as the frontal and parietal cortices.

4. Interventions Based on Impaired Inhibitory Functions in Individuals with Down Syndrome

4.1 Impairment of Attentional Functions in Individuals with Down Syndrome

Attention is a core cognitive process in most higher-order cognitive tasks, and selective attention is a necessary life skill and a prerequisite for learning. Therefore, attention deficits in DS children and adolescents may affect the development of their cognitive functions, leading to cognitive dysfunction, and may limit activities and participation during adolescence and adulthood, negatively affecting health-related quality of life and well-being. Studies have shown correlations between cognitive functions, motor skills, HRQOL, and social participation in DS patients. Consequently, cognitive deficits in patients may impact their daily living skills, communication, socialization, family environment, and parent-child interactions, among others [39]. Research has found that DS patients are more prone to developing Alzheimer's Disease (AD) as they age due to their cognitive deficits, [40] and changes in executive functions have been recognized as one of the earliest symptoms of AD in DS patients.

Researchers have found that the ability to disengage and shift attention is beneficial for the development of joint attention in DS children, while difficulties in disengaging and shifting attention may have a detrimental impact on the coordination of visual attention with objects, which in turn may reduce moments of joint attention and impair language acquisition [1]. Joint attention is a dynamic skill that involves coordinating attention between others and objects, supporting language and social development, meaning that the attention between children and caregivers is focused or shared on the same object or event. Hahn and colleagues [41] meta-analysis on joint attention in DS children indicates that compared to TD children, DS children exhibit similar abilities in joint attention and demonstrate better joint attention compared to children with developmental disabilities (DD) and autism spectrum disorder (ASD). This suggests that joint attention is not a weakness in DS children; rather, it may be on par with their developmental level and could be a relative strength compared to other skills associated with the DS behavioral phenotype. Hahn and colleagues [41] suggest that the social referencing difficulties exhibited by DS patients may stem from early difficulties in attention shifting, or it may be a combination of attention shifting difficulties and preferences for social stimuli, making it challenging for some DS children to disengage their attention from preferred stimuli to engage in moments of joint attention [41]. Consequently, impaired attention disengagement and shifting abilities in DS children and adolescents may also affect the development of joint attention.

Joint attention may have cascading effects on social skills, particularly social referencing, and delays or difficulties in joint attention may prevent DS children from correctly interpreting the desires, needs, and intentions of their social partners [42]. Joint attention also impacts language development [41], [42]. DS infants have a lack of attention to objects and limitations in producing social gestures, which makes it difficult for them to establish joint attention with caregivers. Due to the more limited cognitive abilities of DS infants, shifting their attention may have some negative effects, and redirecting attention may also overload their cognitive capacities. As a result, DS infants lack the remaining resources to focus on the caregiver's guidance, failing to map words onto referents, affecting vocabulary acquisition. It is evident that if joint attention is frequently disrupted in dyads composed of DS infants and their caregivers, then these DS infants may have fewer experiences of joint attention compared to TD infants. Consequently, their exposure to communicative environments that can promote vocabulary and language development would be reduced.

Teaching behaviors refer to the guidance or explanations

provided by parents to their children on how to complete tasks or solve problems. DS children impaired inhibitory function is negatively correlated with parental teaching behaviors in parent-child interactions, that is, the better the inhibitory ability, the more teaching behaviors their parents will use.

In summary, DS individuals have deficits in attention functions, leading to negative cognitive outcomes; therefore, it is necessary to implement interventions targeting the inhibitory functions of DS individuals, adopt appropriate training measures to improve their attention functions, thereby enhancing their cognitive abilities and improving their life quality.

4.2 Interventions for Inhibitory Function Impairment in Individuals with Down Syndrome

Current training methods for DS patients and other intellectual disabilities primarily consist of two forms: computerized training and non-computerized training. Computerized training includes executive function training, shape-based adaptive Navon tasks, and digital assistive technologies. Researchers have found that executive function training can enhance the functional connectivity between the bilateral frontal and parietal cortices [43]. Salminen and colleagues [44] used a dual N-back task for training subjects and discovered that it can enhance the white matter pathways between different brain regions, improving the connectivity of various brain areas [44]. Digital assistive tasks can improve the life quality for DS individuals through supportive communication. However, researchers have found that digital assistive technologies may negatively impact DS individuals' life quality due to a lack of funding and technical support [45]. Additionally, computerized training tasks can be quite complex, requiring patients to have better cognitive abilities, which may not be user-friendly for DS individuals [45]. Non-computerized exercises mainly include aerobic physical activities, cognitive engagement training, and art activity courses. Researchers have found that some physical activities can improve the integrity of brain white matter, increase the volume of the hippocampus, enhance brain activation, and the connectivity of brain networks [46]. Zuk and colleagues [47] found that music training can significantly increase the activation of the right dorsolateral prefrontal cortex [47]. However, the average effect size of these exercise forms is small and not significant. Some researchers have proposed that training could adopt painting, [48] but due to the involvement of a lot of manual work, such as cutting and pasting, it may have certain cognitive requirements for DS children. Younger children or those with poorer cognitive abilities may struggle to understand the meaning, thus failing to achieve the intervention effect. Given that DS patients may have developmental abnormalities in the heart and lungs, and some sports activities, such as 12 weeks of vertical jumping and push-up training, may not be conducive to the health of DS individuals due to the high intensity and long duration [49]. Through review, it has been found that DS patients have deficits in attention functions, including difficulties in sustained attention, shifting attention, and disengaging attention. This paper suggests that these attention deficits may be due to insufficient inhibitory abilities towards distracting stimuli. Mindfulness training, as a way to improve attention, focuses on training an individual's inhibitory abilities by suppressing distracting stimuli and repeatedly reorienting attention to a focal area, learning to cultivate an open, accepting form of attention that is not hindered by thoughts, emotions, or physical sensations. Mindfulness training has been shown to effectively improve inhibitory abilities and thus attention functions in TD individuals, and researchers believe it may also be an effective measure to improve executive functions and behavioral performance in individuals with intellectual disabilities. As a typical subtype of intellectual disability, mindfulness training may also be effective for cognitive functions in DS patients.

Mindfulness training is a psychological intervention where individuals focus their attention on the present experience. Mindfulness exercises for individuals with intellectual disabilities, include both direct and indirect training methods, as well as individual and group training. Direct training refers to providing optimal training programs for the maladaptive behaviors of the patients themselves; indirect training involves training the parents or other caregivers of individuals with intellectual disabilities, with the aim of changing behaviors through altered interaction dynamics. Individual training often employs practices such as the Sole of the Foot Meditation (SoF) and Mindfulness-Based Cognitive Therapy (MBCT), while group training typically uses Mindfulness-Based Stress Reduction (MBSR) methods. However, whether it is individual or group training, they usually include a simple exercise known as breath work, also referred to as breath meditation. In the meta-analysis of mindfulness interventions for individuals with developmental disabilities conducted by Hwang and Kearney [50], it was noted that the SoF meditation is a commonly used intervention plan, this training requires individuals to breathe naturally and, when distracted by emotions or thoughts, to shift their attention to a neutral part of the body to suppress the interference, thereby enhancing the individual's ability to inhibit distracting information. The researchers also believe that individuals with developmental disabilities can not only learn mindfulness but also use mindfulness training to escape behavioral and psychological distress, improving their life quality [50]. This indicates that mindfulness training has a positive impact on individuals with developmental disabilities. In addition, researchers have found that mindfulness training can improve attention and executive control, reduce dysfunctional tension, and free up resources for improving cognitive performance [51]. Furthermore, a amount of research has found that improved attention can enhance an individual's cognitive abilities.

The mechanisms by which mindfulness can influence children's cognitive functions may involve both top-down and bottom-up processes. Researchers have found that mindfulness training can enhance activity and functional connectivity in the prefrontal cortex, increase resting-state functional connectivity between the default mode network and the stress-regulation areas of the dorsolateral prefrontal cortex, and also reduce stress-related resting-state functional connectivity between the amygdala and the subgenual anterior cingulate cortex [52]. Mindfulness training may be more effective in cultivating executive functions in children with intellectual or neurodevelopmental disabilities, as well as those with behavioral issues and atypical development [53]. Executive functions refer to higher-order neurocognitive

processes involved in goal-directed behavior and are a set of cognitive functions that includes working memory, attentional flexibility, and inhibitory control. Studies have employed technology-supported mindfulness strategies, such as using a wearable EEG device known as MUSE, through measurements with the Attention Concentration Scale and the Children's Feeling Scale (CFS), it was found that after the intervention, children with intellectual and developmental disabilities experienced increased levels of state mindfulness, attention control, and acceptance, while state stress levels decreased [54]. Additionally, research has found that adolescents with Intellectual and Developmental Disabilities can also learn and use mindfulness strategies to improve their social behavior, reporting feeling more relaxed after each training [55]. Research on the use of mindfulness strategies for ID individuals have found that mindfulness practices can permeate various aspects of an individual's life. Regardless of the level of understanding or expectations regarding the basic mechanisms and purposes of mindfulness, individuals can benefit from the practice [56].

In summary, due to the underdevelopment of frontal lobe functions in DS patients, and the association of the frontal cortex with inhibitory control abilities, there may be deficits in inhibitory capabilities, which could even impact the development of cognitive functions and lead to attention dysfunction. That is, DS patients exhibit sustained attention deficits, difficulty with attention shifting and disengagement. These issues can further exacerbate cognitive dysfunction, creating a vicious cycle. Compared to typical individuals, DS individuals have poorer inhibitory abilities. Therefore, mindfulness training can provide an effective method to improve inhibitory function and attention deficits in DS individuals. Breathing exercises within mindfulness training may enhance the inhibitory abilities, by this could also enhance sustained attention, attention disengagement, and shifting abilities, thereby improving the cognitive functions. This improvement may lead to an increase in their life quality and self-care abilities, and alleviate the stress on parents or other caregivers.

5. Future

This paper reviews relevant research concludes that DS patients have attention deficits, such as insufficient sustained attention to target stimuli [8], difficulty disengaging attention from distracting stimuli, [26] and difficulty shifting attention to new target stimuli [18]. It also discusses the cognitive and neural mechanisms that may lead to attention deficits in DS patients, namely, the underdevelopment of the frontal and parietal lobes [8], which are closely related to attention functions, [57] especially inhibitory control abilities [57]. Therefore, based on the neural mechanisms, this paper proposes the cognitive mechanism of attention deficits in DS patients, namely, the hypothesis of attention inhibition impairment. The paper posits that the attention deficits exhibited by DS individuals are due to their insufficient inhibitory attention capabilities. In other words, because they have inadequate attention inhibition, they are unable to effectively inhibit the interference of distracting stimuli on target information. As a result, limited attention resources may be disproportionately focused on the distracting stimuli, making it difficult to disengage attention from them, leading to a decline in sustained attention to target stimuli and difficulty in disengaging attention from distracting stimuli. Furthermore, due to impaired attention inhibition, DS individuals are also unable to inhibit their focus on current stimuli when shifting attention, making it difficult to redirect their focus to new target stimuli, resulting in a deficiency in their ability to shift attention. Building on previous research interventions for DS individuals, this paper argues for the possibility of mindfulness training as an attention training to improve the attention inhibitory function in DS patients, based on the attention inhibition deficit hypothesis. It suggests that once the attention inhibitory ability is enhanced, sustained attention, attention disengagement, and shifting attention capabilities may be further improved, thereby effectively ameliorating the attention deficits. Therefore, future research can be conducted in the following areas:

Firstly, future research can continue to explore the cognitive and neural mechanisms underlying attention deficits in DS individuals and verify the validity of the attention inhibition hypothesis. Diamond suggests that inhibition includes the ability to inhibit at the level of attention, [58] and [20] proposes a multi-processing model of attention that posits attentional biases exist in every process of attention [20]. Research has also found that individuals with poorer attention control find it more difficult to disengage their attention from threatening information, [59] and attention control theory also posits that a weakened ability to inhibit attention could lead to difficulty in inhibiting attention to threatening information [60]. This paper proposes the view of attention inhibition deficits, suggesting that the impaired sustained attention to target stimuli and insufficient attention shifting to new target stimuli in DS individuals may be due to insufficient inhibitory functions at the level of attention. That is, due to inhibition deficits, DS individuals cannot inhibit distracting stimuli, which makes it difficult for them to disengage their attention from distractions and also to focus on what needs to be attended to, manifesting as impaired sustained attention to target stimuli and impaired attention disengagement; at the same time, due to inhibition impairments, DS individuals cannot overcome attention to current stimuli, and thus failing to shift their attention to new target information, resulting in deficits in shifting attention, and an inability to direct attention towards target stimuli.

Second, future research can also focus on mindfulness training for DS patients who exhibit attentional inhibition deficits. Mindfulness training has been shown to enhance attention functions and has a positive impact on individuals with intellectual and developmental disabilities as well as those with autism [50], [56]. Given the attention deficits present in DS patients, future studies could employ mindfulness training to intervene in attention inhibitory abilities, helping them to disengage from distracting stimuli and ultimately improve their sustained attention, attention disengagement, and shifting attention capabilities. Additionally, DS patients commonly have intellectual deficits and limited cognitive abilities, simpler mindfulness training can be implemented, such as mindful coloring, breathing exercises, and mindful stretching, to enhance their attention control. Mindful coloring is a brief artistic form of mindfulness, such as structured mandala coloring and free coloring, where individuals focus on coloring within detailed

shapes, allowing them to experience focused awareness of the present moment while developing a state of mindfulness. These activities contain elements of mindfulness and are both simple and enjoyable. Therefore, future research can explore the impact of different mindfulness training methods on the attentional functions of DS individuals and further examine the changes in their self-care abilities and learning capabilities for simple life skills after training, with the aim of improving their life quality.

Future studies can utilize electroencephalogram devices, such as event-related potential (ERP) or fMRI, to study attention issues in DS adolescents. In ERP components, the N2 and P3 are often used to measure inhibitory control processes. N2 reflects the attention control process used to focus on task-relevant attention, [61] and a larger N2 is observed under inconsistent conditions in the Flanker task and under No Go conditions in the Go/No-Go (GNG) task, which can be used to measure the allocation of top-down attention control resources in inhibitory control research [62]. Meanwhile, the P3 is smaller under inconsistent conditions in the Flanker task and under No Go conditions in the GNG task [63]. The P3 reflects the monitoring of the outcome of inhibition [64]. Therefore, ERP components such as N2 and P3 or the use of fMRI can be incorporated into the study of attention issues in DS individuals, and the number of participants can be expanded to provide a larger amount of more accurate physiological data to illustrate the issues.

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