



Do Executive Dysfunction, Delay Aversion, and Time Perception Deficit Predict ADHD Symptoms and Early Academic Performance in Preschoolers

Que Zheng¹ · Yu Yan Cheng¹ · Edmund Sonuga-Barke² · Kathy Kar-man Shum¹

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Abstract

Children with attention deficit/hyperactivity disorder (ADHD) are commonly observed to have learning difficulties. This study examined how three neuropsychological constructs—executive dysfunction, delay aversion, and time perception—were associated with ADHD symptoms and early academic performance in preschoolers at risk of ADHD. One hundred and thirty-one preschoolers (70 boys, 53%) aged 4 to 6 ($M=5.31$ years) were assessed on their ADHD-related behaviors, neuropsychological functioning, word reading, and math abilities at two time points one year apart. Factor analysis indicated that inhibitory and attentional control deficit, delay aversion, and time perception/working memory deficit were three dissociable factors. Among the three factors, inhibitory and attentional control measured at Time 1 was the strongest predictor of ADHD symptoms at both Time 1 and Time 2. Time perception was closely related to working memory, and they predicted word reading and numeration across time most strongly among other neuropsychological constructs. Our findings suggested that inhibitory and attentional control, delay aversion, and time perception are dissociable neuropsychological deficits underlying ADHD symptoms in preschoolers. Poor time perception may serve as a marker for the early identification of preschoolers with potential learning problems, and a possible target of intervention for ADHD.

Keywords ADHD · Early academic skills · Executive dysfunction · Delay aversion · Time perception

Introduction

Attention deficit/hyperactivity disorder (ADHD) is a neuropsychological disorder characterized by developmentally inappropriate and persistent symptoms of inattentiveness, and/or hyperactivity/impulsivity (American Psychiatric

Association [APA], 2013; Posner et al., 2020). According to the Diagnostic and Statistical Manual of Mental Disorders – Fifth Edition (DSM-5; APA, 2013), symptoms of ADHD usually appear first in early childhood, and often persist into later life stages. Children with ADHD may display poor inhibitory control, inattention, and problems with behavioral and emotional regulation (Anastopoulos et al., 2011; Klimkeit et al., 2006; Strine et al., 2006; Wehmeier et al., 2010), and they often experience other co-occurring conditions, such as oppositional defiant disorder, depression, and learning difficulties (Gillberg et al., 2004). In particular, students with ADHD were often reported to have difficulties at school, such as maintaining focus in class and meeting academic goals (Sherman et al., 2006). Moreover, about 25–40% of children with ADHD were reported to have reading disorders (August & Garfinkel, 1990; Carroll et al., 2005; Maughan & Carroll, 2006; Mayes & Calhoun, 2007; Semrud-Clikeman et al., 1992; Sexton et al., 2011; Wisniewska et al., 2007) and up to 60% of them displayed disabilities in math learning (August & Garfinkel, 1990;

✉ Kathy Kar-man Shum
kkmshum@hku.hk

Que Zheng
jeannez@connect.hku.hk

Yu Yan Cheng
cherrycheng517@hotmail.com

Edmund Sonuga-Barke
edmund.sonuga-barke@kcl.ac.uk

¹ Department of Psychology, The University of Hong Kong, Hong Kong, China

² Institute of Psychiatry, Psychology and Neuroscience, King's College London, London, UK

Capano et al., 2008; Langberg et al., 2010; Mayes & Calhoun, 2007; Semrud-Clikeman et al., 1992).

The reasons behind the close correlation between ADHD and academic performance have not been fully explored. A review of the impact of ADHD on academic performance across life stages showed that symptoms of ADHD and cognitive deficits in executive function (EF), instead of other comorbid conditions, are underpinning academic underperformance (Daley & Birchwood, 2010). However, not all children with ADHD exhibit EF deficits (Coghill et al., 2013; Nigg et al., 2005; Sjöwall et al., 2017; Sonuga-Barke et al., 2010; Willcutt et al., 2005). Hence, whether other neuropsychological deficits observed in ADHD also influence academic performance remains an important question to be addressed.

Preschool is a critical period for laying the foundations for a child's social, behavioral, and academic development. A significant proportion of young children subsequently diagnosed with ADHD were shown to experience notable impacts of poor inhibitory control and attention in daily life during their early preschool years (Mariani & Barkley, 1997; Thorell & Wåhlstedt, 2006). Neuropsychological deficits related to ADHD might have compromised their abilities to acquire early academic skills, leading to challenges in later school life. Examining preschoolers' neuropsychological abilities, symptoms of ADHD, and early academic skills from a developmental perspective may offer insights into the causes of academic underperformance commonly observed in children with ADHD and inform early support and intervention that may likely benefit this group of children.

Neuropsychological Models of ADHD

Neuropsychological models of ADHD traditionally emphasize the role of executive dysfunction in ADHD pathophysiology (Barkley, 1997; Bayliss & Roodenrys, 2000). Impairments in EF are often observed in children with ADHD (Seidman et al., 2001; Thorell & Wåhlstedt, 2006). Despite ongoing debates on the components of EF observed among preschool children, inhibition and working memory have been widely recognised as key EF components in early childhood (Anderson & Reidy, 2012; Lan et al., 2011). Moreover, some researchers proposed that attentional control (i.e., the ability to resist distractors and respond in a way that conflicts with the dominant behavior) is also a key element of EF in young children (Anderson & Reidy, 2012; Garon et al., 2008; Lan et al., 2011). Indeed, some studies have reported deficits in EF, such as working memory, inhibition, and attentional control among preschoolers at risk of ADHD (Breux et al., 2016; Pauli-Pott & Becker, 2011; Sjöwall & Thorell, 2018). However, a considerable

proportion of children diagnosed with ADHD do not display any evidence of EF deficits, questioning whether executive dysfunction is either necessary or sufficient to account for ADHD symptoms (Coghill et al., 2013; Nigg et al., 2005; Sjöwall et al., 2017; Sonuga-Barke, 2003; Willcutt et al., 2005).

Later on, Sonuga-Barke (2003) proposed a dual pathway model, postulating that delay aversion is another neuropsychological component that contributes to the behavioral symptoms of ADHD. Delay aversion refers to a motivational style characterized by a drive to avoid or escape delay and a tendency to choose small immediate rewards over large-delayed rewards (Kuntsi et al., 2001a; Marco et al., 2009). ADHD symptoms—such as distractibility, inattention, and hyperactivity—are believed to be functional expressions of delay aversion, which enable the individuals to cope with inescapable delay by expediting the perception of time and reducing the subjective delay (Antrop et al., 2006). As predicted by this model, recent studies suggest that brain circuits recruited when processing aversive cues are hyperactivated to signals of forthcoming delay in ADHD compared to neurotypical individuals (Van Dessel et al., 2018).

According to Sonuga-Barke (2003), there are two distinct pathways in ADHD—a cognitive pathway mediated by executive dysfunction, and a motivational pathway mediated by reduced gratification towards delayed rewards. Previous studies have shown that children with ADHD exhibit both EF deficits and delay aversion, and these two components are independently related to symptoms of ADHD (e.g., Dalen et al., 2004; Paloyelis et al., 2009; Sonuga-Barke et al., 2003; Thorell, 2007). EF deficits were found to correlate with symptoms of inattention, whereas delay aversion was related to symptoms of hyperactivity/impulsivity (Thorell, 2007). However, the total variance of ADHD symptoms explained by executive dysfunction and delay aversion was smaller for preschoolers (25%) than school-age children (65%; Sjöwall et al., 2013), suggesting that other factors are likely to be contributing to ADHD symptoms among preschoolers (Sjöwall et al., 2015).

Some studies have indicated a third component—time perception deficit—that contributes to the neuropsychological heterogeneity in ADHD. Time perception deficit refers to a compromised ability to perceive and represent time, which may affect the perception and sequential organization of events and actions, as well as the anticipation and prediction of future events (Toplak et al., 2006). A meta-analysis of 27 studies revealed that children with ADHD demonstrated impairment in time perception compared with their typically developing peers (Zheng et al., 2022). The time perception deficit in children with ADHD might be associated with the working memory deficit that is commonly

observed in this population. Theories of time perception (e.g., the Scalar Expectancy Theory; Gibbon 1977; Gibbon et al., 1984) hypothesize that temporal pulses are emitted by an “internal clock” and compared against stored information in the memory to enable one’s judgement of duration (Gibbon et al., 1984). Hence, working memory deficit in ADHD may affect the accurate registration of pulses in the timing process and consequently the perception of time (Walig et al., 2017). For instance, Lee & Yang (2018) found an association between time perception and working memory, showing that the time discrimination ability of children with ADHD was no longer significantly poorer than their typically developing peers, when working memory was controlled for. Alongside executive dysfunction and delay aversion, time perception deficit has been examined and observed as another dissociable neuropsychological deficit in ADHD (Sonuga-Barke et al., 2010). However, very few prior studies, if any, have investigated time perception in preschoolers with ADHD symptoms. Hence, although there is evidence supporting time perception deficit as the third important neuropsychological component in ADHD among school-age children and adolescents (Coghill et al., 2013; Sonuga-Barke et al., 2010), it remains unknown whether this model applies to preschoolers with ADHD symptoms.

From a developmental perspective, the three neuropsychological factors—EF, delay aversion, and time perception—have been observed to undergo changes in the early years of life. For instance, EF was hypothesized to develop from a rather unitary factor to a more complex construct with various subcomponents, including inhibition, working memory, and attentional control, starting from the preschool stage (Karchach & Unger, 2014). For delay aversion, the younger ones among 4- to 7-year-olds showed a lower preference for larger delayed rewards (i.e., they displayed stronger delay aversion) than the older children (Rezazadeh, 2007). Moreover, though rarely examined in young populations, there is some evidence indicating that time perception improves with age in preschoolers (Qu et al., 2021). Given the potential changes in these neuropsychological factors occurring in preschoolers, and the likelihood that these changes might affect their correlations with ADHD symptoms, we examined these constructs in a longitudinal design in the current study.

Neuropsychological Deficits and Early Academic Performance

Among the three proposed neuropsychological components implicated in ADHD, executive dysfunction has been commonly found to associate with academic performance deficits in early childhood (e.g., Mariani & Barkley 1997; Sjöwall et al., 2017; Thorell, 2007; Willoughby et al., 2011).

EF task performance was found to correlate significantly with early academic achievement in language and math among preschoolers with (Mariani & Barkley, 1997) and without ADHD (Lan et al., 2011; Traverso et al., 2019; Willoughby et al., 2011). Mariani and Barkley (1997) found that preschool boys with ADHD displayed poorer inhibitory control and working memory, as well as diminished academic performance in contrast to non-ADHD peers. Thorell (2007) showed that inhibition and working memory impairments mediated the relations between inattention and early mathematics and language skills in preschoolers.

For delay aversion, there is some evidence indicating its association with academic achievement (e.g., Willoughby et al., 2011). Nonetheless, these correlations appeared to be weaker than those observed between EF and academic performance. For instance, Willoughby et al., (2011) reported significant association between delay aversion and early academic performance only when delay aversion was considered alone, but not when EF was also considered. However, Sjöwall and colleagues (2017) failed to establish the link between delay aversion and academic performance in their longitudinal study among preschoolers. All in all, the relation between delay aversion and academic performance remains unclear.

Regarding time perception, prior research has shown that visual and auditory temporal processing abilities in preschool predicted letter and word recognition as well as reading fluency in primary school (Hood & Conlon, 2004; Liu et al., 2020). Moreover, preschoolers at risk of developing dyscalculia were observed to perform more poorly in timing tasks compared to their typically developing peers (Tobia et al., 2016), implying a correlation between dyscalculia and timing ability. However, with only a handful of studies that have examined the connections between early academics and time perception among preschoolers, such relations await further investigation.

In sum, it appears plausible that each of the three neuropsychological components involved in ADHD will be associated, to varying extents, with early academic performance in preschoolers. The associations of these neuropsychological deficits with both ADHD (e.g., Sonuga-Barke et al., 2010) and academic skills (Kohli et al., 2005; Passolunghi & Siegel, 2004; Reiter et al., 2005) may reasonably explain the relatively poorer academic performance in children with ADHD. A better understanding of the linkage between them may help to inform early intervention support for preschoolers with ADHD who may also encounter difficulties in learning.

Aims of the Study

The present study aimed to: (1) explore the associations of the three neuropsychological components (i.e., executive dysfunction, delay aversion, and time perception deficit) with ADHD symptoms among preschoolers; (2) examine the role of time perception in preschool ADHD, especially whether time perception deficit accounts for a third dissociable neuropsychological factor in the model, as this has seldom been studied in prior research; and (3) determine whether the three neuropsychological deficits may serve as early markers for later academic difficulties, to inform early intervention for preschoolers at risk of ADHD.

We used factor analysis to examine whether the neuropsychological deficits were dissociable in the preschool sample. Based on prior research, we hypothesised that the results of the factor analysis should reveal three dissociable components. Moreover, we investigated the associations of the neuropsychological factors with ADHD symptoms and early academic performance using correlation and regression analyses. In addition, we conducted a follow-up on the children approximately one year after their initial assessment. This longitudinal design allowed us to investigate whether the neuropsychological deficits measured at Time 1 could predict concurrent and subsequent ADHD symptoms and early academic performance. We hypothesised that the neuropsychological factors under investigation could predict concurrent and subsequent ADHD symptoms and early academic performance one-year apart.

Method

Participants

A total of 131 preschoolers (70 boys, 53%) in Hong Kong participated in this study. They were assessed at Time 1 ($M=5.31$ years, $SD=0.66$ years) and approximately one year later at Time 2 ($M=6.54$ years, $SD=0.63$ years). To enrich the presence of ADHD symptoms in the sample, 52% of the participants were recruited through ADHD parent associations, non-governmental organizations that provided support and services to children with special needs, and social media platforms (e.g., Facebook), while 48% of them were recruited from mainstream preschools. Children were excluded from the study based on the following criteria: (1) with physical and/or motor disabilities that might hinder their participation in the assessment tasks; (2) with a score below 70 based on the Weschler's Non-Verbal Scale of Ability; and (3) with comorbid autistic spectrum disorder. The characteristics of the sample are shown in Table 1.

Table 1 Demographic information of the participants

Variable (Max. possible score)	Mean (SD) / n (%) ^a	
	Time 1 (n = 131)	Time 2 (n = 96)
Age	5.31 (0.66)	6.54 (0.63)
Sex		
Male	70 (53.4%)	52 (54%)
Female	61 (46.6%)	44 (46%)
WNV-general ability ^b	113 (12.8)	114 (12.3)
SNAP-IV: Subscale Scores ^c		
Inattention (4)	1.61 (0.59)	1.88 (0.61)
Hyperactivity/impulsivity (4)	1.56 (0.69)	1.59 (0.63)
Psychosocial treatment condition ^d	27 (20.6%)	19 (19.8%)
Education level of the mother ^e		
Bachelor's degree or above	50 (38.2%)	34 (35.4%)
Post-secondary diploma	24 (18.3%)	19 (19.8%)
High school	56 (42.7%)	43 (44.8%)
Primary school	1 (0.8%)	0 (0%)
Monthly household income ^f		
Less than HK\$20,000	26 (19.8%)	18 (18.8%)
HK\$20,000 – \$40,000	41 (31.3%)	29
More than HK\$40,000	63 (48.1%)	(30.2%)
Missing	1 (0.8%)	48 (50.0%)
		1 (1.0%)

Note

^a The preschoolers' age, general ability measured nonverbally by the Weschler's Non-Verbal Scale of Ability (WNV), and their subscale scores on the Swanson, Nolan, and Pelham Rating Scale Version IV (SNAP-IV) are presented as means and standard deviations (in brackets). Other variables are presented as numbers of preschoolers and percentages within the sample (in brackets)

^b Population mean is estimated to be 100 for the scores on the WNV, according to its manual

^c Mean rating of items under each domain are reported

^d The number of participants reported to be receiving psychosocial and/or behavioral training at the time of assessment

^e According to the territory-wide census survey in 2020, about 60% of the female population in Hong Kong had attained post-secondary diploma or university degree (Census and Statistics Department of Hong Kong SAR, 2021)

^f The median monthly household income in Hong Kong in 2020 was HK\$27,000 (Census and Statistics Department of Hong Kong SAR, 2021)

Procedures

The study was approved by the Human Research Ethics

Committee (HREC) at the authors' affiliated university. Written informed consent was obtained from the parents, and oral assent was sought from the children prior to the assessment at both time points. At Time 1, each child was individually assessed for about one hour (including breaks in between tasks) by a trained experimenter (undergraduate students majoring in psychology) at the university's laboratory or the participant's school. One-minute breaks were given in between tasks, and a 5-min break was taken approximately halfway through the assessment. Moreover, participants could ask for breaks anytime during the assessment when needed. The assessment included measures that examined general ability, executive functioning (i.e., inhibitory control, attentional control, and working memory), delay aversion, time perception, and early academic skills (i.e., Chinese word reading and numeration). Parents were asked to complete a paper questionnaire on demographic information and their child's ADHD symptoms.

Data collection at Time 2 was conducted online due to school suspension and lockdown during the COVID-19 pandemic. Parents were invited to complete an online questionnaire to report on their child's ADHD symptoms. Children's academic skills (Chinese word reading and numeration) were individually assessed during online sessions on Zoom. During the online assessment, parents of the child participants were advised to either leave the room or be silent and stay away from the child if they remained in the room. Among the 131 preschoolers assessed at Time 1, 21 of them dropped out at Time 2, and another 14 participants could not be reached prior to Time 2 data collection. Reasons of attrition stated by the parents included that the children did not have time to participate or that they were no longer interested. A total of 96 children (52 boys, 54%) completed Time 2 assessment.

Measures

Demographic Variables

Demographic information such as child's date of birth, maternal education level, and monthly household income was collected via a parent self-report questionnaire. Among the 131 participants, 34 of them (26%) had received formal clinical assessments by local paediatricians or psychologists, and 18 of them (14%) had been diagnosed or suspected with ADHD. None of the participants were taking medication as reported by the parents at Time 1, and 26 of them were reported to be receiving psychosocial treatment at the time of assessments. Among the children, 97 of them (74%) were primarily taken care of by their parents, 21 (16%) by helpers or relatives, 12 (9%) by grandparents, and one did not specify the details.

ADHD Symptoms

Swanson, Nolan, and Pelham Rating Scale Version IV (SNAP-IV). Parents rated their children's ADHD symptoms using the Chinese version of the SNAP-IV parent form (Swanson, 1992; Swanson et al., 1999). This is a standardized ADHD-rating scale with 9 items on inattentive (IA) behaviors, 9 items on hyperactive/impulsive (HI) behaviors, and 8 items on oppositional and defiant behaviors. The present study used the 18 items on inattentive and hyperactive/impulsive behaviors only, which corresponded directly to the symptoms described in the diagnostic criteria of ADHD in DSM-5 (APA, 2013). Parents rated each item on a 4-point scale to indicate the severity of the respective behavioral symptom (0 = "never", 1 = "little", 2 = "sometimes", 3 = "very often"). The IA and HI subscale scores were calculated based on the average of the item scores. An item with a rating of "2" or above signified symptomatic presence of the specific behavior (Gau et al., 2008; Shum et al., 2021). A child displaying at least six out of the nine symptoms on either IA or HI would have met one of the diagnostic criteria of ADHD in DSM-5 for children under age 17 (APA, 2013). The average item scores for the IA and HI subscales were used for analysis. A higher score denotes more prominent ADHD symptoms. Gau et al. (2008) reported satisfactory psychometric properties of the Chinese version of the SNAP-IV Parent Form among Chinese children, with high internal consistency ($\alpha=0.88-0.90$), and acceptable test-retest reliability (intraclass correlation= $0.56-0.72$) and concurrent validity ($r=.56-.72$). The Cronbach's alpha for this scale in the current sample was 0.92.

General Ability

Weschler's Non-Verbal Scale of Ability. General ability was estimated nonverbally using the Matrix and Recognition subtests from the Weschler's Non-Verbal Scale of Ability (Wechsler & Naglieri, 2006; WNV). In the Matrix subtest, children were shown a visual pattern with a missing part and asked to judge which given option from four to five choices could be the missing part. In the Recognition subtest, children looked at a geometric pattern for three seconds, and then chose from four or five options presented on the next page the pattern that they just saw. The two subtests took about 10 min in total to complete. The full scale score was derived from the sum of the scaled scores of the two subtests. The score from the WNV represented an estimate of the child's general ability, and was used as a screening criterion and a controlled variable in the analyses.

Inhibitory and Attentional Control

Conners' Kiddie Continuous Performance Test, 2nd Edition (K-CPT2). The K-CPT2 (Conners, 2015) is a commonly used computerized task to assess children's ability to control attention and inhibit automatic responses, which takes about 8 min to complete. In this study, the *Z* score for the commission error rate was used as a measure of inhibitory control and the *Z* score for the omission error rate was used as a measure of attentional control. A higher score represented poorer functioning.

Working Memory

Picture Location. The picture location subtest from the Children Memory Scale (Cohen, 1997) was used to test participants' non-verbal working memory. Children were asked to look at pictures on a page for 2 s and to recall and indicate the pictures' locations by putting chips on the right places that matched the positions of the pictures they just saw. There were 10 items in the subtest, which took about 5 min to complete. A score of one was given for each item when the participant correctly indicated all the positions in a picture, a score of zero was given if the positions were not all correct. The scores of the 10 items were summed, converted into a *Z* score and reversed. A higher reversed *Z* score signified a poorer non-verbal working memory. The test-retest reliability for the picture location subtest was found to be high ($\alpha = 0.70 - 0.81$; Cohen 1997).

Delay Aversion

Maudsley Index of Childhood Delay Aversion (MIDA). This is a computerized game-like task that measures children's delay aversion based on their preference for small immediate rewards versus larger delayed rewards (Kuntsi et al., 2001b). The game was presented using a space scenario, in which the child was told that he/she was the "space-keeper" and needed to destroy the "enemy spaceships carrying the invaders". The child could choose either to destroy the enemy spaceship at time point 1 (2-second pre-reward delay) and score 1 point, or to destroy the enemy spaceship at time point 2 (12-second pre-reward delay) and score 2 points. In each trial, the "enemy spaceship" would appear for 2 s on the screen, and the child would choose whether to "attack" it or not to claim the reward. If the child chose to claim the small immediate reward, the next trial would start immediately afterward. If the child chose not to, the spaceship would appear on the screen for 10 more seconds, until the child was offered another chance to "attack" and claim the larger reward. There were 12 trials in this game, which took about 8 min to complete. Test-retest reliability

was reported to be high among preschoolers ($r = .85$; Thorell 2007). The *Z* score for each participant was calculated and reversed, so that a higher score denoted stronger delay aversion in the child.

Delay Frustration Task (DeFT). The DeFT was originally designed to measure delay intolerance of adolescents in a delay-rich setting (Bitsakou et al., 2006). The DeFT used in this study was adapted for young children. This task was introduced as a game, and the child was asked to answer 45 questions comparing the size of two animals, and to choose the smaller one by pressing a button to indicate their choices. For most of the trials ($N = 30$), the next question would appear as soon as the participant responded with a button-press (no post-response delay condition). However, on a small number of trials (post-response delay condition; $N = 15$) the presentation of the next question was delayed by a period of seconds; either by 5 s (10 trials) or 10 s (5 trials). Participants were not informed about the delays beforehand but were told that the computer was old and a bit slow. The duration of the task was about 8 min. The intolerance of delay was measured by the sum of two standardized *Z* scores: the total time and counts of button-pressing during the delay period. A higher composite *Z* score indicated a higher level of delay frustration. The test-retest reliability was found to be high among adults (Bitsakou et al., 2006), and the frequency of button-pressing per second for the two delay conditions (5 and 15 s) in Bitsakou et al. (2006) were found to be highly reliable, with α coefficients of 0.80 and 0.92 respectively. The Cronbach's alphas for the 5 and 10 s conditions were 0.79 and 0.71 respectively for the frequency count, and 0.67 and 0.57 respectively for the total time of button-pressing during delay, based on the current sample. There were no significant differences between the 5 and 10 s conditions in terms of duration ($p = .33$) and frequency ($p = .61$) of button-pressing.

Time Perception

Time Reproduction Task. This computer task was adapted from Gooch et al. (2011) to measure children's ability to recognize and produce a designated duration. The task was presented in a game-like format where the child was asked to look at a lightbulb appearing on the screen and try to determine how long the lightbulb was lightened up. Immediately afterwards, the child was asked to reproduce the same duration by turning on and off another lightbulb via pressing buttons on the keyboard. Each target duration (3s, 5s, 6s, 9s, 12s, and 15s) was presented twice in a randomized order in a total of 12 trials, which took about 6 min to complete. The absolute discrepancy between the actual duration and the duration produced by the child for each trial was calculated and summed. The total discrepancy

score was converted into a Z score. A higher score indicated a larger discrepancy, and hence a poorer time reproduction ability. The Cronbach’s alpha across target durations was 0.73 for this task in the current study.

Time Discrimination Task. This computer task examined children’s ability to discriminate among different durations of time (Gooch et al., 2011). A three-alternative forced-choice (oddball) paradigm was used. On each trial, the child heard three 1000 Hz tones, two of which were 1200ms long and a roving target of a different time length (400ms, 700ms, and 1100ms, each appeared in 9 trials in random order). The child was required to identify the oddball in each trial. Six very easy trials with the target set at 100ms were intermixed randomly with the other trials during the experiment to gauge the attention level of the participants. The task took about 6 min to complete. The percentages of error rate for each condition were calculated, averaged, and were then converted into Z scores. A higher score signified a weaker time discrimination ability. The Cronbach’s alpha across target durations was 0.76 for the current sample. The correlation between the time reproduction and time discrimination tasks was $r = .23$ ($p = .008$) in this study, indicating good convergent validity for the time perception tasks.

Academic Performance

Numeration. The numeration subtest from KeyMath-3 (Connolly, 2008) was used to assess children’s early number skills, including early number awareness, number sense, and the understanding of place values, and the task lasted for about 8 min. Pictorial prompts were presented to the children via a stimulus book at Time 1, and via the computer screen on Zoom at Time 2. Children were asked to respond to all questions verbally. One point was given for each correct answer, and the test was discontinued when the child scored zero on four consecutive items. A total score was computed and converted into a Z score. A higher score signified better performance on numeration. The reliability of this subtest for participants aged 4 to 21 years old was

between 0.80 and 0.90 (Rosli, 2011). The 1-year test-retest reliability of this measure was 0.65 ($p < .001$) in our study.

Chinese Word Reading. The Chinese Word Reading subtest from the Hong Kong Reading Ability Screening Test for Preschool Children (RAST-K; Ho et al., 2011) was used to measure participants’ word reading skill. The RAST-K is a screening test designed to identify preschoolers at risk of specific reading difficulties in Hong Kong. In this subtest, 55 single-character and two-character Chinese words were presented to the children via a stimulus book at Time 1 and via the computer screen on Zoom at Time 2, and they were asked to read aloud as many words as they could. One point was awarded for each word correctly pronounced. A total score was computed and converted into a Z score, with a higher score representing better performance. This task took about 5 min to complete. The reliability of the Word Reading subtest was reported to be 0.97 in the test manual (Ho et al., 2011). The 1-year test-retest reliability of this measure was 0.83 ($p < .001$) in the current study.

Statistical Analyses

First, principal factor analyses were used to examine the factor structure of the neuropsychological constructs measured at Time 1. Second, hierarchical regressions were performed to examine the contribution of the three neuropsychological deficits measured at Time 1 in predicting ADHD symptoms and early academic abilities at Time 1 and Time 2.

Results

Correlations and Factor Structural Models of the Neuropsychological Deficits

Correlations among the neuropsychological tasks are shown in Table 2. Overall, significant correlations were observed among these measures. Working memory associated significantly with most of the other neuropsychological constructs, including inhibitory ($r = .20$, $p = .02$) and attentional control ($r = .17$, $p = .05$), delay aversion (MIDA: $r = .25$, $p = .01$), and

Table 2 Correlations among the neuropsychological tasks

	1	2	3	4	5	6
1. KCPT omission error	-					
2. KCPT commission error	0.11	-				
3. DeFT	0.16	0.19*	-			
4. MIDA	0.04	0.20*	0.06	-		
5. Picture location	0.17*	0.20*	0.02	0.25**	-	
6. Time discrimination	0.11	0.06	-0.09	0.08	0.31***	-
7. Time reproduction	0.13	0.09	0.04	0.02	0.28***	0.19*

Note. * $p < .05$; ** $p < .01$; *** $p < .001$

K-CPT = Conners’ Kiddie Continuous Performance Test; DeFT = Delay frustration task; MIDA = Maudsley Index of Childhood Delay Aversion

time perception (time discrimination: $r = .31, p < .001$; time reproduction: $r = .28, p < .001$), among which the correlations with time perception tasks were the strongest. Inhibitory control correlated significantly with both measures of delay aversion—MIDA ($r = .20, p = .03$) and DeFT ($r = .19, p = .03$).

Z scores of all the neuropsychological tasks were entered into the principal component analysis (PCA). PCA using the oblique rotation method indicated three factors with eigenvalue larger than 1. Factor loadings of the measures on the three components are presented in Table 3. Component 1 (17.33% variance) had high loadings for the KCPT measures and the DeFT, and the factor was labelled as inhibitory and attentional control (IAC) deficit. DeFT was originally intended to be a measure of delay aversion; nonetheless, it was shown to load most strongly on Component 1 along with measures of KCPT. This finding perhaps suggested that the task was tapping more heavily on the child's lack of inhibitory control than their impatience towards delay. Component 2 (15.13% variance) loaded robustly on the MIDA task and was labelled as delay aversion (DAv). Component 3 (25.53% variance) had high loadings for measures of time perception and working memory, and was labelled as time perception/working memory (TP/WM) deficit. Although working memory is generally considered a key component

Table 3 Factor loadings of the neuropsychological measures based on principal component analysis

Measures	Component 1: Inhibitory and attentional control deficit	Component 2: Delay aversion	Component 3: Time percep- tion/ working memory deficit
KCPT omission error	0.55	-0.20	0.38
KCPT commission error	0.47	0.51	0.07
DeFT	0.80	0.05	-0.15
MIDA	-0.02	0.84	0.01
Picture location	0.00	0.36	0.66
Time discrimination	-0.25	0.07	0.70
Time reproduction	0.14	-0.23	0.69
Eigenvalue	1.21	1.06	1.79
% Variance	17.33	15.13	25.53

Note. KCPT=Conners' Kiddie Continuous Performance Test; DeFT=Delay frustration task; MIDA=Maudsley Index of Childhood Delay Aversion

Loadings higher than 0.40 are bolded

of EF, the results from both the correlation and factor analyses revealed a significant linkage between working memory and time perception, which was stronger than those between working memory and measures of inhibition and attentional

Table 4 Hierarchical regression analyses predicting ADHD symptoms (measured by the Swanson, Nolan, and Pelham Rating Scale Version IV) at Time 1 and 2 from neuropsychological deficits at Time 1

	Inattentiveness		Hyperactivity/Impulsivity	
	Time 1	Time 2	Time 1	Time 2
	ΔR^2	β	ΔR^2	β
Step 1: Covariates^a	0.23***		0.11*	
Step 2: IAC	0.06*		0.08*	
KCPT omission error		0.21**		0.24**
KCPT commission error		0.12		0.14
DeFT		-0.01		-0.05
Step 2: DAv	0.01		0.03 ⁺	
MIDA		0.08		0.17 ⁺
Step 2: TP/WM	0.06*		0.03	
Picture location		0.13		0.05
Time discrimination		0.17*		0.12
Time reproduction		-0.15 ⁺		-0.15
Step 2:	0.11**		0.13*	
KCPT omission error		0.21**		0.25**
KCPT commission error		0.09		0.12
DeFT		0.01		-0.04
MIDA		0.04		0.14
Picture location		0.09		-0.02
Time discrimination		0.16 ⁺		0.09
Time reproduction		-0.17*		-0.15

Note. ⁺ $p < .10$; * $p < .05$; ** $p < .01$; *** $p < .001$. Standardized regression coefficients (β) of the variables at the final step of each analysis are given

^a Age, general ability, and treatment condition were included as covariates

IAC=Inhibitory and attentional control deficit; DAv=Delay aversion; TP/WM=Time perception/working memory deficit; KCPT=Conners' Kiddie Continuous Performance Test; DeFT=Delay frustration task; MIDA=Maudsley Index of Childhood Delay Aversion

control. This lent support to the hypothesis that working memory is involved in the perception of time (Walsh et al., 2017). Our findings showed that the three components— inhibitory and attentional control deficit, delay aversion, and time perception/working memory deficit—were dissociable in the current preschool sample and provided evidence for a three-factor model of the neuropsychological constructs.

Regression Analyses

Hierarchical regression analyses were then conducted to examine the relative contribution of the neuropsychological deficits measured at Time 1 to ADHD symptoms and academic performance measured at Time 1 and Time 2. Children’s age, general ability, and psychosocial treatment condition (i.e., whether they were reported to be receiving psychosocial and/or behavioral training at the time of assessment) were entered as controlled variables in the first step of each regression. Next, measures of each of the three components (IAC deficit, DAv, and TP/WM deficit) were entered into the second step of separate regression models, to account for their respective associations with ADHD symptoms and academic performance. Last, all neuropsychological measures were entered simultaneously into the second step of the regressions after the controlled variables

to examine their unique contribution in the prediction. The results are presented in Tables 4 and 5.

In predicting IA and HI symptoms (Table 4), age, general ability, and treatment condition together significantly explained 11–23% of the variance in IA but not HI across time. All neuropsychological tasks together accounted for 11–19% of the variance in the outcome measures at each time point. When the three neuropsychological components were considered separately, children’s IAC deficit at Time 1 was a significant predictor of their ADHD symptoms across Time 1 and Time 2, and the strongest among the three components. Specifically, Time 1 IAC deficit contributed significantly to HI symptoms at both Time 1 ($\Delta R^2=0.08, p=.02$) and Time 2 ($\Delta R^2=0.11, p=.05$), as well as IA symptoms at Time 1 ($\Delta R^2=0.06, p=.02$). Moreover, measures of inhibition and attentional control at Time 1 remained to be significant predictors of IA and HI across time even when other tasks were simultaneously considered. For the TP/WM deficit, it was shown to be a significant predictor of IA symptoms at Time 1 ($\Delta R^2=0.06, p=.02$) beyond the controlled variables. Time discrimination, in particular, was found to predict IA at both Time 1 ($\beta = 0.17, p=.05$) and Time 2 ($\beta = 0.21, p=.05$), and HI at Time 2 ($\beta = 0.26, p=.02$), and remained a unique predictor of IA and HI at Time 2 when all tasks were considered. By contrast, DAv only associated

Table 5 Hierarchical regression analyses predicting early academic performance at Time 1 and 2 from neuropsychological deficits at Time 1

	Word Reading				Numeration			
	Time 1		Time 2		Time 1		Time 2	
	ΔR^2	β	ΔR^2	β	ΔR^2	β	ΔR^2	β
Step 1: Covariates^a	0.27***		0.23***		0.36***		0.26***	
Step 2: IAC	0.01		0.00		0.03		0.06 ⁺	
KCPT omission error		0.01		0.03		-0.17*		-0.17 ⁺
KCPT commission error		-0.07		0.01		0.08		0.00
DeFT		-0.02		0.01		-0.01		-0.18 ⁺
Step 2: DAv	0.00		0.00		0.00		0.01	
MIDA		-0.06		-0.02		0.00		0.08
Step 2: TP/WM	0.06*		0.06 ⁺		0.03 ⁺		0.05	
Picture location		-0.10		-0.21 ⁺		-0.04		-0.30*
Time discrimination		-0.20*		-0.17		-0.08		0.04
Time reproduction		-0.07		0.05		-0.17*		-0.05
Step 2:	0.07		0.07		0.06		0.11 ⁺	
KCPT omission error		0.04		0.07		-0.15*		-0.14
KCPT commission error		-0.04		0.03		0.09		-0.00
DeFT		-0.04		-0.00		-0.02		-0.17 ⁺
MIDA		-0.04		0.03		0.02		0.13
Picture location		-0.08		-0.23 ⁺		-0.04		-0.29*
Time discrimination		-0.21*		-0.18		-0.07		0.03
Time reproduction		-0.08		0.03		-0.16*		0.00

Note. ⁺ $p < .10$; * $p < .05$; *** $p < .001$. Standardized regression coefficients (β) of the variables at the final step of each analysis are given.

^a Age, general ability, treatment condition, and monthly household income were included as covariates.

IAC=Inhibitory and attentional control deficit; DAv=Delay aversion; TP/WM=Time perception/working memory deficit; KCPT=Conners’ Kiddie Continuous Performance Test; DeFT=Delay frustration task; MIDA=Maudsley Index of Childhood Delay Aversion.

marginally with HI at Time 1 but not Time 2, and did not predict IA symptoms at any time point.

For the prediction of academic performance (Table 5), besides children's age, general ability, and psychosocial treatment condition, we also included monthly household income as an indicator of the family's socioeconomic status (SES) in the regression models, as SES was often found to correlate with children's academic performance in prior research (Lurie et al., 2021). The controlled variables (children's age, general ability, treatment condition, and SES) together explained a significant proportion of the variance (23–36%) in early academic skills. Among the covariates, age was a significant predictor of both Chinese word reading (Time 1: $\beta = 0.51$, Time 2: $\beta = 0.49$, $ps < 0.001$) and numeration (Time 1: $\beta = 0.57$, Time 2: $\beta = 0.50$, $ps < 0.001$). General ability measured at Time 1 significantly predicted numeration at both time points (Time 1: $\beta = 0.33$, $p < .001$; Time 2: $\beta = 0.28$, $p = .01$), and word reading at Time 1 ($\beta = 0.21$, $p = .01$). Moreover, difference in numeration performance between children from the highest and lowest SES groups was significant at Time 1 ($\beta = 0.48$, $p = .02$), but this result was not observed in Chinese word reading. The standardized regression coefficients of the controlled variables are reported in Appendices 1 and 2 in the supplementary information online.

Beyond the covariates, the TP/WM deficit remained a significant predictor of Chinese word reading at Time 1 ($\Delta R^2 = 0.06$, $p = .02$) and a marginally significant predictor at Time 2 ($\Delta R^2 = 0.06$, $p = .07$). Specifically, time discrimination significantly predicted word reading at Time 1 ($\beta = -0.20$, $p = .02$) and numeration was significantly predicted by time reproduction ($\beta = -0.17$, $p = .04$) and working memory ($\beta = -0.30$, $p = .02$) respectively at Time 1 and Time 2. Importantly, these measures still contributed uniquely to predicting word reading and numeration when all neuropsychological tasks were considered simultaneously. By contrast, neither the IAC nor DAV component predicted academic skills assessed concurrently or one year later.

Hence, our results from the regression analyses showed that both the IAC and TP/WM components were related to the children's ADHD symptoms, but the former appeared to play a more salient role than the latter. For early academic performance, the TP/WM component was the strongest predictor among the three neuropsychological deficits.

Discussion

Factorial Structure of the Neuropsychological Deficits Among Preschoolers

The present study examined the profile of neuropsychological deficits for ADHD in a young population. The results of factor analysis in this study showed that the three proposed neuropsychological constructs in ADHD, namely inhibitory and attentional control deficit, delay aversion, and time perception/working memory deficit, were dissociable from each other in preschoolers.

However, not all factors loaded on the three components as expected. First, working memory, a construct commonly accepted as an element of EF, did not load on the same component as other well recognised measures of EF, including inhibitory and attentional control. This might suggest that working memory is somewhat distinct from inhibitory and attentional control even during the preschool stage, and provide evidence for the differentiation of these abilities in early years of life. By contrast, we observed a strong linkage between working memory and time perception. Based on the principal component analysis, we found that working memory and time perception loaded on the same factor. A similar finding was likewise noted by Sonuga-Barke et al. (2010). Prior research suggested that working memory deficit may affect the accurate registration of temporal pulses emitted by the "internal clock" in the timing process (Gibbon et al., 1984) and thus influence an individual's perception of time (Pan & Luo, 2012; Walg et al., 2017; Lee & Yang, 2018). A study on cognitively impaired adults (including elderly people, patients with Parkinson's disease, and those with severe traumatic brain injuries) has shown that impairments in memory processing might affect the perception of time (Pouthas & Perbal, 2004). Moreover, evidence from a neuroimaging study indicated that the intraparietal and posterior cingulate areas might play a role in the interface of memory and timing (Üstün et al., 2017). Our results provided further evidence to support the hypothesis that working memory is involved in the perception of time (Walg et al., 2017). Future studies should investigate how these two constructs relate to each other in children to foster a better understanding of the developmental etiology of ADHD.

Second, although both considered as measures of delay aversion, the DeFT did not load on the same component as the MIDA. Instead, the DeFT correlated significantly with measures of inhibitory and attentional control. These results corroborated the findings of Sonuga-Barke et al. (2010), who observed two different components of delay aversion based on the two tasks—the DeFT revealed an individual's negative performance due to imposed delay, while the MIDA measured an individual's commitment to wait when

the delay has not yet been imposed. We hypothesized that the amount of button-pressing recorded during the unexpected delay in the DeFT might reflect both the child's level of frustration as well as his/her inhibitory control (or a lack thereof). The current findings further supported the concept that delay aversion might be a complex neuropsychological factor.

Neuropsychological Deficits and Preschool ADHD

Our results confirmed the significant role of executive dysfunction in ADHD pathophysiology among preschoolers, which echoed the results of previous studies that reported distinctive contribution of executive dysfunction to ADHD symptoms among preschoolers (e.g., Brocki et al., 2009; Dalen et al., 2004; Pauli-Pott & Becker, 2011; Sjöwall et al., 2015; Sjöwall & Thorell, 2018; Thorell, 2007). Delay aversion was found to associate marginally with hyperactivity/impulsivity but not inattention, a finding that was in accordance with the results obtained by Thorell (2007). By contrast, time perception deficit in preschool ADHD has been relatively less explored in prior research. In the current study, we found that time discrimination significantly predicted inattention at both Time 1 and Time 2, and remained a unique predictor of ADHD symptoms at Time 2 even after controlling for all other measures and covariates. Hence, our results lent support to the proposition that time perception deficit is an important neuropsychological component in ADHD among preschoolers.

The strengths of the associations between neuropsychological deficits and ADHD symptoms observed in this study were comparable to prior findings, and the amounts of variance in ADHD symptoms accounted for by these components were similar to those previously reported (e.g., Berlin et al., 2004; Breaux et al., 2016; Sjöwall et al., 2017). Nonetheless, these three neuropsychological deficits together only accounted for about 11–19% of the variance in ADHD symptoms, suggesting the presence of other factors that were associated with ADHD. For one thing, we found that the demographic variables, including children's age, their general ability, and treatment condition, predicted a significant portion of variance in inattention at both time points. Other variables not included in the current study might likely be related to ADHD as well, and this awaits further investigation in future studies.

Neuropsychological Deficits and Early Academic Performance

The linkage of the three neuropsychological deficits with early academic skills were less apparent compared to their relations with ADHD symptoms. Notably, children's age

and their general ability were found to be strongly associated with their early academic performance, accounting for 23–36% of the variance along with other controlled variables. The robust linkage between age and academic performance implied rapid development of word reading and numeration skills during the preschool years and the importance of early identification and intervention for children with learning difficulties. Moreover, our results showed that children's general ability predicted a larger proportion of variance in their numeracy than word reading at both time points. Here in our study, general ability was measured nonverbally using the Matrix and Recognition subtests from the WNV (Wechsler & Naglieri, 2006). These two subtests primarily involved matrix reasoning and visual pattern recognition respectively, which might explain why general ability correlated more strongly with mathematics than literacy skills (Kyttälä & Lehto, 2008). Similar results have been found in a cross-cultural study among children in Japan, China, and the U.S., showing that general ability was strongly associated with academic performance, and a higher correlation was found between general ability and mathematics compared to reading (Stevenson et al., 1985).

Another important finding of this study was that timing ability was significantly associated with early academic performance. When children's age, general ability, psychosocial treatment condition, and their family's socioeconomic status were controlled for, time perception and working memory contributed uniquely to children's academic performance at Time 1 and Time 2 respectively, over and above other neuropsychological constructs.

Specifically, we found that Chinese word reading was associated with time discrimination at Time 1 and marginally with working memory at Time 2. Our results corroborated the findings of previous studies on timing and literacy development (e.g., Hood & Conlon 2004; Share et al., 2002; van Zuijen et al., 2012), which indicated that temporal processing ability at an early age could predict reading performance (e.g., word recognition, reading rate, reading comprehension) at a later timepoint. Analogous findings have been observed in the Chinese language (Chung et al., 2008; Wang et al., 2020), showing that temporal processing played an important role in Chinese literacy development. Different from alphabetic languages, Chinese orthography is character-based and each character is composed of one or more radicals (i.e., stroke patterns) and maps onto a syllable. The pronunciation of Chinese characters can be inferred from their phonetic radicals only about 40% of the time (Shu et al., 2003). Therefore, Chinese script is regarded as more opaque than other orthographies with more predictable print-to-sound translation (Chen, 1993; Shum et al., 2016; Sun et al., 2018). This also implies that more memory load is required to recall words in Chinese than in alphabetic

languages. Indeed, working memory has been found to associate with Chinese but not with English reading in a cross-cultural study among preschoolers in China and the U.S. (Lan et al., 2011). The association of time perception and working memory with Chinese word reading in this study lent further support to the importance of these constructs in Chinese literacy development.

For mathematical abilities, we observed significant prediction by time perception at Time 1 and by working memory at Time 2. Results here were comparable to those obtained by Tobia et al., (2016) among preschoolers, which also showed a close relation between time perception and numeration. Vicario et al., (2012) reported similar findings in older children, showing that eight-year-olds with developmental dyscalculia performed more poorly than healthy controls in time processing. These findings suggested that children's temporal and numerical processing abilities might be closely linked. Walsh's theory of magnitude (2003) has provided a plausible explanation for such correlation, suggesting that the mental representations of the magnitude of time, space, and numbers are inherently connected. There is also growing evidence indicating that the interactions of these perceptual dimensions are mediated by neuronal structures in the parietal cortex of the brain (Buetti & Walsh, 2009; Cappelletti et al., 2013; Riemer et al., 2016), which may likely account for the association between temporal processing and mathematical abilities. Interestingly, working memory assessed at age 5 significantly predicted children's numeration skills a year later but not concurrently, which might reflect the increasing reliance on working memory in math learning as children advanced to the next grade.

This study added to the extant literature on the relations between time perception and early academic performance, and provided empirical support for the importance of temporal processing in children's early development of literacy and number skills. Conversely, neither inhibitory and attentional control nor delay aversion was found to correlate with early literacy and math performance. This finding was rather unexpected as executive dysfunction has been commonly associated with subpar academic performance in early childhood (Mariani & Barkley, 1997; Lan et al., 2011; Sjöwall et al., 2017; Thorell, 2007; Traverso et al., 2019). However, it is worth mentioning that most of these prior studies have examined the combined effects of different domains of EF (e.g., inhibitory control, attention, and working memory) on academic performance (Mariani & Barkley, 1997; Sjöwall et al., 2017; Thorell, 2007). By contrast, inhibition and attention deficits were not coupled with working memory in predicting word reading and number skills in the current study, as working memory was loaded on a component distinct from the other EF deficits in the factor analysis.

Clinical Implications

The current study provided evidence to support the heterogeneity of neuropsychological deficits in preschool ADHD. Our findings suggest the importance of adopting a holistic approach to intervention that targets different neuropsychological constructs, including EF, delay aversion, and time perception, in the early support for children at risk of ADHD.

Apart from their associations with ADHD symptoms, time perception and working memory were also indicated to predict word reading and numeration skills among preschoolers. As such, poor performance in time perception and working memory tasks may possibly serve as early markers for later academic difficulties. Moreover, they may also turn out to be plausible points of intervention for young children displaying early signs of learning problems. However, whether time perception and working memory are mutable, and therefore intervenable, is still not entirely clear to date. Prior research has shown that temporal processing ability gradually improves with age in preschoolers, suggesting that time perception is probably mutable (Qu et al., 2021). This postulation is further supported by an intervention study that reported improvement in time perception in preschoolers with and without special needs (Ahlström et al., 2021). By contrast, interventions on working memory have yielded mixed results (Au et al., 2014; Klingberg et al., 2002; Shipstead et al., 2012; Melby-Lervåg & Hulme, 2016), which calls into question the changeability of working memory. Given that relatively little is known about temporal processing in preschoolers, future studies may further explore whether time perception can serve as a plausible target for intervention among young children.

Limitations and Conclusions

There were some limitations in the present study. First, the sample size of the present study was relatively small, and the sample consisted of a large proportion (about 50%) of participants from families with monthly household income above the median in Hong Kong (Census and Statistics Department of Hong Kong SAR, 2021). This might partly account for the high general ability of the children on average in this study. Future studies may consider recruiting a larger sample and with a better representation of families from different SES backgrounds to explore the generalizability of the current findings.

Moreover, we included a community-based sample instead of a clinical sample of children with ADHD. Although parent-report on the SNAP-IV revealed that about 65% of the participants met the DSM-5 diagnostic criteria on inattention and hyperactivity/impulsivity symptom

presentation, not all these children had been clinically diagnosed with ADHD at the time of participation. Future studies may recruit clinical samples of preschoolers with ADHD to further investigate the relations between neuropsychological deficits and early academic performance in preschool ADHD. Furthermore, we did not collect teacher-reports but solely relied on parent-reports on children's ADHD symptoms. The validity of the results could be strengthened by including the teachers as informants to evaluate the children in school settings.

Lastly, it is worth mentioning that due to the COVID-19 pandemic, we did not manage to collect data on children's neuropsychological deficits at Time 2. The correlations between the deficits measured at Time 1 and the outcome variables at Time 2 were expected to be weaker than concurrent associations between the variables. Hence, the current findings based on the regressions of Time 2 outcomes on Time 1 measures needed to be interpreted with caution. Also, assessments of academic skills were conducted online at Time 2. Despite following the same experimental procedures at the two assessment time points (except for the method of stimulus presentation), we were uncertain how the different modes of assessment (face-to-face versus online) might have affected the results. In addition, we were not able to account for the effects of the pandemic on our results as mediated by its impact on children's education, physical health, and psychological well-being. Due to recurrent periods of suspension of face-to-face classes at school, parents were spending more time with their children at home and might have experienced more parenting stress and parent-child conflicts that could have affected their ratings on children's ADHD-symptom behaviors.

In conclusion, the present study demonstrated that inhibitory and attentional control deficit, delay aversion, and time perception deficit were three dissociable neuropsychological constructs in preschoolers. Among them, inhibitory and attentional control was most strongly correlated with ADHD symptoms. Moreover, a strong linkage was observed between time perception abilities and working memory. They significantly predicted early word reading and math performance, suggesting the important role of time perception and working memory in the development of early academic skills. Hence, while poor inhibitory control and inattention might help to indicate preschoolers at risk of ADHD, the detection of deficits in time perception and working memory might serve as a marker to identify children with early learning problems. Whether time perception can be incorporated as a target of intervention for children with ADHD and learning difficulties awaits further investigation.

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Data availability statement The data that support the findings of this study are available from the corresponding author, K. K. M. Shum, upon reasonable request.

Compliance with Ethical Standards

Conflict of Interest K. K. M. Shum, Q. Zheng, Y. Y. C. Cheng, and E. Sonuga-Barke declare that they have no conflict of interest.

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