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A FEASIBILITY TRIAL OF DIGITAL GAME INTERVENTION IN CHINESE CHILDREN VULNERABLE TO ADHD

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A Feasibility Trial of Digital Game Intervention

in Chinese Children Vulnerable to ADHD

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ABSTRACT

Attention deficit hyperactivity disorder (ADHD) is a neurodevelopmental condition characterized by persistent inattention, hyperactivity and impulsivity. Children with ADHD face challenges in multiple domains including emotion regulation, impulse control, organizational skills, academic achievement, and social interaction. In China, ADHD is often overlooked or underdiagnosed due to limited awareness among parents and educators, stigma associated with mental health problems, or inadequate diagnostic infrastructure, resulting in a significant gap between actual cases and patients receiving appropriate treatment. Traditional treatments such as medications and cognitive behavioral therapy have limitations such as side effects and high cost. In contrast, digital play interventions are an ideal alternative. However, digital interventions still have limitations, such as device accessibility issues, focus on a single ADHD problem, unappealing design, and unclear subclinical treatment effects. To address these limitations, this study developed a digital game, and explored the feasibility of the digital intervention for ADHD through an 8-week randomized controlled trial (RCT). A sample of 100 children aged 6-12 years with ADHD (74%) or subclinical ADHD (26%) was recruited. The study employed a 3 (within-subject, Test: baseline vs. 8-week post-test vs. 16-week post-test) × 2 (between-subject, Group: intervention vs. waitlist group) mixed-model design. The intervention and the waitlist groups received the intervention in the first and the second 8 weeks, respectively, during the study period. The intervention comprised 40 sessions (30 minutes each, 5 sessions per week) grounded in Executive Function Theory. The two groups demonstrated reduced symptoms measured by the Conners Abbreviated Symptom Questionnaire (C-ASQ), the Swanson, Nolan and Pelham scale (SNAP), and the Clinical

Global Impression of Severity scale (CGI-S) after the intervention phase.

Multivariate Analysis of Covariance (MANCOVA) revealed time-by-group interactions: C-ASQ ($F = 69.89$, $\eta^2 = 0.419$, $p < 0.001$), SNAP ($F = 10.54$, $\eta^2 = 0.098$, $p < 0.001$), and CGI-S ($F = 5.67$, $\eta^2 = 0.063$, $p < 0.05$) after controlling for training sessions. Simple effect comparison analysis showed that in the intervention group, significant reduction of ADHD symptoms were observed from the baseline to the 8-week post-test (C-ASQ: 16.54 ± 3.33 to 13.72 ± 3.02, $p < 0.001$; SNAP: 1.48 ± 0.20 to 1.37 ± 0.22, $p < 0.001$; CGI-S: 3.50 ± 1.31 to 3.26 ± 1.21, $p > 0.05$). In addition, symptom levels remained stable from the 8-week post-test to the 16-week post-test (C-ASQ: 13.72 ± 3.02 to 13.58 ± 3.09, $p > 0.05$; SNAP: 1.37 ± 0.22 to 1.33 ± 0.19, $p > 0.05$; CGI-S: 3.26 ± 1.21 to 3.08 ± 1.05, $p > 0.05$), a period during which no additional intervention was administered for the intervention group. In the waitlist group, C-ASQ scores showed minimal natural reduction from baseline to the 8-week post-test (C-ASQ: 16.10 ± 3.84 to 15.22 ± 4.05, $p < 0.05$; SNAP: 1.49 ± 0.23 to 1.44 ± 0.30, $p > 0.05$; CGI-S: 3.56 ± 1.26 to 3.30 ± 1.06, $p > 0.05$), and substantial reductions were observed from the 8-week post-test to the 16-week post-test (C-ASQ: 15.22 ± 4.05 to 9.96 ± 3.20, $p < 0.001$; SNAP: 1.44 ± 0.30 to 1.17 ± 0.20, $p < 0.001$; CGI-S: 3.30 ± 1.06 to 2.20 ± 0.64, $p < 0.001$), a period during which the waitlist group received the intervention.

This study highlights the potential of this digital game as a low-cost, engaging tool for ADHD intervention. These results reveal that the digital intervention can reduce the patient's symptoms and have a beneficial effect on children with clinical and subclinical ADHD. The successful implementation of the game also suggests that digital interventions have the potential to reduce stress in families, healthcare systems, and professional care facilities.

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Chapter 1: Introduction

Attention deficit hyperactivity disorder (ADHD) is defined as a neurodevelopmental disorder characterized by inattention, hyperactivity and impulsivity (American Psychiatric Association, 2022). People with ADHD may have difficulty concentrating and show excessive movement and restlessness. They may also engage in impulsive behavior that disrupts relationships and impairs long-term goals (American Psychiatric Association, 2022). A diagnosis of ADHD requires a combination of various aspects of the patient's presentation: the patient continues to present with classic ADHD symptoms that significantly interfere with functioning or development for at least six months and cause related social, academic, or occupational problems (Koutsoklenis & Honkasilta, 2023). Subclinical ADHD, in which the patient shows some symptoms of ADHD but does not meet the full diagnostic criteria for ADHD, may be more prevalent in the population. Some subclinical forms of ADHD have difficulty obtaining a formal diagnosis and professional support (Boot & Baas, 2017). The global prevalence of ADHD in children and adolescents is high (about 7.2%), which brings a considerable burden to society (Thomas et al., 2015). At the same time, the recognition and diagnosis of ADHD in children are seriously inadequate, resulting in a significant difference between the actual prevalence rate and the proportion of individuals receiving diagnosis and medical services (Wigal et al., 2007). In China, the prevalence of ADHD is 6.26%, which is similar to the global average. It is estimated that about 23 million Chinese children and adolescents are affected by the disorder, indicating that ADHD has a significant impact on a large number of Chinese children and adolescents under the age of 18 years (Wang et al., 2017). And ADHD is often overlooked or under-diagnosed due to limited awareness among parents and educators, stigma associated with mental health problems, or inadequate diagnostic infrastructure, resulting in a significant gap between actual cases and patients receiving appropriate treatment (Wang et al., 2017).

Numerous theories and models have been proposed to elucidate the etiology and mechanisms underlying ADHD. The executive function mode converts ADHD deficits into a leveled, trainable skill set, making it the ideal backbone for game design; its tasks can also be precisely graded and enriched by other theories. To be Specific, Barkley suggests that impaired behavioral inhibition in ADHD affects self-control, leading to difficulties in working memory, self-regulation of affect, internalization of speech, and reconstitution (Barkley, 1997). Brown provides a more detailed framework for executive functional partitioning and specific interventions. Brown identifies six deficits in executive function in ADHD, including activation, focus, effort, emotion, memory, and action (Brown, 2001). Both Barkley and Brown agree that ADHD is strongly linked to executive function and has a far-reaching impact, not just in childhood but also in adolescence and adulthood. They emphasize that different areas of cognition are closely related (Brown, 2013). Improvements in one area can positively influence others (Brown, 2013). Therefore, it is important to take comprehensive approaches to alleviate ADHD symptoms. Intervening in multiple areas simultaneously may lead to more effective results (Chacko et al., 2024).

Traditional ADHD interventions, such as medication, cognitive behavioral therapy or mindfulness therapy, are typically provided by a professional in a hospital or psychiatric facility. These treatments may require a high cost or long wait time (Antai-Otong & Zimmerman, 2016). The growing global demand for telemedicine services and advances in technology are making digital interventions increasingly popular in healthcare. The accessibility and convenience of digital interventions provide location-independent and immediate support, as well as help individuals self-manage diseases (Haleem et al., 2021). Existing studies showed that digital interventions could improve attention levels, enhance working memory, develop motor skills, or promote self-control, ultimately achieving the training goal of children (Oh et al., 2024). Digital intervention sessions typically span one to three months. The frequency occurs one to seven times weekly (Kim et al., 2022; Kollins et al., 2020; Bikic et al., 2017; Benzing & Schmidt, 2019; Sudnawa et al., 2018; Lim et al., 2019; Lee et al., 2015). Although many different types of digital intervention have been developed and experimental studies have been conducted, these digital intervention programs or study designs have some common limitations. First, some interventions involve complex procedures, such as neurofeedback, which are difficult to scale up for large-sample implementation (Sudnawa et al., 2018), and others use expensive technologies like virtual reality, which may hinder widespread adoption (Benzing & Schmidt, 2019). Many trials are also conducted in controlled laboratory settings differing from real-life environments. This may affect participants' natural behavior and performance, limiting the intervention's effectiveness in home settings (Cullen et al., 2018). Second, some digital interventions only address a single ADHD issue, with repetitive, monotonous training content. This may reduce children interest in and adherence to training (Chuang et al., 2010). Third, existing research mainly focuses on children diagnosed with ADHD, with little attention to subclinical ADHD (Kim et al., 2022). Fourth, there is a lack of Chinese localization (Sudnawa et al., 2018; Benzing & Schmidt, 2019). To address these limitations, I designed a digital intervention that is easy to implement and low-cost, reducing the need for complex procedures and expensive technologies. The intervention can also be applied in a wide range of environments, making it suitable for various settings beyond laboratories. Based on the theory proposed by Barkley and Brown, I designed specific and engaging tasks to improve ADHD symptoms and incorporated mechanisms to stimulate children's interest and motivation. This study includes children with both ADHD and subclinical ADHD, allowing us to evaluate the intervention's effectiveness across a broader spectrum of ADHD symptoms and provide therapy for children waiting for professional healthcare. Additionally, Chinese localization and cultural adaptation were carried out to improve the applicability and acceptance of the game in china.

Definition and Symptoms of ADHD

Attention Deficit Hyperactivity Disorder (ADHD) is widely defined as a neurodevelopmental disorder characterized by symptoms of inattention, hyperactivity, and impulsivity that primarily affect children and often continues into adulthood (Frank-Briggs, 2011; Epstein & Loren, 2013). Diagnosis of ADHD is established when individuals exhibit persistent symptoms that significantly impair their functioning or development over a period of at least six months, resulting in notable difficulties in social, academic, or occupational contexts (Koutsoklenis & Honkasilta, 2023). The Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition, Text Revision (DSM-5-TR) recognizes three ADHD presentations: Predominantly Inattentive Presentation; Predominantly Hyperactive-Impulsive Presentation; Combined Presentation. Individuals with Predominantly Inattentive Presentation often have difficulty maintaining their attention continuously and are prone to distraction. They also face many challenges in organizing affairs and time management. Such patients may also have manifestations such as forgetfulness and disordered life (American Psychiatric Association, 2022). Predominantly Hyperactive-Impulsive Presentation is characterized by excessive physical activity, restlessness and difficulty in suppressing impulsive behavior. Patients often find it very difficult to calm down or control their impulses. Combined Presentation has the characteristics of the other two presentations. The use of “presentation” emphasizes that symptoms can vary over time, and clinicians may specify the current manifestation of ADHD based on observed symptoms during assessment. (American Psychiatric Association, 2022).

As a neurodevelopmental disorder, the pathological mechanism of ADHD is related to brain development and function, and may be subject to the interaction of genetic and environmental factors (Cortese, 2012). For example, studies have shown that individuals with ADHD exhibit developmental delays or abnormalities in specific areas of the brain (Cortese, 2012; Arnsten, 2009). They may have a smaller prefrontal cortex—a brain region that is critical for higher cognitive functions such as attention, impulse control, and planning (Arnsten, 2009). Studies have shown that individuals with ADHD may have lower levels of certain neurotransmitters, such as dopamine and norepinephrine. Neurotransmitters are chemicals in the brain that facilitate communication between neurons and affect brain function and development (Madras et al., 2005; Prince, 2008). If one child in a family is diagnosed with ADHD, other siblings are also likely to have the disorder, which reflects the fact that ADHD is linked to genetic factors (Faraone & Larsson, 2019). Environmental factors such as maternal smoking or alcohol consumption during pregnancy are associated with an increased risk of ADHD in children (Han et al., 2015).

Various ADHD symptoms can significantly affect patients' daily functioning and quality of life in different ways (Agarwal et al., 2012). When patients are hyperactive, they show excessive physical movement, fidgeting, difficulty sitting still, and often display impulsive behaviors such as interrupting conversations or blurting out answers (Goulardins et al., 2017). When patients are inattentive, they are easily disturbed by external stimuli or distractions, have difficulty focusing on tasks, often have difficulty organizing tasks and following instructions, resulting in difficulties in completing learning and work tasks, and are often forgetful and lose important items (Brown, 2005). When impulsive, patients act without regard for consequences, make rash decisions, jeopardize relationships and long-term goals, and engage in risk-taking behaviors such as dangerous activities without regard for personal safety (Dekkers et al., 2022).

These symptoms of ADHD may be persistent, affecting patients from childhood into adulthood (Pliszka, 2016). Problems such as difficulty maintaining attention and high levels of restlessness during classroom activities may hinder their academic development, which in turn may affect their future career development (Wilens & Spencer, 2010). Furthermore, adults with ADHD often struggle in personal relationships because they tend to be forgetful or disorganized. They may also have trouble prioritizing work tasks and meeting deadlines regularly. Their impulsivity can lead to impulsive spending and taking risks without thinking through the consequences (Goodman, 2007).

ADHD affects not only the patients but also their families. When ADHD causes academic problems in children, both children and parents feel frustrated. ADHD can disrupt the social life of the whole family, making it difficult for them to form and maintain friendships with others. The effects of ADHD often extend to the parents. For example, parents may face unique challenges in managing their child's behavior. Parents also need to make sure that each child feels valued and supported, otherwise other siblings may become resentful or jealous (Harpin, 2005).

Diagnosed ADHD and Subclinical ADHD

The diagnosis of ADHD is usually made with reference to authoritative definitions and typical symptoms, which are clearly defined in a particular diagnostic tool or system (Sibley et al., 2012). The Diagnostic and Statistical Manual of Mental Disorders (DSM) and the International Classification of Diseases (ICD) are widely used diagnostic manuals worldwide and can effectively guide the clinical diagnosis of ADHD (Sibley et al., 2012; Doernberg & Hollander, 2016). ADHD is confirmed when a person meets the criteria from these diagnostic manuals. For example, the diagnostic criteria outlined in the DSM-V, published by the American Psychiatric Association, state that ADHD produces persistent symptoms that interfere with functioning or development. Symptoms need to be present for at least six months across two or more settings like home, school, or social situations. They must significantly impair social, academic, or occupational functioning and emerge before age 12. Other mental disorders or substance/illness effects can not explain these symptoms (American Psychiatric Association, 2022). Conditions such as anxiety disorders, mood disorders (e.g., depression), and learning disabilities (e.g., dyslexia) can coexist with or resemble ADHD symptoms, illustrating the complexity of the diagnosis (American Psychiatric Association, 2013). The physician's evaluation of ADHD requires a comprehensive consideration of the patient's medical history, symptoms, behavior, and psychological status, as well as possible alternative diagnoses. Timely and formal diagnosis can help patients gain early access to support services and interventions tailored to their specific needs (Sibley et al., 2012).

In the general population, subclinical ADHD symptoms are also widespread. Subclinical ADHD is defined as individuals displaying some ADHD symptoms but not fulfilling all the diagnostic criteria (Rivas-Vazquez et al., 2023). Many children display core ADHD symptoms but do not meet formal diagnostic criteria (Rivas-Vazquez et al., 2023). Subclinical ADHD can cause symptoms similar to ADHD. Though these symptoms don't meet ADHD diagnostic standards, they can still impact academic and work life, relationships, and daily functioning (Norén et al., 2016). Thus, educators, parents, and healthcare professionals should identify and manage subclinical ADHD symptoms early to prevent progression to more severe clinical levels (Balázs & Keresztény, 2014).

Prevalence rate of ADHD

ADHD is a disease that seriously endangers the health of adolescents and brings heavy social burden, which is widespread globally (Faraone et al., 2021). The global prevalence of ADHD in children and adolescents was 8.0%. And the prevalence estimate for boys (10%) was twice as high as that for girls (5%) (Ayano et al., 2023). The prevalence of ADHD can be obtained by counting the number of people with ADHD in a given population at a given time point (Salari et al., 2023). The reported prevalence varies in different regions, which may be related to demographic and cultural differences (Salari et al., 2023; Faraone et al., 2021). For example, in mainland China, Hong Kong, and Taiwan, ADHD prevalence rates are approximately 6.5%, 6.4%, and 4.2% (Cortese et al., 2023). A study in the United States found that the prevalence of ADHD in children aged 2-17 years was about 9.4%. The study also found that the case identification rate in this age group (about 8.4%) was lower than the prevalence of ADHD (Danielson et al., 2018). The rate of ADHD case identification was determined by the diagnosis of the healthcare provider (Danielson et al., 2018). This rate may differ from the actual prevalence of ADHD, as some cases may not be identified or diagnosed (Ginsberg et al., 2014). The reasons for these cases not being diagnosed are varied. Such as when girls have ADHD, they often show symptoms of inattention rather than hyperactivity or impulsivity, which may cause their cases to be overlooked. Older children may also develop compensatory strategies to mask their symptoms over time, making it more difficult for healthcare providers to identify ADHD (Cortese et al., 2023).

ADHD in Chinese Children

The prevalence of ADHD in China is similar to the global average (Wang et al., 2017). Relevant studies show that the proportion of Chinese children and adolescents suffering from ADHD is about 6.26% (Wang et al., 2017). The prevalence rates vary greatly in different Chinese regions. For instance, the prevalence rate among children aged 3 to 6 in Nanjing City was 2.50% (Wang et al., 2002), while that among children aged 5 to 6 in Shenzhen City was as high as 14.40% (Ren et al., 2009). Additionally, Liaoyang City reported a rate of 11.50% among individuals aged 7-16 (Han et al., 2011), Lanzhou City reported a rate of 9.09% among individuals aged 5-13 (Zhang & Lu, 2013), and Guangzhou City reported a rate of 4.83% among individuals aged 3-6 (He et al., 2014). It is estimated that about 23 million children under the age of 18 in China have ADHD, which hinders the growth and development of many Chinese children and adolescents (Wang et al., 2017).

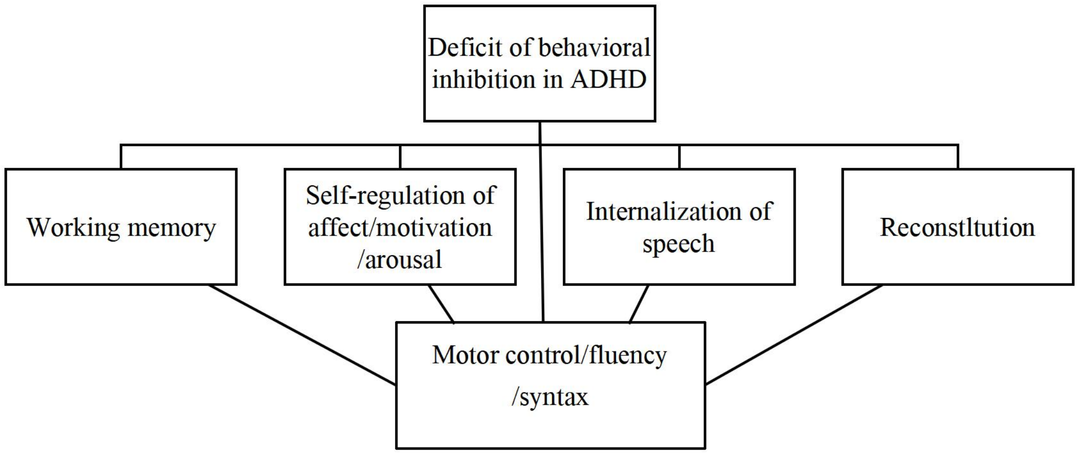
In China, children with ADHD face multiple difficulties in diagnosis, treatment, and social support. Due to insufficient understanding and cultural biases, the diagnosis rate is low, with an average delay for professional evaluation (Wang et al., 2017). Medical resource shortages lead to a long diagnostic waiting period in top-tier hospitals, and the diagnostic accuracy in primary healthcare institutions is low (Wang et al., 2017). Additionally, China has a shortage of child psychiatrists (Jiang et al., 2024). Only some drugs are covered by medical insurance, families bear most of the cost, and the proportion of reimbursement is lower in rural areas (Chang & Kleinman, 2002). In the education system, a few schools have special education resource teachers, and grade retention rates are higher for children with ADHD than for general children (Jiang, 2022). The community support system for ADHD in China is almost non-existent, with only a few registered mutual aid organizations covering a very small population (Li, 2018). These systemic issues are pushing children with ADHD into a vicious cycle of educational marginalization and impaired social functioning.

ADHD Theoretical Frameworks

Numerous theories and models have been proposed by researchers to clarify the mechanisms of ADHD. According to the neurodevelopmental model, delays or abnormalities in specific brain regions such as the prefrontal cortex and cerebellum contribute to ADHD development (Krain & Castellanos, 2006). The environmental model suggested that exposure to adverse environmental factors such as smoking during pregnancy might cause ADHD in children (Mill & Petronis, 2008). Genetic modeling found that people with ADHD relatives were more likely to develop the disorder (Faraone & Larsson, 2019). The executive function (EF) model holds that the core issue of ADHD is impaired executive function, which in turn affects cognitive processes such as planning, organization, and task execution (Barkley, 1997; Brown, 2001).

This study is based on the executive function model proposed by Barkley and Brown as the theoretical basis. The EF mode converts ADHD's core deficits into a leveled, trainable skill set, making it the ideal backbone for game design in our study; its tasks can also be precisely graded and enriched by other theories. To be specific, the response behavioral inhibition theory (self-control deficit theory) proposed by Russell A. Barkley points out that the key problem of ADHD is the lack of behavioral inhibition, which weakens self-control (Barkley, 1997). The theory declares behavioral inhibition as the ability to pause or stop actions, thoughts, and emotional reactions. This ability helps individuals better adapt to the demands of the environment and achieve long-term goals. The theory also links behavioral inhibition to four key executive function components: working memory, emotional self-regulation, verbal internalization, and reconstruction (Barkley, 1999). Working memory functions as a temporary storage system, aiding in information retention, event processing, initiation of complex actions, and behavior organization based on past experiences and future aspirations. Individuals with stronger working memory were better able to focus on task-relevant information even in the presence of distractions (Oberaue, 2002). Effective self-regulation promotes better emotional well-being and goal attainment. Self-regulation of affect/ motivation/arousal is actually learning to control one's own feelings, adjust one's motivation and excitement level, and move forward towards the goal better from one's own perspective (Baumeister & Vohs, 2012). Internalization of speech can guide behavior and enhance cognitive flexibility. It is the process by which people "talk" to themselves in their minds. It helps people describe situations, reflect on problems, follow rules, solve problems, and better understand the logic behind actions (Barkley, 2012). Planning and problem solving are key to achieving goals. People need to make detailed plans to achieve their goals, and be able to adapt their plans and strategies when they encounter problems (Barkley, 2012). Together, the four executive functions affect motor control, fluency, and syntax. Empirical evidence suggests that executive function training improves motor coordination and task performance (Barkley, 2012). The model highlights the critical role of executive functions, such as inhibiting task-irrelevant responses, performing goal-directed actions, maintaining goal-directed persistence, responding to feedback, and refocusing on the task after interruptions (Barkley, 1997, 1999, 2012) (Figure 1). A number of studies have provided empirical support, such as neuroimaging studies (Hart et al., 2021), longitudinal follow-ups (Alamos et al., 2022), and intervention studies (Bikic et al., 2017).

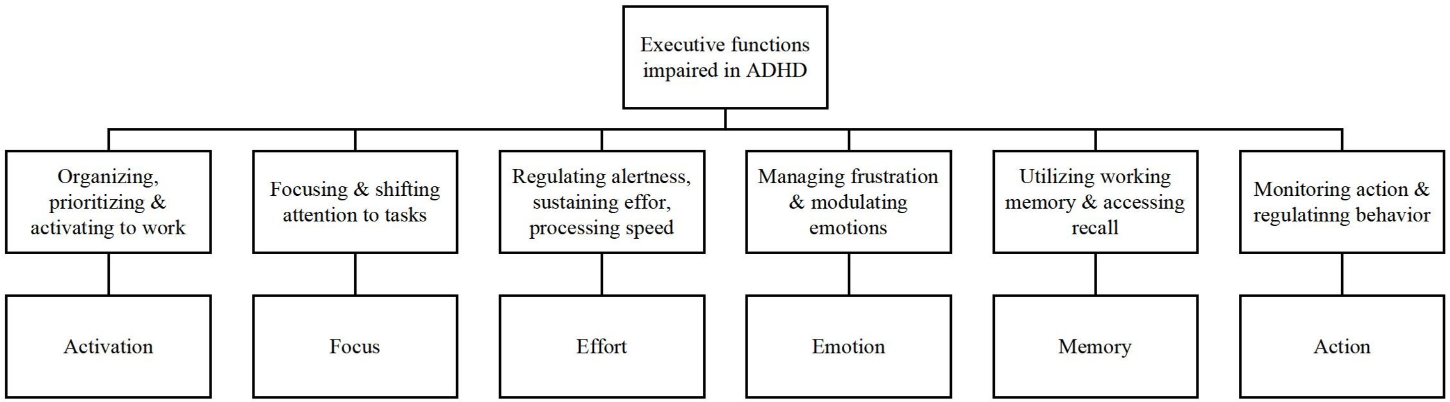
Figure 1. *Barkley's Response Inhibition Model*



-Barkley R. A. (1997). Behavioral inhibition, sustained attention, and executive functions: Constructing a unifying theory of ADHD. *Psychological bulletin*, *121*(1), 65–94.

Thomas E. Brown's understanding of executive dysfunction in ADHD is based on six related deficits that jointly affect behavioral and cognitive abilities. According to Brown's model, ADHD is a complex disorder of self-regulation involving activation, focus, effort, emotion, memory, and action. The model affects multiple domains of life and goes beyond mere attention issues (Brown, 2001). Activation involves patients having difficulty organizing, prioritizing, and activating tasks, resulting in confusion and inefficiency in daily life. These six aspects are interrelated, and changes in one area have a knock-on effect on other areas. Attention involves difficulty focusing and shifting attention, which in turn negatively affects academic performance and tasks that require sustained attention. Effort involves facing challenges in regulating alertness, sustained effort, and speed of processing, thereby impeding productivity and achievement. Emotionally, they have difficulties in frustration management and emotion regulation, and face challenges in social interaction and stress management. They have impaired working memory and recall, easy to forget things, and difficulty remembering information they have learned. They may have insufficient awareness of their actions, difficulty self-monitoring, and poor adaptability (Brown, 2001, 2006, 2013) (Figure 2). Some empirical evidence also supports the Brown model, such as Meta-analyses (Cortese et al., 2015) and Intervention studies (Brown et al., 2011).

Figure 2. *Brown's Executive Function Model*



-Brown, T. E. (2001). *Brown Attention-Deficit Disorder Scales: For Children and Adolescents*. Psychological Corporation.

These key executive function (EF) components exhibit different developmental trajectories. Inhibitory control emerges showing steep gains from 3-5 years, with emotional suppression maturing by mid-adolescence (Davidson et al., 2006). Working memory capacity doubles during the preschool years, followed by slower growth in updating efficiency driven by dorsolateral–parietal theta–gamma coupling until approximately 14 years (Huizinga et al., 2006; Best & Miller, 2010). Cognitive flexibility markedly reduces switch costs between 7 and 9 years and asymptotes near adolescence, yet mixing costs persist under dual-task loads. Metacognitive monitoring and planning develop last, with prospective calibration and multi-step planning reaching adult levels only in the third decade (Roebers & Feurer, 2016). Environmental factors modulate each slope, indicating distinct windows for targeted EF interventions. The two models have laid a theoretical foundation for grasping the essence of ADHD, formulating effective intervention measures and promoting related research. The Barkley's model focuses on the core defect of behavioral inhibition to explain the pathological mechanism of ADHD (Barkley, 1997); The Brown's model proposes a more comprehensive and multi-dimensional executive function framework (Brown, 2001). The two deeply analyzed the executive function deficits of ADHD from different perspectives, and their viewpoints complemented each other: It is acknowledged that there are complex correlations among various fields of executive function, and the improvement in one field may have a positive impact on other fields (Barkley, 1997; Brown, 2001).

Some recent models offer additional perspectives. For example, the Delay Aversion Model explains behaviors in ADHD as a motivational, not cognitive problem: children shun delays because past waits have reliably ended in failure, so they prefer immediate rewards and act impulsively (Sonuga-Barke et al., 2003). This habit may be linked to weak dopamine signaling between the ventral prefrontal cortex and the amygdala, possibly arising from dysfunction in this dopaminergic system (Van Dessel et al., 2018) or from avoidance behavior patterns that children with ADHD develop through repeated experiences of waiting and failure (Sonuga-Barke et al., 2003). Providing shorter waiting times and immediate rewards can accordingly alleviate ADHD symptoms (Fernández-Martín et al., 2025). A number of empirical studies have shown evidence in support of this model (Bitsakou et al., 2009; Karalunas et al., 2011; Fernández-Martín et al., 2025).

The Triple Pathway Model posits that ADHD stems from dysfunctions in three independent neural pathways: cognitive, motivational, and temporal processing. An individual may show a deficit in only one of them. Patients' insensitivity to time, impulsive actions, and impatience can be countered with timing cues, inhibition training, and shrinking-gradient rewards (Sonuga-Barke et al., 2010). Studies demonstrating dissociable impairments in timing, inhibition, and delay-related processes in individuals with ADHD have supported this view (Keulers et al., 2021; Mette, 2023). These models not only help us understand the causes of ADHD symptoms, but also provide a theoretical basis for the development of targeted interventions to reduce ADHD symptoms more effectively.

Traditional Treatments

Comprehensive treatment enables ADHD patients to effectively manage their symptoms. Traditional therapies, including medication, cognitive behavioral therapy, mindfulness practice, can reduce ADHD symptoms and enhance the overall prognosis level (Antai-Otong & Zimmerman, 2016). Patients respond differently to different therapies, and medical professionals should tailor treatment to each individual's unique condition and preferences (Whalen & Henker, 1991).

Medications control ADHD symptoms by affecting specific neurotransmitters in the brain related to attention and impulse control, helping people with ADHD to improve attention, reduce hyperactivity, and regulate their behavior (Hosenbocus & Chahal, 2012). Medication can also cause different side effects, such as not wanting to eat, not sleeping well, or having an upset stomach. Some ADHD medications may also be less stable in quality. So we have to be very careful with the medications we give our kids, and we can't just treat ADHD with medications (Graham & Coghill, 2008).

Cognitive behavioral therapy (CBT) treats ADHD based on identifying negative thought patterns and behaviors that contribute to difficulty with attention and self-control. Through CBT techniques such as psychoeducation, goal setting, problem-solving skills training, and organizational strategy development, patients can learn effective mechanisms to cope with ADHD. However, these may require patients to bear high costs and exert a lot of effort (Antshel & Olszewski, 2014).

Mindfulness practice can reduce the stress response of ADHD patients, improve their self-cognition, and help them manage their emotions more effectively. Mindfulness practice is recommended by the American Psychiatric Association as a beneficial treatment for ADHD. It helps people stay focused on their current thoughts and feelings, thereby maintaining focus and controlling impulses. But it may also need a high patient effort and cost (Sultan et al., 2025).

In addition to the common treatment methods, there are also various alternative therapies to choose from. For example, physical exercise can alleviate the symptoms of ADHD and promote cognitive function (Christiansen et al., 2019), while social skills training can help patients enhance communication skills and improve interpersonal relationships (Givertz, 2003). Similarly to art therapy, which helps patients express emotions and thoughts through painting or sculpture (Buchalter, 2009), music therapy can help patients relax and improve their emotional well-being (Hillecke et al., 2005). Family therapy can help people with ADHD by guiding parents or caregivers to work together to create a supportive family environment and accompany them (Carr et al., 2020); Some trained animals also provide comfort and emotional support to patients, which is animal assisted therapy. (Kruger & Serpel, 2010). The traditional Chinese medicine therapy (TCM) for ADHD is based on Chinese medicine theory for diagnosis and treatment (Ni et al., 2014).

Digital Interventions

Digital interventions use digital technology to treat or relieve ADHD symptoms. Compared with traditional approaches, the recent systematic review shows that digital intervention therapy has significant advantages, high accessibility and effectiveness, and can achieve low-cost self-management (Liu et al., 2024; Gabarron et al., 2025). The safety was good, and most adverse reactions were mild (Liu et al., 2024). It also increases acceptance due to gamified design (Liu et al., 2024).

Digital interventions have been developed to target various aspects, including motor ability development (Sudnawa et al.,2018; Benzing & Schmidt, 2019), attention training (Kollins et al., 2020; Sudnawa et al., 2018; Lim et al., 2019; Lee et al., 2015; Bikic et al., 2017), control and inhibition improvement (Kollins et al., 2020), working memory enhancement (Sudnawa et al.,2018; Bikic et al., 2017), and enhancement of other cognitive functions such as problem-solving abilities (Penuelas-Calvo et al., 2020). Digital interventions studies have mostly lasted 1 month (Kim et al., 2022; Kollins et al., 2020), 2 months (Benzing & Schmidt, 2019; Bikic et al., 2017; Lim et al., 2019), or 3 months (Lee et al., 2015; Sudnawa et al., 2018). The evidence has shown that digital intervention therapy can significantly reduce ADHD symptoms during the intervention period, ranging from 1 to 7 times per week (Kim et al., 2022; Kollins et al., 2020; Bikic et al., 2017; Sudnawa et al., 2018; Lim et al., 2019; Lee et al., 2015; Benzing & Schmidt, 2019).

Common forms of digital interventions are neurofeedback (Marzban et al., 2016), cognitive behavioral training software (Rapport et al., 2013), virtual reality technology (Cibrian et al., 2016), and digital game interventions (Păsărelu et al., 2020). Digital game interventions provide interactive training to children with ADHD through mobile apps and computer software. With games varying widely in quality, parents and experts must help children choose wisely (Păsărelu et al., 2020). Digital game interventions also require further research to verify their long-term effects and optimal methods of application (Păsărelu et al., 2020). To address different cognitive deficits, researchers must design games based on evidence-based principles. For example, in attention training games, the game system can dynamically adjust the duration of stimulus presentation based on the player’s performance (Wu et al., 2020). Virtual reality (VR) technology provides an attention and self-control training platform for children with ADHD by simulating the environment. The long-term effects and best practices of VR need to be further determined. Limited by the cost of equipment, ordinary families and schools can not afford VR, and long-term use is easy to cause eye fatigue and other discomfort (Cibrian et al., 2022). Cognitive behavioral training (CBT) software alleviates symptoms in children with ADHD by performing cognitive tasks on a computer or mobile device. This intervention effects vary among individuals, may require continued support from therapists, and may take longer to achieve significant reductions in ADHD symptoms. What's more, patients typically need to exercise regularly to maintain therapeutic benefits, with professionals overseeing progress and adjusting task difficulty as needed (Rapport et al., 2013). Neurofeedback (NF) involves monitoring brain waves and responding to brain activity in real time, enabling patients to learn self-regulation of their brain wave patterns. In treatment sessions, patients can practice enhancing brain waves associated with focus and calmness while reducing those linked to hyperactivity and impulsive behavior (Marzban et al., 2016). These devices are expensive and generally require the patient to attend multiple training sessions with a professional (Chapin, 2016).

Current digital interventions have limitations, such as focusing on a single ADHD problem (Lim et al., 2019), unappealing designs (Chuang et al., 2010), limited device accessibility (Benzing et al., 2019), not considering the needs of subclinical ADHD (Kim et al., 2022; Lee et al., 2015), and not adapting to the localization environment in China (Lim et al., 2019; Kim et al., 2022). Specifically, many current ADHD digital interventions are not comprehensive and are designed with tasks that address only a single symptom or are monotonous and repetitive (Smith et al., 2021). These games neither fully meet patient needs nor maintain user interest, and may reduce adherence to training (Lim et al., 2019; Chuang et al., 2010). Laboratory Settings can be quite different from those in which people with ADHD live, also limiting the generalisability of digital interventions (Benzing et al., 2019). Previous studies have mainly focused on children with ADHD, but few have included subclinical ADHD in study populations to explore the efficacy of digital interventions on subclinical ADHD (Kim et al., 2022). At the same time, these games lack Chinese localization. Most games only have an English interface or introduction (Lim et al., 2019; Kim et al., 2022). Therefore, a novel digital intervention that targets multiple ADHD symptoms at once could prove more effective. To increase engagement and efficiency, games need to be personalized and include a better incentive system. To meet the diverse needs of people with ADHD and their families, digital interventions should be more accessible and participatory (Chuang et al., 2010). Furthermore, these interventions should be suitable for patients with subclinical ADHD to participate in and further explore their effectiveness in preventing the development of subclinical ADHD to confirmed ADHD. Chinese localization and cultural adaptation should also be carried out to improve the applicability and acceptance of the game in china.

To address these limitations, my study developed and evaluated a digital game for ADHD symptoms and conducted an 8-week randomized controlled trial (RCT). This game can be played on any tablet or mobile phone. It is free and accessible to all, and combines treatment with early intervention. The aim of this study was to develop a digital game suitable for children susceptible to ADHD and evaluate its possible intervention effects. Previous studies have found that 4 to 16 weeks of digital therapy, 1 to 7 sessions a week, can help relieve ADHD symptoms. To balance feasibility, cost-effectiveness, and intervention efficacy, I designed a digital game-based intervention with a duration of 8 weeks and 5 sessions per week. I hypothesize that the digital game intervention can alleviate ADHD symptoms in children, such as inattention, hyperactivity, and impulsivity. The effectiveness of the intervention was evaluated by using ADHD rating scale and clinical impression scale. The performance of ADHD vulnerable children was compared before and after the intervention to determine whether the digital game reduces ADHD symptoms.

Chapter 2: Methods

Participants

The study recruited 100 children who are vulnerable to ADHD, aged between 6 and 12 years old (M_{age} = 8.87, SD = 1.93, 65 boys) from schools or communities in Guangzhou City, China. The convenience sampling method is used, in which the sample is selected based on convenience or availability. The sample size of 100 participants exceeds the minimum requirement of 86 participants, which allows for the detection of a medium effect size with 80% power at a significance level of 0.05 using a 3 × 2 mixed model factorial design (Faul F et al., 2007). The sample size was also determined with reference to the 83-98% patient completion rates reported in previous studies (Bikic et al., 2017; Dovis et al., 2015; Kollins et al., 2020).

Participants were recruited according to the following inclusion and exclusion criteria. Inclusion criteria include (1) Meeting the subclinical screening criteria for ADHD or above; (2) Age between 6 and 12 years; (3) The family owning a tablet/smartphone and having internet access. Exclusion criteria, as reported by parents, includes (1) Receiving any form of treatment, including pharmacological or behavioral interventions; (2) Having comorbid conditions such as conduct disorder, autism spectrum disorders, or other psychological disorders; (3) Previous cranial injury or confirmed presence of a neurological disorder; (4) Impairments in motor skills or sensory perception that hinder their ability to use a computer.

(5) Color blindness and color weakness. The study was approved by the Institutional Review Board at The Hong Kong Polytechnic University (approve number: HSEARS20240219009). Each participant received a certificate of participation, and small gifts as recognition for their time and contribution.

ADHD children aged 6-12 years have been selected as subjects for digital intervention because children in this age group are at a critical stage of development, such as children's cognitive, social and behavioral skills. These children also have a high acceptance of digital technology. By intervening during this time, the potential of digital interventions can be maximized to help children with ADHD improve their symptoms and boost their overall development (Diamond & Lee, 2011).

Children vulnerable to ADHD screened using the Swanson, Nolan, and Pelham Rating Scale (SNAP) (Swanson et al., 1981) and the Conner's Abbreviated Symptom Questionnaire (C-ASQ) (Conners, 1996). Child behaviors observed daily by parents and teachers, such as inattention or hyperactivity, are assessed against DSM criteria using these tools (Swanson et al., 1981; Conners, 1996). For the 26-item SNAP, some daily life behaviors are taken as examples, such as "Often is distracted by extraneous stimuli" and "Often has difficulty awaiting turn." Parents rated these behaviors on a 4-point scale of 0 (Not at all) to 3 (Very much) based on how often they occurred with their children. If the mean score is between 1.1 and 1.5, the child has subclinical ADHD (empirical range); A mean score of more than 1.5 was classified as ADHD (Zhou et al., 2013). The C-ASQ contains 10 items such as "Inattentive, easily distracted" and "Restless or overactive." Teachers rate how often the behaviors described in these items occur with students on a scale of 0 (Not at all) to 3 (Very much). A total score of more than 10 indicates the possibility of subclinical ADHD, whereas a total score of more than 15 suggests the possibility of clinical ADHD (Conners, 1996). I recruited children who met the subclinical criteria or above on both scales. The children neither used any drugs nor received any behavioral interventions during the experimental period. At the same time, I also excluded other factors that could affect the results, such as those children with severe psychological illness, sensory nerve disorders, seizures, or intellectual disability were not included in the study.

Study Design

The eight week study focused on children who are vulnerable to ADHD. The study employed a 3 (test, within-subject: baseline vs. test 1 vs. test 2) ×2 (group, between-subject: first-wave vs. second-wave intervention) mixed-model design. For the between-subject factor, children were divided into two groups according to the order in which they received the intervention, with the second-wave intervention group serving as the waitlist control group in the study. Setting a waitlist control group is more ethical considerations because it can ultimately make the intervention available to all participants, ensuring that no participant is deprived of the potential benefits of the intervention. It also helps to reduce attrition because participants know that they will eventually receive the intervention and are more likely to remain in the study (Sima et al., 2021). For the within-subject factor, each participant was tested at three different times: a baseline assessment, an 8-week post-test, and a 16-week post-test. This approach allows for a comprehensive assessment of effects during the intervention.

Participants were randomly assigned to the digital intervention or waitlist control group, with stratification by sex (male/female) and disease status (ADHD/subclinical ADHD). In each subgroup, participants were further randomly distributed into different groups. To ensure allocation concealment, the assistant used a computer-generated sequence to place the list in a numbered, sealed envelope, which was not opened until the first test was completed. This method can reduce grouping bias, maintain balance between groups in important characteristics such as gender and disease status, make groups more comparable (Murray, 1998), and enhance the credibility of statistical analysis and research conclusions (Alferes, 2012). The treatment was blinded to ensure the scientificity and fairness of the study. Teachers and parents were told all kids would get the game later. Doctors had never seen the kids before and took no part in assigning groups.

Measurements

This study comprehensively assessed ADHD symptoms and treatment response using three scales. Teachers use the Conners Abbreviated Symptom Questionnaire (C-ASQ) to rapidly screen for core ADHD symptoms (Conners, 1998). Parents completed the Swanson, Nolan, and Pelm Scale (SNAP) to assess ADHD symptoms meeting detailed Diagnostic and Statistical Manual of Mental Disorders (DSM) criteria (Swanson et al., 1981). Clinicians' propensity to assess symptom severity and treatment response using the Clinical Global Impression-Severity Scale (CGI-S) (Busner & Targum, 2007). These scales appear to work together to assess the child's behaviors from multiple dimensions, ostensibly ensuring an accurate grasp of the child's condition, as well as the effect of the digital intervention.

Conners Abbreviated Symptom Questionnaire (C-ASQ)

The Conners Abbreviated Symptom Questionnaire (C-ASQ) is a rapid screening tool for

ADHD in children aged 3 to 16 years (Conners, 1998). The C-ASQ contains 10 items such as "Inattentive, easily distracted" and "Restless or overactive." These questions cover various aspects of a child's behaviors, including distractibility, fidgeting, inability to stay still, learning difficulties, and interrupting behaviors (Conners, 1998). Teachers rate how often the behaviors described in these items occur with students on a scale of 0 (Not at all) to 3 (Very much). A total score of more than 10 indicates the possibility of subclinical ADHD, whereas a total score of more than 15 suggests the possibility of clinical ADHD (Fan & Du, 2004). In this study, C-ASQ reliability remained high: Cronbach's $\alpha = 0.88$ at baseline, 0.86 at 8 week, and 0.83 at 16 week.

Swanson, Nolan, and Pelham Rating Scale (SNAP)

The Swanson, Nolan and Pelham Rating Scale (SNAP) is primarily used for screening, diagnosis, and treatment efficacy evaluation of ADHD in children and adolescents, especially for assessing behavioral problems (Swanson et al., 1981). The full version of the SNAP consists of 26 items. Among them, the core symptoms of ADHD consist of 18 items. However, the 26 item SNAP scale can provide a more comprehensive assessment of ADHD and related behavioral problems (Swanson et al., 2001). Some daily life behaviors are taken as examples, such as "Often is distracted by extraneous stimuli" and "Often has difficulty awaiting turn." Parents rated these behaviors on a 4-point scale of 0 to 3 (0: not at all; 1: just a little; 2: quite a bit; 3: very much) based on how often they occurred with their children. The study calculated the mean item score based on the full set of 26 items (Zhou et al., 2013). Setting the cut-off range of "subclinical" ADHD at 1.1-1.5 is an "empirical range" formed by researchers in clinical practice after sensitive-specificity analysis. A SNAP-26 mean score <

1.0 is taken to indicate successful treatment, a threshold derived from DSM diagnostic criteria (Swanson et al., 2001). An average item score > 1.5 signifies full clinical ADHD (World Federation of ADHD Guidelines, 2009). In the study, the SNAP-26 scale demonstrated excellent reliability in the first measurement (at 0 weeks) (Cronbach's $\alpha = 0.94$), maintained an excellent level at 8 weeks (Cronbach's $\alpha = 0.92$), and still had good reliability at 16 weeks (Cronbach's $\alpha = 0.89$).

Clinical Global Impression-Severity (CGI-S)

The Clinical Global Impression Scale (CGI) is a core tool in psychiatric research that enables clinicians to quantify changes in symptoms before and after treatment. It consists of two subscales: CGI-severity (CGI-S) and CGI-Improvement (CGI-I). Clinicians use CGI-S to assessed overall symptom severity on the basis of a comprehensive clinical assessment (Busner & Targum, 2007). In this study, the CGI-S scale contains only one question and is answered by the treating doctor of the participating children. The representative question was: "Considering your total clinical experience with this particular population, how mentally ill is the patient at this time?". CGI-S scores range from 1 (Normal) to 7 (Among the most extremely ill). The CGI scale has shown a wide range of utility in pediatric clinical studies, including studies on psychiatric disorders, ADHD, and neurodevelopmental/behavioral disorders (Dunlop et al., 2017). The CGI-S trends were correlated with other outcome measures during hospitalization and discharge, supporting its sensitivity, efficiency, and reliability across diagnostic groups (Busner & Targum, 2007). The reliability of the three measurements was good (Cronbach's $\alpha = 0.82$).

Game Design

Participants will be instructed to play the “Lucky Panda” digital game for 8 weeks. The game comprises three subgames that target various cognitive behavioral abilities based on Barkley’s and Brown’s model of ADHD (Table 1). The training sequence of the three subgames is Jump Color, Memory Flip Card, and Push Box. Each subgame had five levels and required approximately seven minutes of training. After seven minutes the current subgame is stopped and the next subgame is entered, where the participant does not have to pass all levels. The game itself requires approximately 20 minutes to play, and with instruction reading and breaks included, the total time commitment will be around 30 minutes each day.

Table 1. *Target Components in Subgames based on Barkley and Brown Models*

Subgame Name	Target Components	Specific Functions/Mechanisms
Jump Color (around 7 minutes)	Barkley: Inhibition, Working Memory	Players need to inhibit impulsive actions to avoid jumping to the wrong color obstacles while using working memory to remember color changes for successful navigation.
	Brown: Focus, Effort	The game requires players to maintain focus on specific tasks despite distractions and encourages them to think before acting to enhance self-control and effort.
Memory Flip Card (around 7 minutes)	Barkley: Focus, Working Memory	Players need to remember card locations, which helps practice keeping information in mind and improves focus and working memory.
	Brown: Memory	By matching cards, players exercise their memory abilities, aiding in better remembering and recalling information in daily life.
Push Box (around 7 minutes)	Barkley: Planning and Problem-solving, Self-regulation	Players need to devise strategies and execute steps to solve puzzles, helping them learn to think before acting and enhancing self-regulation.
	Brown: Action, Activation, Effort	The game's complexity and step-by-step problem-solving process prompt sustained mental effort from players, channeling hyperactive energy into purposeful actions.

In the game's story, Lucky Panda resided in a vibrant forest until an evil wizard stole its precious crystal stone, plunging the forest into darkness. To restore color to the forest, players will join forces with the panda in three challenging subgames. Each subgame has 5 levels and encourages young players to reach advanced levels. By successfully completing all three subgames, they will bring back the forest's colorful beauty (Table 2).

Jump color. The first subgame is called Jump color. It focuses on inhibition in working memory based on Barkley's model. And it emphasizes attention engagement and shifting as well as effort sustainment based on Brown's model. In the task, rectangular obstacles of varying colors are displayed on the screen; players can click left or right of the screen to guide their square block through same-colored obstacles while avoiding those with different colors. Upon successfully passing same-colored obstacles, the block will change its color and the obstacles will shift positions. They will ascend until 15 obstacles have been passed for progression to the next level. Each subsequent level introduces an additional color. If players touch the wrong obstacles or fail to select a direction for their block in time, that round ends and they must restart.

For example, in the Level 1, the screen displays two colors, such as the blue obstacle on the left and the red obstacle on the right. The block starts as red and needs to pass the red obstacle on the left without touching the blue obstacle on the right. Once it passes, the obstacles change positions, and the block turns blue and must then pass through the blue obstacle without touching the red one. If the player successfully passes 15 obstacles, he can proceed to the next level. In the second level, the screen displays three colored obstacles, such as blue, yellow, and green, from left to right. The block starts as yellow and needs to pass the central yellow obstacle without touching the blue and green obstacles. After passing it, the block becomes blue, and the obstacles change positions from left to right for green, blue, and yellow. Then the block goes through the blue obstacle but cannot touch the green and yellow ones. The block jumps left and right repeatedly in a transformation of blue, yellow, and green until it passes all obstacles to enter the next level. In Level 3, the positions of the four-colored obstacles change, and the block with its color constantly changing jumps left and right repeatedly until it successfully passes all obstacles to the next level.

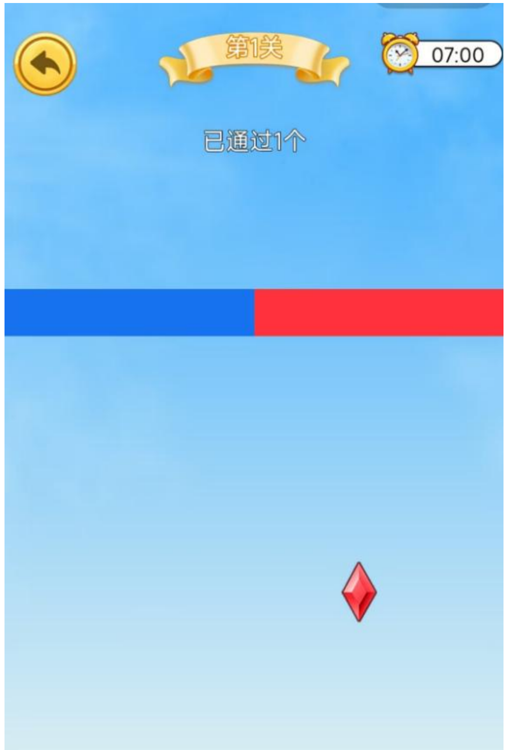
Memory Flip Card. The second subgame is called Memory Flip Card. Target domain in Barkley's Model of Inhibition includes non-verbal working memory and internalization of speech, while the target domain in Brown's Model focuses on memory operations. The task is to memorize the information on the positive side of each card and choose the two cards that contain the same information.

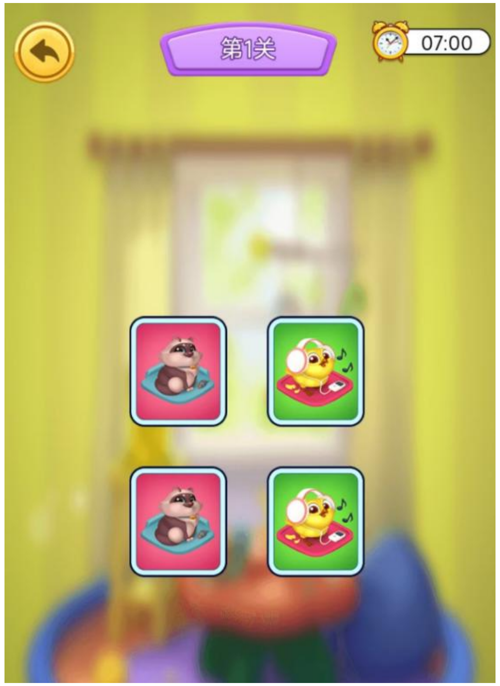
Level 1 presents the positive information of four cards for 10 seconds. After that, all cards are flipped over. The goal is to tap the two cards with matching information on the positive side to make them disappear. The objective is to clear all the cards. If the player fails to select a correct pair, all cards will be refreshed. To advance to Level 2, successfully match 2 pairs in Level 1. Level 2 introduces 8 cards while retaining the same rules as Level 1. Level 3 has 12 cards, and so on, with increasing 4 cards in subsequent each level.

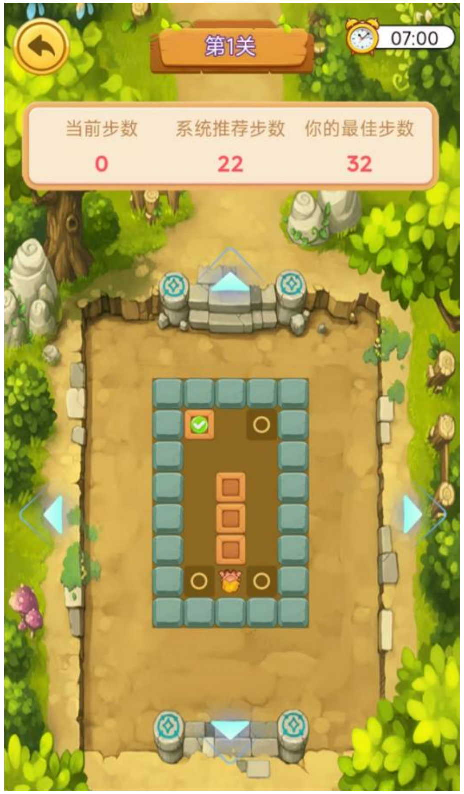
Push Box. The third subgame is called Push Box. In Barkley's Model, the target domain is inhibition, specifically focusing on planning and problem-solving skills in. While in Brown's Model, the target domain includes task organization and activation, as well as behavior monitoring. The task is to move boxes to the target positions in a grid using the fewest number of steps.

In Level 1, the game does not limit the number of steps, but displays the player's number of steps, the historical number of steps, and the recommended best number of steps after the game is over. If the player has more than the recommended number of moves, the player can choose to restart the game. Upon successfully achieving the minimum step count in Level 1, the children will advance to Level 2. This level introduces a more complex grid, where the minimum step count changes. In Level 3 and subsequent levels, it will continue to change the minimum step count, providing progressively more challenging puzzles.

Table 2. *Descriptions and Illustrations of the Game*

Content	Descriptions	Illustrations
Jump Color	Click left/right to guide the block through same-colored ones. The block changes color and moves up after each successful pass. Each level adds a new color. Hitting wrong obstacles or no action in time ends the round.	

Content	Descriptions	Illustrations
Memory Flip Card	The cards were presented for 10s and then flipped to the back. Two cards with the same positive information were selected blindly according to memory. Select the wrong game will refresh. Match a certain number of cards to advanced; Add 4 cards to each level.	

Content	Descriptions	Illustrations
Push Box	Move the box to the target location in the grid. After the game, the number of steps, historical steps, and recommended steps are displayed. If the steps exceed the recommended, children can restart.	

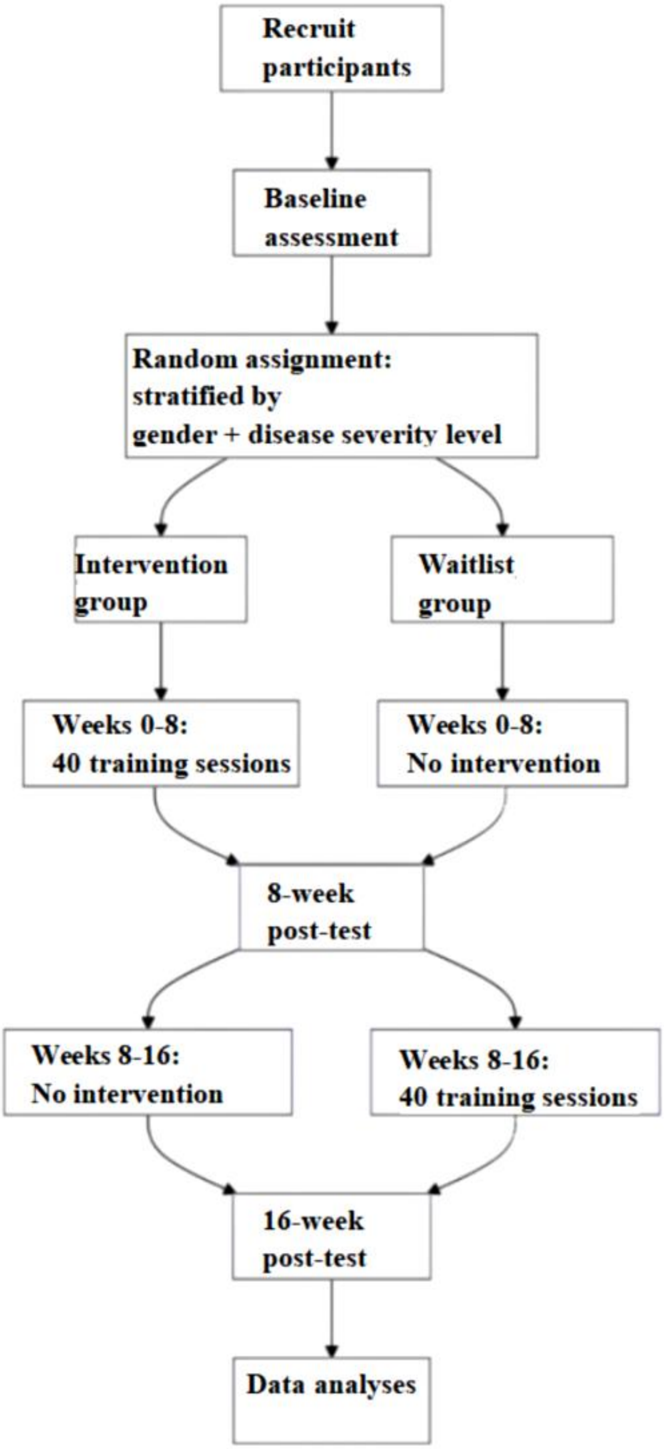
Procedures

The digital intervention involved 40 sessions (30 minutes each session) of training for 8 weeks (5 sessions per week). The waitlist group received the same 8-week intervention after a wait-time of 8 weeks. During the initial 8 weeks, the participants underwent intensive training through these 40 sessions. This concentrated approach aims to maximize their understanding and skill development within a relatively short time. Clinical studies have shown that children with ADHD may achieve the best results by arranging about five intervention sessions per week. This arrangement helps the child establish a steady training rhythm and makes it easier for the child to establish new habits (Phungsuk et al., 2017).

The waitlist group did not receive any intervention during the first 8 weeks of the study and served only as a control to assess the effect of the digital intervention. After the waiting period, members of this group participated in the same program as the initial intervention group. This design ensures that all participants ultimately receive targeted training to enhance their growth and development. It was also able to assess changes and improvements in both groups after receiving the digital intervention (Figure 3).

The game's backend automatically logs each session's start time and whether all three sub-games were completed. If a child fails to finish any subgame, the session is marked "incomplete." When more than three sessions are missed or incomplete in a week, the system automatically sends a reminder to the parents.

Figure 3. *Flowchart of Procedures*



Data Analyses

The study used the SPSS version 27 to analyze the scale data. The analysis focused on the Conners' Abbreviated Symptom Questionnaire (C-ASQ), the Swanson, Nolan, and Pelham Scale (SNAP), the Clinical Global Impression Scale-Severity (CGI-S). Each of these measures were analyzed separately to determine the interaction effect between time and group main effects of time. The Simple effect comparison analysis was conducted when an interaction effect was significant, to further investigate the effect of one factor on another at a specific level. The main effect of Time showed whether there is a consistent impact of the different test time points (baseline, 8-week, 16-week) on the dependent variable, without considering the differences in intervention groups. The main effect of Group showed whether there is a consistent impact of the different intervention groups (first-wave vs. second-wave) on the dependent variable, without considering the differences in the test time points.

Chapter 3: Results

Descriptive Information

A total of 100 participants were included in the study (50 in the intervention group and 50 in the waiting group). The average age of the whole sample was 8.87 (SD = 1.93) years old. The gender and disease distribution were balanced between the two groups. The average number of training sessions was 32.71 (SD = 2.54), and no children dropped out (Table 3).

Table 3. *Descriptive Information*

Characteristic	All Participants (N = 100)	Intervention Group (N = 50)	Waitlist Group (N = 50)	*p*
Age (M ± SD)	8.87 ± 1.93	8.54 ± 1.87	9.20 ± 1.94	0.09
Training Sessions	32.71± 2.54	33.86 ± 1.50	31.56 ± 2.84	0.00
Male	65 (65%)	33 (66%)	32 (64%)	1.00
Female	35 (35%)	17 (34%)	18 (36%)	1.00
ADHD	74 (74%)	37 (74%)	37 (74%)	1.00
Subclinical ADHD	26 (26%)	13 (26%)	13 (26%)	1.00

Multivariate Covariance Analysis (MANCOVA)

This study employed multivariate analysis of covariance (MANCOVA) to evaluate the multidimensional effects of the intervention and dynamic intergroup differences. After controlling for participation frequency (0–40 sessions), the time-by-group interaction effects emerged as the central finding. Significant interactions were observed for C-ASQ (F = 69.89, $\eta^2 = 0.419$, $p < 0.001$), SNAP (F = 10.54, $\eta^2 = 0.098$, $p < 0.001$), and CGI-S scores (F = 5.67 ,$\eta^2 = 0.063$, $p < 0.05$), indicating fundamentally divergent improvement trajectories between groups over time. The strong interaction suggests that the intervention's efficacy in reducing child behavioral problems far exceeds natural changes in the waiting group (Table 4). Group main effects show the intervention's superiority. The intervention group showed significantly better outcomes than the waiting group in C-ASQ (F = 10.34, $p < 0.01$) and SNAP scores (F = 11.24, $p < 0.001$), confirming that the intervention itself drives these improvements. The absence of group differences in CGI-S score (F = 0.89, $p > 0.05$) may reflect susceptibility of subjective ratings to baseline heterogeneity or rater bias. No significant main effects of Time were detected for any measure. The covariate (number of training sessions) may have captured some of the time variation (Table 4).

Table 4. *MANCOVA Results of the Main Effects and the Interaction Effects*

MANCOVA	Time (F)	Time×Group (F)	Group (F)	Interaction Partial η^2
C-ASQ	0.463	69.892***	10.344**	0.419
SNAP	0.222	10.540***	11.242***	0.098
CGI-S	1.023	5.671*	0.893	0.063

Notes:

1. ***$p < 0.001$, **$p < 0.01$, *$p < 0.05$.

2. Covariates included: Number of sessions attended (0–40).

Simple Effect Comparison Analyses

Simple effect comparison analysis showed that in the intervention group, significant reduction of ADHD symptoms were observed from the baseline to the 8-week post-test (C-ASQ: 16.54 ± 3.33 to 13.72 ± 3.02, $p < 0.001$; SNAP: 1.48 ± 0.20 to 1.37 ± 0.22, $p < 0.001$; CGI-S: 3.50 ± 1.31 to 3.26 ± 1.21, $p > 0.05$). In addition, symptom levels remained stable from the 8-week post-test to the 16-week post-test (C-ASQ: 13.72 ± 3.02 to 13.58 ± 3.09, $p > 0.05$; SNAP: 1.37 ± 0.22 to 1.33 ± 0.19, $p > 0.05$; CGI-S: 3.26 ± 1.21 to 3.08 ± 1.05, $p > 0.05$), a period during which no additional intervention was administered for the intervention group (Table 5). In the waitlist group, C-ASQ scores showed only minimal natural reduction from baseline to the 8-week post-test (C-ASQ: 16.10 ± 3.84 to 15.22 ± 4.05, $p < 0.05$; SNAP: 1.49 ± 0.23 to 1.44 ± 0.30, $p > 0.05$; CGI-S: 3.56 ± 1.26 to 3.30 ± 1.06, $p > 0.05$), and substantial reductions were observed from the 8-week post-test to the 16-week post-test (C-ASQ: 15.22 ± 4.05 to 9.96 ± 3.20, $p < 0.001$; SNAP: 1.44 ± 0.30 to 1.17 ± 0.20, $p < 0.001$; CGI-S: 3.30 ± 1.06 to 2.20 ± 0.64, $p < 0.001$), a period during which the waitlist group received the intervention (Table 6).

During Weeks 0-8, the proportion of participants in the intervention group who exceeded the clinical threshold decreased from 64% to 24% on the C-ASQ scale and from 48% to 26% on the SNAP scale, corresponding to large effect sizes. During Weeks 8-16, the proportion of participants in the waitlist group who exceeded the clinical threshold decreased from 36% to 6% on the C-ASQ scale and from 30% to 6% on the SNAP scale, also corresponding to large effect sizes (Table 8).

Table 5. *Simple Effect Comparison Analysis of the Intervention Group (N = 50)*

	T1 (M ± SD)	T2 (M ± SD)	T3 (M ± SD)
C-ASQ	16.54 ± 3.33^a	13.72 ± 3.02^b	13.58 ± 3.09^b
SNAP	1.48 ± 0.20^a	1.37 ± 0.22^b	1.33 ± 0.19^b
CGI-S	3.50 ± 1.31^a	3.26 ± 1.21^a	3.08 ± 1.05^a

Note:

Superscript letters (a, b, c) indicate significant differences between time points ($p < 0.05$) after Bonferroni correction for multiple comparisons.

Table 6. *Simple Effect Comparison Analysis of the Waitlist Group (N = 50)*

	T1 (M±SD)	T2 (M ± SD)	T3 (M ± SD)
C-ASQ	16.10 ± 3.84^[a]	15.22 ± 4.05^[b]	9.96 ± 3.20^[c]
SNAP	1.49 ± 0.23^[a]	1.44 ± 0.30^[a]	1.17 ± 0.20^[b]
CGI-S	3.56 ± 1.26^[a]	3.30 ± 1.06^[a]	2.20 ± 0.64^[b]

Note:

Superscript letters (a, b, c) indicate significant differences between time points (p<0.05) after Bonferroni correction for multiple comparisons.

Table 7. *Means (M) and Standard Deviations (SD) by Group and Time*

	Scale	Intervention Group (M ± SD, N = 50)	Waitlist Group (M ± SD, N = 50)	*F*
Baseline Test	C-ASQ	16.54 ± 3.33	16.10 ± 3.84	0.37
	SNAP	1.48 ± 0.20	1.49 ± 0.23	0.08
	CGI-S	3.50 ± 1.31	3.56 ± 1.26	0.05
8-Week Post-test	C-ASQ	13.72 ± 3.02	15.22 ± 4.05	4.41*
	SNAP	1.37 ± 0.22	1.44 ± 0.30	1.55
	CGI-S	3.26 ± 1.21	3.30 ± 1.06	0.03
16-Week Post-test	C-ASQ	13.58 ± 3.09	9.96 ± 3.20	33.10***
	SNAP	1.33 ± 0.19	1.17 ± 0.20	18.53***
	CGI-S	3.08 ± 1.05	2.20 ± 0.64	25.75***

Notes:

1. ***$p < 0.001$, **$p < 0.01$, *$p < 0.05$.

2. All F-values represent the between-group main effect of Intervention vs. Waitlist at the given time-point for the given scale.

Table 8. *Effect Sizes and the Magnitude of Change Relative to Clinical Thresholds*

Grouping and Intervention period	Measure	*p*	Cohen's *d*	The proportion of Clinical ADHD before and after the intervention
Intervention Group	C-ASQ	< 0.001	1.14	64% → 24%
(Week 0 → Week 8)	SNAP	< 0.001	0.94	48% → 26%
Waitlist Group	C-ASQ	< 0.001	2.73	36% → 6%
(Week 8 → Week 16)	SNAP	< 0.001	0.82	30% → 6%

Notes:

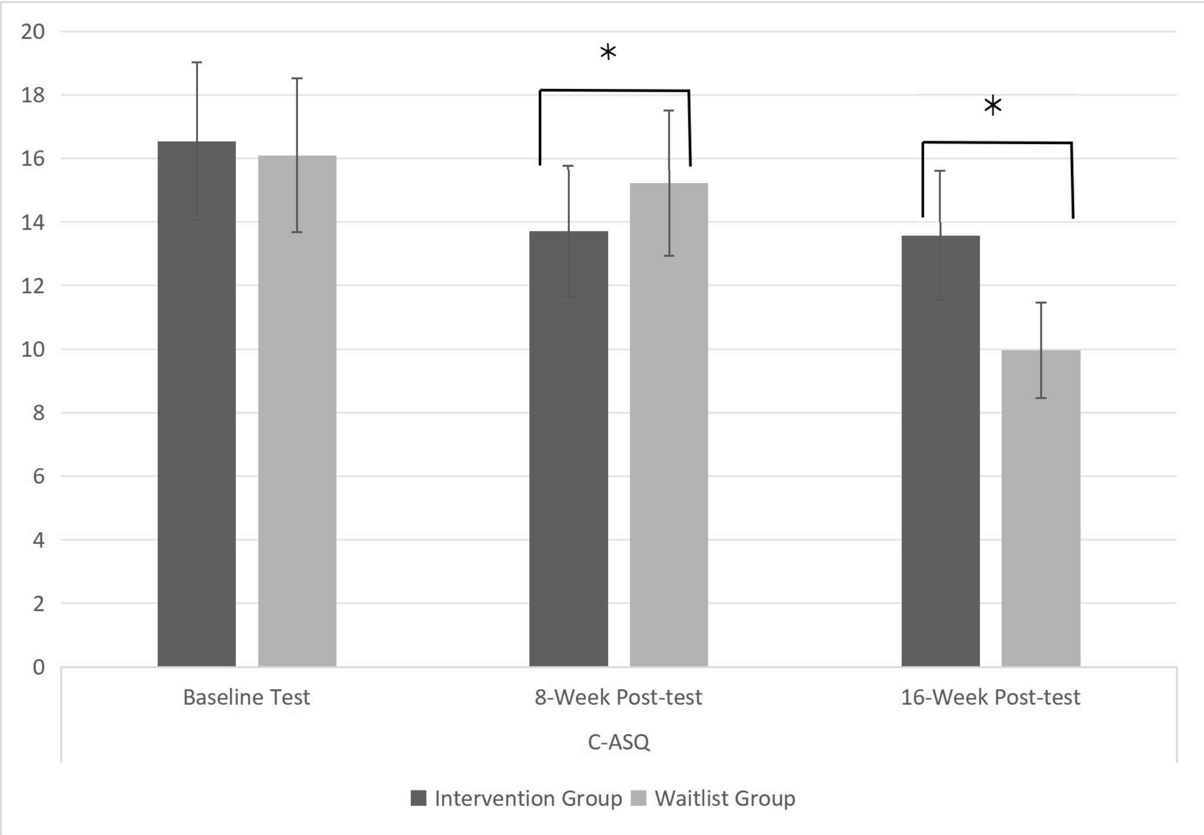
1. The waitlist group received the intervention for the first time between Week 8 and Week 16; the intervention group received it between Week 0 and Week 8; N = 50 per group.

2. Paired-sample t-test, two-tailed, $\alpha = 0.05$.

3.Cohen's $d = (M_{pre} - M_{post}) / SD_{pooled}$; effect-size conventions: $d \geq 0.8$ = large.

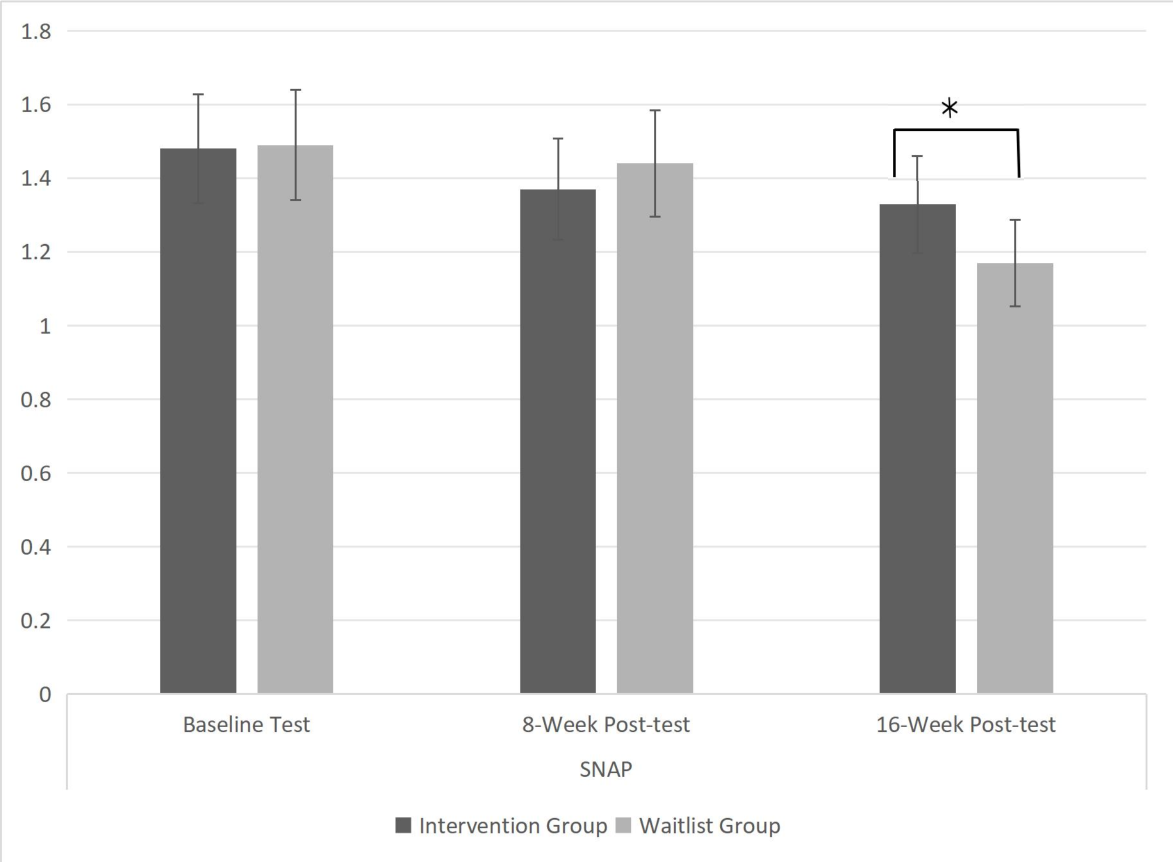
4. The values before and after the arrow show the percentage of participants who fell within the clinical range, defined as a total score > 15 on the C-ASQ scales and a mean score > 1.5 on the SNAP scales; the CGI-S scale does not involve the clinical range of ADHD.

Figure 4. *Means (M) and Standard Deviations (SD) of C-ASQ by Group and Time*



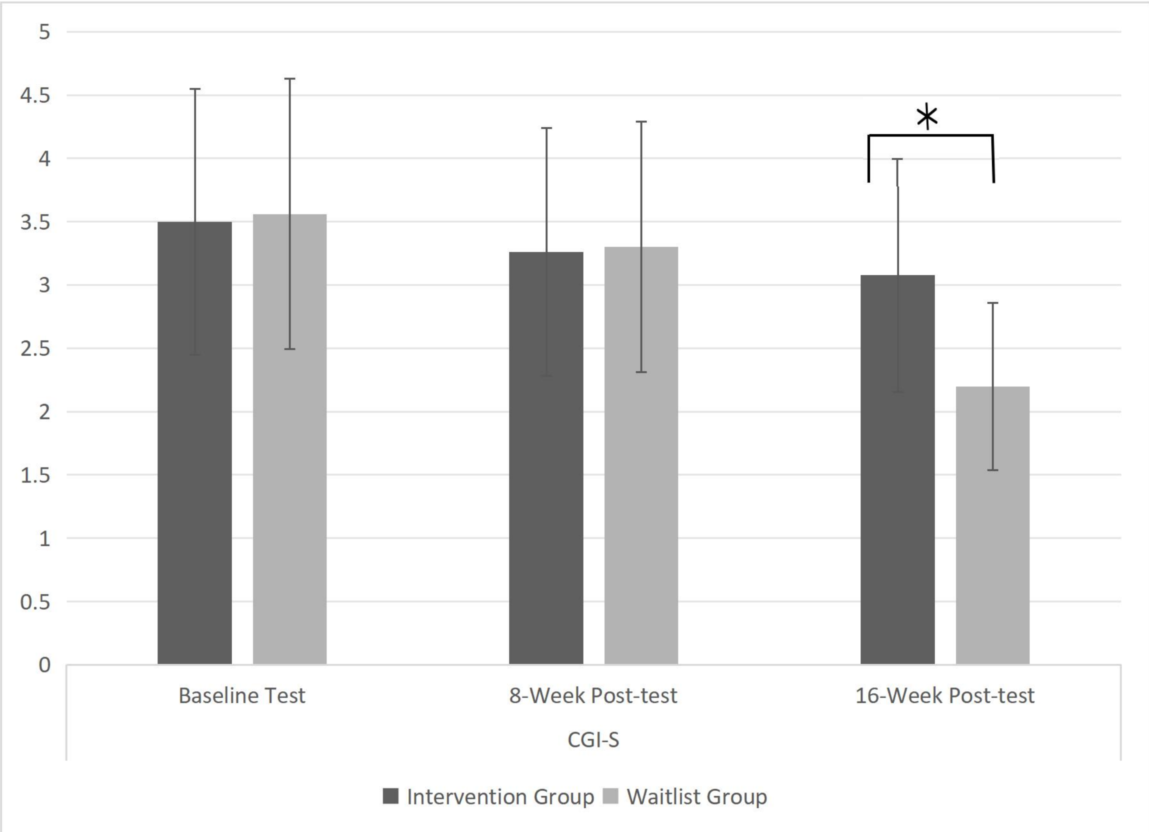
Note: $*p < 0.05$.

Figure 5. *Means (M) and Standard Deviations (SD) of SNAP by Group and Time*



Note: *$p < 0.05$.

Figure 6. *Means (M) and Standard Deviations (SD) of CGI-S by Group and Time*



Note: $*p < 0.05$.

Chapter 4: Discussion

This study provides evidence for the efficacy of a digital intervention for ADHD, revealing significant group-by-time interactions across multiple outcome measures, C-ASQ, SNAP, and CGI-S, emphasizing intervention specific effects rather than natural fluctuations in symptoms. During the active treatment phase, the intervention group had significant reductions in ADHD symptoms, which were sustained 16 weeks after the intervention. Notably, the waitlist group showed accelerated symptoms reduction during the subsequent intervention phase.

Consistency, Unexpected Results and Explanations

The results demonstrate significant interactions across all three outcome measures (C-ASQ: $F = 69.89$, $\eta^2 = 0.419$, $p < 0.001$; SNAP: $F = 10.54$, $\eta^2 = 0.098$, $p < 0.001$; CGI-S: $F = 5.67$, $\eta^2 = 0.063$, $p < 0.05$) (Table 4). It indicates that the differences between groups change over time. Time changes did not significantly affect C-ASQ, SNAP, or CGI-S scores. This means that the covariate (number of training sessions) may have captured some of the time variation. The Group main effect was significant on the C-ASQ and SNAP scores, indicating essential differences between the intervention and waitlist groups. These findings align with prior research on digital interventions for ADHD. Previous studies have reported significant group-by-time interactions for ADHD symptoms following digital game-based interventions (Lee et al., 2025). The dominance of interactions over main effects (Time or Group alone) further supports the specific efficacy of the intervention rather than natural symptom fluctuation or generic group differences (Oh et al., 2024).

A further simple comparison analysis between the intervention group (8-week waiting period after the initial 8-week intervention) and the waitlist group (8-week intervention period after the initial 8-week waiting) confirmed that both groups showed improvement in their respective intervention phases. The intervention group showed significant reductions in C-ASQ, SNAP, and CGI-S scores from baseline to 8 weeks (Table 5). Similarly, the waitlist group exhibited accelerated improvements during their intervention phase (week 8 to week 16; Table 6). The significant improvement in the intervention group at 8 weeks is consistent with studies showing short-term cognitive benefits from computerized training (Oh et al., 2024). The waitlist group showed only a marginal spontaneous reduction in symptoms on the C-ASQ score during the initial 8-week waiting period. This suggests that the intervention is crucial for significant improvements, as natural changes without intervention are limited (Baumann & Müller, 2018).

The intervention group did not receive additional intervention from the 8-week post-test to the 16-week post-test. Although the C-ASQ and SNAP scores were still stable, this digital intervention did not show significant long-term effectiveness (He et al., 2023). The CGI-S score showed no significant change between 8 and 16 weeks, possibly because it relies on a single item and lacks specific behavioral descriptors. In contrast, the C-ASQ and SNAP scales use a 4-point scale to score multiple specific items, which helps to dilute individual bias (Lee et al., 2025; Guy, 2018). The smaller change in ADHD symptoms between weeks 8 and 16 in the intervention group may be related to the “ceiling effect” that is often associated with digital therapy and warrants further investigation (Cortese et al., 2015).

Based on Figures 4-6, baseline equivalence ensured comparability between groups. Group differences at the 8-week post-test were only observed for the C-ASQ, but not for the

SNAP or CGI-S. The C-ASQ specifically targets inattention and hyperactive/impulsive symptoms, which show greater responsiveness to digital intervention. Empirical evidence suggests that improvements in ADHD core symptoms may precede broader functional improvements (Oh et al., 2024). The CGI-S scale captures broad behavioral problems and global impairment but is relatively insensitive to subtle improvements (Guy, 2018). It is also necessary to take into account the differences in individual responses to treatment. Participants showed variable adaptations to the intervention protocol, with some responding quickly and others requiring more time to achieve similar benefits (Tamm et al., 2012).

The waiting group demonstrated accelerated symptom reduction during their intervention phase, even surpassing the intervention group at the 16-week post-test (Table 7). This phenomenon is closely related to individual differences. Factors such as the baseline neurocognitive level and the sensitivity to the game mechanism may weaken or enhance the improvement effect (Coghill et al., 2021). Another possible explanation is that after the waiting period, patients in the waiting group may have an increased need and motivation to participate in treatment. Patient motivation and readiness to engage in treatment can enhance the intervention’s effectiveness (Herbst, 2024). The training completion rate of the waiting group (86.36%) was slightly higher than that of the intervention group (84.76%). In addition, a longer waiting period also stimulated positive lifestyle changes. Families on the waiting list might actively improve their children’s sleep, diet, and daily routines. These factors jointly contributed to the accelerated symptom relief in the later stage of the waitlist group.

Subgroup analyses showed intervention effectiveness varied by severity, sex, and age. Children with subclinical ADHD (N = 26) exhibited significant time-by-group interactions on

C-ASQ, SNAP, and CGI-S scores (e.g., C-ASQ: $F = 28.80$, $\eta^2 = 0.72$, $p < 0.001$; CGI-S: $F = 6.25$, $\eta^2 = 0.36$, $p < 0.01$), whereas those with diagnosed ADHD (N = 74) showed significant interactions on C-ASQ and CGI-S scores (e.g., C-ASQ: $F = 108.04$, $\eta^2 = 0.76$, $p < 0.001$; CGI-S: $F = 3.47$, $\eta^2 = 0.09$, $p < 0.05$). The results suggest that this digital intervention is effective for both children with subclinical ADHD and those with confirmed ADHD, and may be more effective for children with subclinical ADHD. The SNAP scale may be able to detect treatment effects at lower baseline symptom severity and better reflect milder subthreshold behavioral performance (He et al., 2022). Boys (N = 65) displayed significant interactions on both C-ASQ and SNAP scores (e.g., C-ASQ: $F = 100.67$,$\eta^2 = 0.77$, $p < 0.001$), whereas girls (N = 35) showed a significant interactions only on C-ASQ scores (e.g., C-ASQ: $F = 34.44$, $\eta^2 = 0.69$, $p < 0.001$); neither boys and girls demonstrated a significant interaction on CGI-S scores. The results suggest that this digital intervention is effective for both boys and girls. Girls may more often present with internalizing features (e.g., anxiety, perfectionism) that are less represented in scale items (Veloso et al., 2020). The single-item CGI-S scale that does not parse attentional, emotional, or behavioral domains, lacked the detail to detect differential change (Lee et al., 2025; Guy, 2018). Older children (10-12 y, N = 62) exhibited significant interactions across all measures (e.g., C-ASQ: $F = 102.87$, $\eta^2 = 0.78$, $p < 0.001$), whereas younger children (6-9 y, N = 38) showed an effect only on C-ASQ scores (e.g., C-ASQ: $F = 38.62$, $\eta^2 = 0.69$, $p < 0.001$). The results suggest that this digital intervention is effective for all children, and may be more effective for older children. Greater cognitive capacity and ongoing prefrontal plasticity in older children may facilitate the internalization of the self-monitoring and planning strategies taught in the intervention, whereas younger children remain more dependent on parental support (Fandakova et al., 2020). These findings need to be validated in future studies with larger samples.

Contributions

This game has a Chinese background and adaptation, combining three subgames and five levels to get rid of repetitive tasks. It can be used on any mobile phone or tablet, free and no additional cost. The multi-EF training can be applied to both subclinical and confirmed ADHD population, and explore a new way to prevent ADHD. The short and long term training objectives were different for each subgame. Jump Color can make the player more responsive and less impulsive in the short term, but the effect may be unclear in the long term. Memory Flip Card allow players to match more cards in the short term, reduce the number of matching errors, and moderately improve working memory span in the long term. Push Box gets the player thinking about completing tasks in fewer steps in the short term, and helps build long-term planning and organization skills.

This study confirms that digital interventions are effective for children with ADHD, offering accessible and affordable self-management options. Patients can access the game anytime and anywhere, making the therapy activities more convenient. Digital interventions enable early treatment of subclinical cases before progression to clinical ADHD. Treatment options may also be offered to confirmed patients while they await specialist care, bridging the gap between initial diagnosis and specialist intervention. This approach reduces the waiting time for treatment, provides flexible treatment site selection, improves treatment motivation and treatment compliance, and thus reduces the long-term negative impact of ADHD on the overall health of individuals.

Cultural and structural barriers within the healthcare system often lead to the elimination of ADHD services, which are insufficient in many regions (Young et al., 2021). The study highlights the range of adverse consequences associated with untreated ADHD, with high long-term personal, social, health, and economic costs. Treatment services can be improved by training professionals who treat people with ADHD and by increasing funding, commissioning, and monitoring. At the same time, communication between health services should be simplified to help people with ADHD from all aspects.

This study revealed the need for an easy-to-use self-management treatment program and provided insights for decision makers to facilitate the implementation of self-management interventions. Digital interventions are inexpensive and can benefit children who are unable to access professional treatment due to scarce medical resources. Interventions such as web-based platforms and digital games enable children with ADHD and their families to engage in treatment outside the hospital setting (Lee et al, 2025).

This study provides concise summaries or diagrams for parents and teachers to facilitate participating families to communicate with each other and help them recognize the positive effects of digital games on children vulnerable to ADHD. Findings can be shared through academic conferences, seminars, and publications, making them accessible to experts in child psychology and education. The results of this study may also encourage service providers such as child psychotherapists to incorporate digital interventions into educational or treatment programs for children with ADHD.

Existing Limitations and Directions of Future Research

This study has limitations that led to some unexpected findings, but it also suggests directions for future research. There was a lack of precise task time data, and there were differences in completion rates among groups. The study focused on EF training, and no specific timing task or social task was designed. This study did not include direct executive function (EF) assessments. This was mainly because the focus of this study was to evaluate the acceptability and initial efficacy of digital games in children's daily life scenarios. EF tests can detect small changes, but they don't always show how a child actually behaves each day. A systematic review found that most studies did not use the EF task but took the ADHD symptom scale as the main indicator, and "indirectly inferred" an increase in EF through a decrease in symptoms (Oh et al., 2024).

To address these limitations, future research can take the following improvement suggestions. Qualitative interviews will be conducted to understand the participants' viewpoints. Future studies should identify factors that influence training completion and develop detailed, standardized implementation and recording protocols to improve participant compliance. EF measurements such as the BRIEF (Behavior Rating Inventory of Executive Function), and other objective indicators such as neuroimaging and biomarkers will be introduced. In addition, studies could be conducted in populations with different socioeconomic backgrounds, races, and age groups to enhance the applicability of the findings.

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