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ORIGINAL PAPER

Examining Temporal Cognition in Preschoolers With Attention Deficit Hyperactivity Disorder: Insights From Parent–Child Interactions

Valentina Tobia[1] · **Taylor Landis**[2] · **Paulo Graziano**[2]

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Abstract

Increasing evidence supports the existence of time-related impairments in school-aged children and adults with Attention-Deficit/Hyperactivity Disorder (ADHD), but this deficit has not yet been investigated in preschoolers with ADHD. The aim of the current study was to determine the extent to which time-related impairments can be identified within the context of parent–child interactions in preschoolers with ADHD. Participants for this study included 29 children with ADHD and 34 typically developing (TD) children (63.5% male; $M_{age} = 4.77$, $SD = 0.65$; 82.5% Hispanic/Latinx), and their parents. A ten-minute play session was video-recorded for each parent-child dyad. The verbal interactions were transcribed and coded for words/expressions related to the categories of time (e.g., "later", "tomorrow"), as well as mathematics (e.g., "two more", "some"), and space (e.g., "here/there", "behind"). The proportion of tokens (total number of terms) and types (different terms) of each category was calculated in relation to the total verbal production for each individual (i.e., parents and children separately), and differences between groups were analyzed. Results indicated that compared to TD children, children with ADHD showed a poorer vocabulary of time-related words ($d = 0.63$), whereas similar rates between groups were found for the math- and space-related words. Correlation analyses revealed significant associations between the types of time-related words used by children, and problems with attention and executive functioning. These results offer some evidence for not only the presence of time-related deficits in preschoolers with ADHD, but also the association between time-related deficits and impairments in cognitive functioning.

Keywords Time processing deficit · Time-related words · Attention-Deficit/Hyperactivity Disorder · Preschool · Parent–child interaction

Highlights

- Time-related impairments characterize individuals with ADHD, but they have never been investigated in preschoolers with ADHD.
- A poorer vocabulary of time-related words was found in preschoolers with ADHD, compared to controls.
- Preschoolers with ADHD and controls showed similar rates of math- and space-related words.
- Significant associations between the types of time-related words used by children, and problems with attention and executive functioning, were identified.

The capability of processing and estimating time, also definable as sense of time or temporal cognition (Zakay & Block, 1997), is a fundamental and complex function in human beings: individuals need to keep track of temporal durations of inner and outer events, for developing a sense of their own story and for interacting efficiently with the surrounding environment (Grondin, 2010). Increasing evidence supports the existence of time-related impairments in individuals with Attention-Deficit/Hyperactivity Disorder

✉ Valentina Tobia
tobia.valentina@unisr.it

[1] Vita-Salute San Raffaele University, Via Olgettina, 58, 20132 Milan, Italy

[2] Florida International University, 1200 SW 8th St, Miami 33199 FL, USA

(ADHD; Hart et al., 2012; Noreika et al., 2013; Toplak et al., 2006). ADHD is a neurodevelopmental disorder characterized by inattention and/or hyperactivity/impulsivity, associated with poor social, behavioral, and academic outcomes (American Psychiatric Association, 2013; Currie & Stabile, 2004; Ros & Graziano, 2018). Theoretical models of neuropsychological functioning, such as the triple pathway model, recognizes that individuals with ADHD have deficits in timing, inhibition and delay (Sonuga-Barke et al., 2010). Alterations in temporal cognition may represent a primary cause of key symptoms in ADHD, and the assessment of time estimation skills has been recently hypothesized to be a potential useful method for differential diagnosis, distinguishing between confirmed cases of ADHD and other psychiatric disorders characterized by symptoms similar to that of ADHD (Walg et al., 2017).

Time-Related Skills in Preschoolers

Literature on temporal cognition and time comprehension in typically developing preschoolers offer insights that are meaningful for the purposes of the present study. A sense of time is exhibited as early as infancy, and improvements in temporal skills are observed between 3 and 10 years of age (Droit-Volet, 2013). By age 5, children's time processing skills are associated with short-term memory span and the development of attention and executive functioning (EF; Zélanti & Droit-Volet, 2011), working memory and information processing speed (Droit-Volet & Zélanti, 2013). More specifically, a recent study in 4-year-old children demonstrated the association between time comprehension and the ability to delay gratification, such that preschoolers who performed at chance level in a time estimation task, showing scarce comprehension of the time concept, had more difficulty waiting during a delay-of-gratification task (Zmyj, 2018).

Time processing difficulties can be identified with both behavioral tasks (e.g., time reproduction, time estimation, time discrimination; Plummer & Humphrey, 2009; Smith et al., 2002) and self- or proxy-report questionnaires (e.g. "It's About Time" questionnaire; Barkley, 1998). However, preschool children are often not aware of the passage of time and its relevance since time judgments are context-dependent at this age (Droit-Volet, 2013). For this reason, use of experimental tasks for assessing time processing, in which explicit time judgment are required, can lead to an inaccurate estimation of children's time-processing skills. However, when the duration of daily activities is in question, children are able to accurately judge the length of temporal intervals as early as 3–5 years (Friedman, 1990).

One way for investigating temporal cognition, not yet applied to children with ADHD, is through analysis of caregiver-child verbal interactions to identify abnormal patterns in the use of time-related terms. Play sessions in which the child interacts with his/her caregiver, are ecologically valid situations in which spontaneously produced language can be observed. A similar approach has been used, to investigate the use of temporal terms in children from different socio-economic backgrounds (Rosemberg et al., 2014). As pointed out by this last study, children's understanding of time concept is not directly observable. Language allows individuals to conceptualize the abstract aspects of temporality. By analyzing linguistic production, it is possible to identify indicators of understanding of time concept, such as the time-related terms produced in verbal interactions (Rosemberg et al., 2014). Because children acquire linguistic terms for describing time-related concepts during the preschool years (Busby Grant & Suddendorf, 2014), 4–5 years of age is an optimal period for investigating this issue. At this stage of development, children are able to produce time-related terms such as temporal (e.g., always) or sequential (e.g., after) adverbs, adverbial phrases (e.g. in the afternoon), and nouns referring to time (e.g., minutes; Busby Grant & Suddendorf, 2014; Rosemberg et al., 2014).

To date and to the best of our knowledge, the literature has not directly analyzed the association between the use of temporal terms by children and their actual time-related skills. However, a few recent studies could shed some light on this topic. For example, Tobia et al. (2019) analysed the predictive power of a questionnaire investigating preschoolers' "sense of time" on time processing tasks. Results demonstrated a significant association between teachers' reported "sense of time" and tasks of time reproduction and time discrimination both concurrently and longitudinally (Tobia et al., 2019). This finding is noteworthy because the majority of the items on the "sense of time" teacher questionnaire related to the use of temporal terms and time-related speech (e.g., spontaneous references to durations in their speech), thus supporting the existence of an association between use of temporal terms and performance in time processing tasks. Furthermore, it has been hypothesized, starting from studies investigating how children learn temporal terms (e.g., Tillman et al., 2017), that the use of temporal terms in children's language provides the primary source of the temporal reasoning system (Tillman, 2019).

Time-Related Skills in Children with ADHD

Time processing deficits characterize the profile of ADHD in school-aged children (Houghton et al., 2011; Huang et al., 2012; Meaux & Chelonis, 2003; Smith et al., 2002; Walg et al., 2015), potentially affecting daily routines, home and school activities, and social relations. However, despite many results reflecting time-related deficits in ADHD, these findings are equivocal, and some studies have reported no significant temporal or timing deficits in this population (e.g., Brown & Vickers, 2004).

Despite the increasing evidence of time processing deficits in older children and adults with ADHD, there is limited research examining these processes as early as preschool. Some evidence comes from the administration of the Behavior Rating Inventory of Executive Function-Preschool Version (BRIEF-P; Gioia et al., 2003), containing a Plan/Organized subscale that assesses behaviors related to time management, estimation of time and organization of steps directed to a goal. Preschoolers with ADHD score significantly worse on the Plan/Organized scale when compared to typically developing controls (Mahone & Hoffman, 2007). However, considering the inconsistent validity of the BRIEF subscales (Spiegel et al., 2017), Mahone and Hoffman's (2007) result may reflect general self-regulation problems in preschoolers with ADHD, rather than a difficulty specifically related to time management. Similarly, Marks et al. (2005) assessed memory of time in preschoolers with ADHD and found that children with ADHD demonstrated significantly weaker temporal sequencing performance compared to typically developing peers. However, results indicated weaker observed performance may be a byproduct of deficits in nonexecutive abilities, and not directly related to a specific memory of time deficit. The well-known deficits in working memory, attention, speed of processing (Kalff et al., 2005; Mahone & Hoffman, 2007), and delayed gratification (Pauli-Pott & Becker, 2011) in preschoolers with ADHD support the expectation of finding weaker time-related skills in this population. Furthermore, deficits in time processing skills may be associated with deficits in EF and symptoms of ADHD (Zélanti & Droit-Volet, 2011).

Math- and Space-Related Difficulties in Children with ADHD

Underachievement in students with ADHD has been identified across both the literacy and mathematics domains (Barry et al., 2002), with particularly severe problems in learning mathematics. However, these deficits have been partly interpreted as consequences of poor attention and EF, associated with ADHD and essential skills for determining mathematical knowledge and procedures (Zentall, 2007). Considering the developmental path of learning skills in children with ADHD, deficits in mathematical learning become progressively larger with age, with discrepancy between IQ scores and achievement in mathematics increasing in older students (Nussbaum et al., 1990). However, little is known about the mathematical skills of preschoolers with ADHD. The investigation of math-related words during play interaction can be an indirect way to investigate the onset of such learning difficulties among young children (Anderson, 1997; Blevins-Knabe & Musun-Miller, 1996).

One cognitive process associated with mathematical skills as early as preschool is spatial ability (Cornu et al., 2018; Verdine et al., 2014). Visuo-spatial deficits have been identified in some samples of children with ADHD. In particular, children with ADHD performed more poorly on tasks assessing visuo-spatial working memory (Alloway & Stein, 2014; Westerberg et al., 2004) and on the spatial tasks of the WISC-R and WISC-V (Bonafina et al., 2000; Raiford et al., 2015). However, visuo-spatial difficulties dissipate in early adolescence (Westerberg et al., 2004), and data on preschoolers are still limited.

The Present Study

To date, no research has directly investigated time-related difficulties in children aged 4-5 years with ADHD. As Pauli-Pott and Becker (2011) suggested, it is important to isolate time windows suitable for an early reliable assessment of the deficits associated with ADHD. This study contributes to the literature by investigating the time-related deficit characterizing ADHD in preschoolers through the analysis of parent–child interactions. In the past, some studies observed language production during interactions between parents and children with ADHD, mainly for investigating the use of language to guide and control children's behavior (Bindman et al., 2013) or analyzing children's pragmatic language abilities (Camarata & Gibson, 1999). Thus, it is possible to investigate the role of parents' linguistic input in relation to key features of ADHD through the analysis of the verbal interactions between parents and their children. Analyzing both children's and parents' production of time-related words will therefore clarify the extent to which caregiver linguistic input relates to children with ADHD's time-processing difficulties. Poor time-related language in children with ADHD, in a situation in which the linguistic input by their parents is adequate, will offer evidence in favor of a time processing deficit in ADHD independent from environmental influences.

The primary aim of the present study was to examine temporal cognition in a sample of preschoolers with ADHD, compared to typically developing peers. We investigated this issue by observing parent-child play interactions and analyzing the use of time-related words in spontaneous verbal production. We hypothesized that verbal interactions between children with ADHD and their parents would contain a weaker set (in terms of quantity and diversity) of time-related terms, compared to typically developing peers, whereas similar quantity and diversity were expected for math- and space-related words. Difficulties related to these domains may indeed emerge later in development, as a consequence of poor EF (Zentall, 2007). This result would offer some evidence in favor of an early time-related deficit as a neuropsychological marker in children with ADHD (Sonuga-Barke et al., 2010), and would support the existence of this deficit in the preschool age group. Furthermore, this would be the first investigation of temporal cognition obtained by the analysis of spontaneous verbal production during child-parent play interactions in children with ADHD. The consideration of parents' utterances would determine if time-related language in children with ADHD is associated to time-related expressions used by their parents.

The secondary aim was to examine the associations between the time-, math- and space-related words and core features or impairments that characterize ADHD in preschoolers (e.g., symptom severity, EF, and academic and cognitive functioning). Past studies with typically developing children suggest links between time and EF, as well as attentional skills (Zélanti & Droit-Volet, 2011). The current study will expand such works by examining these associations in preschoolers with ADHD. Deficits in academic functioning, higher rates of hyperactivity and attention problems, as well as weaker EF characterize the profile of children with ADHD (Kalff et al., 2005; Mahone & Hoffman, 2007). Furthermore, attention and EF are related to both temporal cognition (Zélanti & Droit-Volet, 2011) and mathematical ability (Zentall, 2007). Thus, we expected greater time-related word production would be associated with fewer attention problems, better academic performance, and better EF.

Method

Participants

The sample included 29 children with ADHD (79.30% males, mean age = 4.85 ± 0.56 years old) and 34 TD (50% males, mean age = 4.71 ± 0.72 years old) children. Sample demographics and screening variables for both groups are described in Table 1. For each participant, a parent was involved including 28 mothers and 1 father of children with

Table 1 Participants' demographic and screening variables

	ADHD ($N = 29$)	TD ($N = 34$)
Child sex (% male)	79.30	50.00*
Child age (mean)	4.85 (0.56)	4.71 (0.72)
Child ethnicity (%Hispanic/Latino)	79.30	85.30
Child prime language (%)		
English only	44.80	29.40
Spanish only	6.90	2.90
English and Spanish	44.80	64.70
Other	3.40	2.90
Caregiver age (mean)	35.83 (6.43)	35.91 (4.82)
Caregiver level of education[a] (mean)	4.69 (1.26)	5.00 (0.89)
Child full scale IQ (Mean)	96.45 (14.45)	108.15 (10.60)**
BASC-2 hyperactivity T-score parent (mean)	71.10 (12.71)	43.97 (7.26)**
BASC-2 attentional problems T-score parent (mean)	65.65 (7.87)	45.68 (6.79)**
BASC-2 hyperactivity T-score teacher (mean)	68.76 (2.28)	N/A
BASC-2 attentional problems T-score teacher (mean)	61.52 (1.25)	N/A
BRIEF plan/organize T-score (Mean)	66.41 (14.41)	47.38 (11.23)**
BRIEF global executive functioning T-score (mean)	73.00 (13.77)	44.12 (7.81)**
Head–toes–knees–shoulders total score	14.21 (14.09)	27.41 (12.10)**
WJ-III achievement standard score (Mean)	104.68 (16.06)	117.94 (11.27)**
Total number of tokens produced by children	342.83 (141.53)	382.59 (149.57)
Total number of tokens produced by parents	730.03 (207.98)	757.15 (217.38)
Total number of types produced by children	158.55 (45.72)	176.85 (49.39)
Total number of types produced by parents	256.76 (44.62)	277.21 (54.34)

Note: ADHD Attention-Deficit/Hyperactivity Disorder, *BASC-2* Behavior Assessment System for Children, 2nd Edition, *BRIEF* Behavior Rating Inventory of Executive Function.

*$p < 0.01$ significant group differences, **$p < 0.001$ significant group differences.

[a]1 = Some high school, 2 = High school graduate, 3 = Some college, 4 = Associates degree, 5 = College graduate (bachelor degree), 6 = Advance graduate (masters, MBA, MD, Ph.D, JD).

ADHD and 28 mothers and 6 fathers of TD children. Parents of children in the two groups were balanced for age and level of instruction (see Table 1).

Participants were recruited via brochures, radio and newspaper ads, involving local preschools and mental health agencies, open houses, and parent workshops. A total of 78 families responded, 40 of whom indicated having children with behavioral problems. A screening appointment was scheduled for all 78 families, and written informed consent was provided by the primary caregivers of all the participants. Due to technical problems with the transcription of child-parent interactions, 6 children in the group of children with behavioral concerns were excluded from the sample. For the selection of the ADHD group, the following criterion were applied to the remaining 34 children initially identified as having behavioral problems, leading to a sample of 30:

(a) Meeting DSM-IV criteria for a diagnosis of ADHD ($n = 21$),

(b) Meeting DSM-IV criteria for a diagnosis of oppositional defiant disorder (ODD) *plus* having clinically significant levels of hyperactivity or inattention ($n = 7$) as indicated by:

(b1) at least 6/9 items of Inattention or Hyperactivity/Impulsiveness scored as “Pretty much” and “Very much” on the parent version of the Disruptive Behavior Disorder Rating Scale (DBD; Pelham et al., 1992),

(b2) a T-score of 60 or higher on the Hyperactivity and Attention Problems subscales of the parent/teacher BASC-2 (Reynolds & Kamphaus, 2004) or

(c) Showing hyperactivity *and* inattention symptoms as indicated by the (b1) criteria ($n = 2$).

The diagnosis of ADHD or ODD (criterion a/b) was obtained through a parent structured interview (Diagnostic Interview Schedule for Children Version IV; Shaffer et al., 2000) and parent and teacher rating scales (Pelham et al., 1992) based on standard practice recommendations (Pelham et al., 2005) by a psychologist. According to these criterion, four participants were excluded from the ADHD group.

Children included in the typically developing (TD) group did not meet DSM-IV criteria for any developmental disorder and could not have had elevated levels of hyperactivity or inattention symptoms as indicated by

(a) a Hyperactivity *and* Attentional problems T-score <60 on the parent BASC-2 (Reynolds & Kamphaus, 2004), and
(b) less than 6/9 items of Inattention and Hyperactivity/Impulsiveness scored as “Pretty much” and “Very much” on the parent version of the Disruptive Behavior Disorder Rating Scale (DBD; Pelham et al., 1992).

According to these criterion, four children were excluded from the TD group.

Finally, IQ was measured through the administration of the Wechsler Preschool and Primary Scale of Intelligence–Forth Edition (WPPSI-4; Wechsler, 2012), conducted by doctoral level graduate students under the supervision of a licensed psychologist (third author). All children were required to have a full scale IQ score of 70 or higher for inclusion in the current study. According to this criteria, one additional participant was excluded from the ADHD group, resulting in a final sample of 29 children with ADHD.

In terms of compensation, families who participated in this study were provided individualized feedback regarding their children’s academic performance while those in the ADHD group were also eligible to receive a summer treatment intervention (Graziano et al., 2014) at a subsidized cost.

Procedure

Two 5-minute play sessions were video-recorded for each parent-child dyad. In one session, parents were instructed to direct the play session (parent directed interaction; pdi), choosing the games and the game-rules; in the other session, children were encouraged to lead the game (child directed interaction; cdi). These CDI and PDI play sessions are routinely done in parent training research, specifically parent–child interaction therapy (PCIT; Hembree-Kigin & McNeil, 2013). The play sessions were transcribed and coded for identifying words and expressions related to time, mathematics, and space. Time words/expressions included temporal adverbs (e.g., “later”, “always”), temporal adverbial expressions (e.g., “in the evening”, “for a minute”), and nouns denoting time (e.g., “week”). Temporal terms were identified based on past research investigating time-related words in preschoolers (Busby Grant & Suddendorf, 2014; Rosemberg et al., 2014). Mathematics words and expressions were derived congruent with past research analyzing math-related activities and discourses in parent-child and teacher-child interactions (Anderson, 1997; Blevins-Knabe & Musun-Miller, 1996; Klibanoff et al., 2006). Mathematics words/expressions included number words, expressions describing quantities (e.g., “all”, “some of”), manipulation of quantities (e.g., “two more”), and terms describing shape attributes (e.g., “bigger”, “small”). Space words/ expressions included terms referring to the location of objects and people (e.g., “here/there”, “far/near”, “behind”) consistent with previous studies (Anderson, 1997; Ferrara et al., 2016).

All videos were transcribed into the CHAT (CHILDES system) format (MacWhinney, 2000). The total number of words/expressions in the time, math, and space categories (tokens) and the different terms within a category (types) were determined for both children and parents by a trained developmental psychologist. For the 20% of participants (Syed & Nelson, 2015), tokens and types for the three categories were independently coded by a second observer, showing very good to excellent reliability (r's = 0.83-0.94). The second observer was trained by a developmental psychologist based on the math, space, time coding scheme described above. The percentages of tokens and types in each category, in relation to the total tokens and types of words produced by each individual, were then calculated.

Florida International University institutional review board approved the project.

Measures

Behavioral Functioning

Within the ADHD and TD samples, parents and teachers competed the Behavior Assessment System for Children, 2nd Edition (BASC-2; Reynolds & Kamphaus, 2004). The BASC-2 is a widely-used tool that assesses emotional and behavioral domains. For the purposes of this study, the Hyperactivity and the Attention Problems T-scores were used ($\alpha s = 0.93$–0.95; Reynolds & Kamphaus, 2004). This instrument proved to have adequate concurrent and predictive validity (see Pelham et al., 2005).

Parents within the ADHD and TD samples also completed the Disruptive Behavior Disorder (DBD) Rating Scale (Pelham et al., 1992) to measure symptoms of ADHD. Each symptom of ADHD is rated on a 4-point frequency scale from 0 ("not at all") to 3 ("very much"). For the purposes of the present study, the Inattention ($\alpha = 0.93$) and Hyperactivity/Impulsivity ($\alpha = 0.93$) scales were used (Pelham et al., 1992); more information on DBD validity and reliability can be found in Pelham et al. (2005).

Executive Functioning (EF)

Parents of children of both groups completed the Behavior Rating Inventory of Executive Function–Preschool version (BRIEF-P; Gioia et al., 2003). The BRIEF-P assesses five clinical scales (inhibit, shift, emotional control, working memory, and plan-organize). Higher scores on clinical scales/composites are indicative of weaker EF skills. The plan/organize subscale ($\alpha = 0.90$) and the global composite score ($\alpha = 0.98$) were used as measures of EF; validity based on convergence or divergence with a variety of measures and on internal factor structure was proven (Gioia et al., 2003).

Children were administered the head–toes–knees–shoulders task (HTKS; Ponitz et al., 2008). HTKS is a widely-used measure of EF, suitable for preschoolers. In this task, children are required to follow a set of behavioral rules paired with conflicting behavioral responses. There are two parts to the task, each with 10 trials. Prior to each part, children are given a set of rules (e.g., "touch your head" and "touch your toes"), such that the child must respond with the opposite behavior. In the second part, a new set of rules is added (i.e., shoulders and knees). Children received two points for a correct response, one point for a self-corrected response, or zero points for an incorrect response, with a total possible score of 40. Higher scores indicate better EF performance. Examinations of the HTKS revealed 3-month test–retest reliability above 0.90 (Ponitz et al., 2008), good concurrent validity with parents' ratings of attention and inhibitory control (Ponitz et al. 2009), and validity in a sample of children with externalizing behavior problems (Graziano et al., 2015).

Academic functioning and IQ

Children were administered six subsets from the Woodcock–Johnson Test of Achievement, 3rd Edition (WJ-III, Woodcock et al., 2001). The six subsets (i.e., applied problems, calculation, writing samples, letter-word identification, passage comprehension, spelling) were standardized and combined to create an academic achievement composite score ($\alpha = 0.85$ on our sample), such that higher scores indicated better academic achievement. Median reliability coefficients for the subtests were .80 or higher (Woodcock et al., 2001). Extensive evidence of content, construct, and concurrent validity of the WJ-III is reported in the test's manual (Woodcock et al., 2001).

The full-scale IQ was obtained through the administration of the WPPSI-4 (Wechsler, 2012) for the age range 4:0–7:7. Reliability values have been found to be between the good ($\alpha = 0.86$) to excellent ($\alpha = \geq 0.90$) range, with FSIQ having 0.96 as internal consistency and 0.93 as test–retest reliability (Syeda & Climie, 2014). The WPSSI-4 also shows good content validity and internal structure (Syeda & Climie, 2014).

Data Analyses

All analyses were conducted using Statistical Package for the Social Sciences, version 25 (SPSS 25). Preliminary analyses investigated any associations among the dependent variables and demographics, as well as any difference in the global number of tokens and types produced by children and parents in the two groups during interactions. MANOVAs were then conducted to investigate the differences between children with ADHD ($n = 29$) and TD children ($n = 34$) in parents' tokens and types used for each semantic category (i.e., time, math, space). Finally, correlation analyses on the entire sample were conducted to determine if the variables of interest (tokens and types) were associated with demographic variables (parents' educational level, children's IQ), ADHD-related symptoms (Hyperactivity and Attentional problems subscales of the BASC-2; Reynolds & Kamphaus, 2004); children's EF (measured with the BRIEF; Gioia et al., 2003, and via the HTKS task; Ponitz et al., 2008); and children's academic functioning (WJ-III; Woodcock et al., 2001).

Results

Preliminary Analyses

Preliminary analyses examined any potential associations between demographic variables and the study's outcomes. There were no significant associations between demographics and the study's dependent variables. In particular, no sex differences emerged, ts(61) = −1.705–1.963, ps = 0.054–0.737. However, as seen in Table 1, a significant difference in IQ was found between children with ADHD and TD. For this reason, IQ was included as a covariate in subsequent analyses. No significant differences between groups were found in the total number of tokens and types produced by children and parents in the interactions, ts(61) = 0.503–1.614, ps = 0.112–0.617. Additionally, associations between child and parent types and tokens were examined (see Table 2). For both parents and children, a significant correlation between types and tokens within each category emerged; therefore, tokens and types of each category were included together as dependent variables in subsequent MANCOVAs.

Analyses of verbal production

Children

The results of the MANCOVAs run for the time category, revealed a significant multivariate effect of Group, $F(2, 59) = 3.67$, $p = 0.03$; $\eta^2 = 0.11$, and a non-significant effect of the covariate, $F(2, 59) = 1.77$, $p = 0.18$; $\eta^2 = 0.06$. Children with ADHD produced a significantly lower proportion of types of time-related terms compared to TD children, $F(1, 60) = 4.45$, $p = 0.04$, $d = 0.63$, whereas time-related tokens were similar across groups, $F(1, 60) = 1.03$, $p = 0.31$; $d = 0.21$. On the contrary, for both the math and space categories, the MANCOVAs lead to non-significant multivariate results for both Group, $F(2, 59) = 0.19$, $p = 0.83$; $\eta^2 = 0.01$ and $F(2, 59) = 0.05$, $p = 0.95$; $\eta^2 = 0.002$ respectively, and for the covariate, $F(2, 59) = 0.35$, $p = 0.71$; $\eta^2 = 0.01$ and $F(2, 59) = 0.78$, $p = 0.46$; $\eta^2 = 0.03$ respectively. Figure 1 represents the percentage of children's types and tokens in each category.

Table 2 Pearson correlations for types and tokens in the time, math and space categories, for (a) children and (b) parents

(a) Children	Math tokens	Time tokens	Space tokens	Math types	Time types
Time tokens	−0.02	–			
Space tokens	−0.07	−0.10	–		
Math types	0.88**	0.07	−0.10	–	
Time types	−0.004	0.86**	−0.15	0.02	–
Space types	−0.06	−0.06	0.73**	−0.09	−0.06
(b) Parents					
Time tokens	0.38**	–			
Space tokens	0.51**	0.32*	–		
Math types	0.71**	0.16	0.05	–	
Time types	−0.06	0.54**	−0.17	0.08	–
Space types	0.07	0.09	0.57**	−0.10	0.001

*$p < 0.05$; **$p < 0.01$.

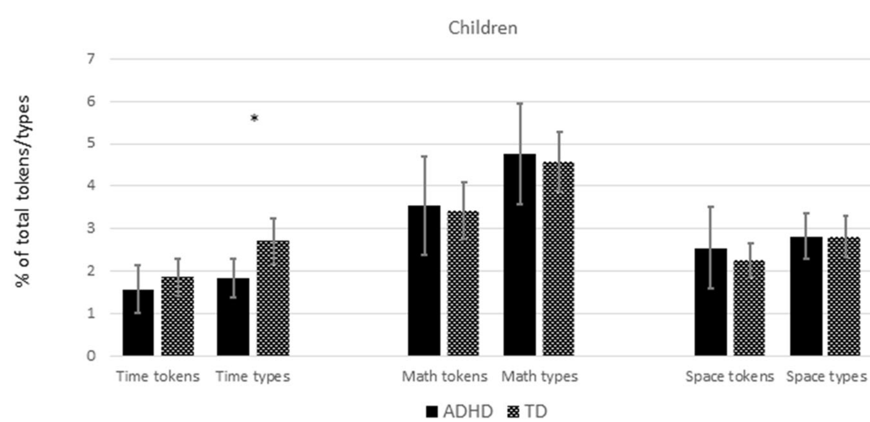

Fig. 1 Percentage of tokens and types in the time, math and space categories, produced by children with ADHD and with typical development (TD). *$p < 0.05$

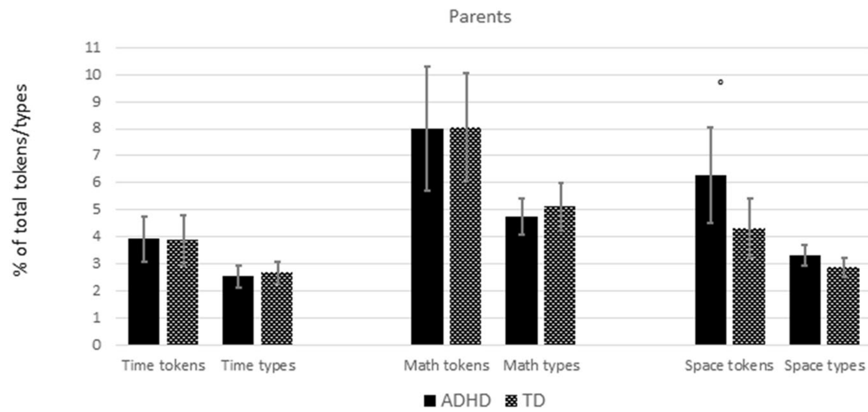

Fig. 2 Percentage of tokens and types in the time, math and space categories, produced by parents of children with ADHD and with typical development (TD). °$p = 0.052$

Parents

The analysis of parent's verbal production showed a non-significant effect of Group for all the categories considered: time-related terms, $F(2, 60) = 0.25$, $p = 0.78$; $\eta^2 = 0.01$, math-related terms, $F(2, 60) = 0.42$, $p = 0.66$; $\eta^2 = 0.01$, and space-related terms, $F(2, 60) = 2.13$, $p = 0.13$; $\eta^2 = 0.07$. It should be noted that, when looking at the univariate effects, a marginal significant effect of Group was found for the space-related tokens, $F(1, 61) = 3.92$, $p = 0.052$; $d = 0.50$, with parents of children with ADHD showing a higher number of words produced within the space category. The percentage of parents' types and tokens in each category are presented in Fig. 2.

Correlational Analyses

Pearson correlations between types and tokens in the time, math and space categories, and children's ADHD symptoms, executive functioning, and academic and cognitive functioning were performed.

Demographic factors

There were no significant associations between children's age, caregivers' level of instruction and the study's dependent variables.

ADHD symptoms

As seen in Table 3, children's time types were significantly correlated with parent rated attention problems, $r = -0.34$, $p = 0.006$. Children who showed more time types demonstrated less attention problems. No other child or parent tokens or types were significantly associated with ADHD symptoms.

Executive functioning

As seen in Table 3, children displaying a greater number of time types were reported by parents as having less EF problems as indicated by the BRIEF Plan-Organize Scale and Global Executive Functioning Composite, $r = -0.28$, $p = 0.029$ and $r = -0.31$, $p = 0.012$, respectively. Correlations between parent's verbal production and children's executive functioning variables revealed that more tokens of space-related words produced by parents was associated with weaker EF performance on the HTKS task, $r = -0.26$, $p = 0.04$.

Academic and cognitive functioning

As shown by Table 3, no significant correlations were found between children's verbal production and their academic and cognitive functioning. A significant correlation emerged between parent's tokens of space-related words and children's IQ, $r = -0.32$, $p = 0.01$, with greater use of space-related words by parents being related to lower child IQ.

Discussion

This study was primarily aimed at analyzing temporal cognition in preschoolers with ADHD, considering the lack of research on this topic. The language production—i.e., total number of terms within the time, math and space categories (tokens), and the diversity of these terms (types)—was examined during parent-child play interactions. Play sessions are ecologically valid situations which minimize problems related to the request of explicit time judgments to such young children (Droit-Volet, 2013). Results indicated that preschoolers with ADHD produced fewer types of time-related words and expressions compared to TD peers, whereas no group differences were found for math- and space-related terms. The secondary aim of the current study was to examine the associations between children's and parents' language production and children's ADHD symptoms, executive functioning, and academic and cognitive functioning. We found that a higher number of time-related types produced by children was linked to lower parent-rated attentional problems and lower executive functioning problems. Furthermore, more tokens

Table 3 Pearson correlations between types and tokens in the time, math and space categories, demographics and children's screening measures for (a) children and (b) parents

(a) Children		Time tokens	Math tokens	Space tokens	Time types	Math types	Space types
Demographics	Caregiver level of instruction	0.03	0.05	−0.06	−0.09	0.04	0.05
	Child's age	0.04	−0.11	0.04	0.04	−08	0.03
ADHD symptoms	BASC-2 hyperactivity	−0.06	0.02	0.10	−0.23	0.07	0.02
	BASC-2 attentional problems	−0.17	−0.04	0.10	−0.34**	0.002	0.02
Executive functioning	BRIEF plan-organize	−0.17	−0.10	−0.01	−0.28*	−0.09	−0.04
	BRIEF global executive functioning	−0.16	−0.01	0.04	−0.31*	0.03	−0.02
	HTKS	0.07	−0.07	−0.18	0.20	−0.02	−0.17
Academic and cognitive functioning	WJ-III achievement	0.13	0.04	−0.05	0.25	0.08	0.04
	IQ	0.03	0.07	−0.16	0.16	0.08	−0.06
(b) Parents							
Demographics	Caregiver level of instruction	0.05	0.18	−0.01	−0.01	0.06	0.09
	Child's age	−0.06	−0.22	−0.07	−0.06	−07	0.09
ADHD symptoms	BASC-2 hyperactivity	−0.10	−0.13	0.03	−0.10	−0.09	0.05
	BASC-2 attentional problems	−0.04	−0.07	0.19	−0.11	−0.10	0.19
Executive functioning	BRIEF plan-organize	−0.04	−0.02	0.17	−0.16	−0.10	0.10
	BRIEF global executive functioning	−0.05	0.03	0.22	−0.15	−0.08	0.12
	HTKS	−0.13	−0.15	−0.26*	−0.12	0.01	−0.20
Academic and cognitive functioning	WJ-III achievement	0.05	−0.06	−0.22	0.15	0.07	−0.22
	IQ	−0.23	−0.11	−0.32*	−0.07	−0.02	−0.14

Note: BASC-2 Behavior Assessment System for Children, 2nd Edition, *BRIEF* Behavior Rating Inventory of Executive Function, *HTKS* Head–toes–knees–shoulders task, *WJ-III* Woodcock–Johnson Test of Achievement, 3rd Edition.

**$p < 0.01$; *$p < 0.05$.

of space-related words produced by parents were associated with weaker EF performance showed by children on the HTKS task. Math-related words were not associated with ADHD symptoms, executive functioning, or academic and cognitive functioning. The implications of our findings are discussed below.

Our primary result, namely fewer types of time-related words used by children with ADHD relative to their TD peers, suggests that the time processing impairments characterizing ADHD (Noreika et al., 2013) emerge as early as the preschool age. The current study found early time processing deficits in children with ADHD in the quality (i.e., heterogeneity) of time-related language production, but not quantity. Furthermore, this gap between children with ADHD and TD was found exclusively for time-related words, as no significant differences emerged for words in the math- or space-categories. This is the first direct evidence of deficits in temporal cognition of children with ADHD as young as preschool.

The lower heterogeneity of time-related words found in preschoolers with ADHD could be related to the linguistic input received by their parents. In fact, it is expected that children's use of words and verbal expressions is closely tied to the communicative input they receive by their caregivers (e.g., Tomasello, 2009), especially for time-related words (Hudson, 2006; Levy & Nelson, 1994). However, the present study showed weaker production of time-related terms in children with ADHD compared to TD children in a context in which all parents produced similar amounts of temporal terms. This suggests that fewer types of temporal terms used by children with ADHD likely do not lie in the linguistic input they receive from their primary caregivers, rather are influenced by other variables. Considering the hypothesis that identifies time processing deficits as an independent neuropsychological component, and as an endophenotype of ADHD (Hwang-Gu & Gau, 2015; Sonuga-Barke et al., 2010), the reduced heterogeneity of temporal terms in preschoolers with ADHD may reflect this specific and early feature of ADHD. Also, it has been hypothesized that the use of temporal terms in young children could support the development of the temporal reasoning system (Tillman, 2019), and the assessment of children with a questionnaire investigating, among other time-related skills, their use of temporal terms, has been found to be predictive of time processing skills measured with behavioral tasks (Tobia et al., 2019). This literature supports an important role the use of time-related words could have in the development of time-related skills. Furthermore, considering children with ADHD underperformed TD peers only in time-related terms, rather than all three categories, this result cannot be considered the consequence of the recognized comorbidity between ADHD and language deficits (Tirosh & Cohen, 1998).

Another result of the present study is the lack of differences found between the ADHD and TD groups in children's use of math and spatial words, which may be also related to the young age of our sample. In accordance with this interpretation, some studies showed that math difficulties in children with ADHD are a consequence of their attentional and EF deficits, and tend to emerge when children are exposed to academic requests during the school years (Zentall, 2007). A similar path has been demonstrated for space-related problems, which become stronger with age when compared to TD's skills (Westerberg et al., 2004). It is therefore possible that impairments in language production related to the math and space domains would emerge in the following years, but may not yet be detectable in preschoolers. Alternatively, it is also possible that math- and space-related deficits in ADHD would never affect children's language production but would emerge only in their performance in behavioral tasks and learning. Consistent with this hypothesis, the current study identified lower academic achievement in children with ADHD.

Secondary aim of this study was analyzing the association between the time-, math- and space-related words and core features characterizing ADHD, specifically EF and achievement. The current study only found significant associations between children's types of time-related terms and attention problems and executive functioning. These findings are consistent with past research showing the association of time processing with attention skills and EF (Droit-Volet & Zélanti, 2013; Zélanti & Droit-Volet, 2011). Our findings contribute to this emerging literature by demonstrating that a language measure of temporal cognition is correlated with attention and EF in young children. Additionally, the current study offers indirect evidence that a profile of high inattention and low EF, typical of ADHD, is associated with a weaker temporal cognition, corroborating the group differences found in the present sample of preschoolers.

As it relates to our analyses of parents' verbal production, we found a marginal effect in terms of higher use of space-related words by parents of children with ADHD. This may be a function of a greater use of commands as a way to manage their children's behavior. In fact, past studies have shown more frequent use of verbal direction and commands during interactions between caregivers and children with ADHD, compared to TD (Danforth et al., 1991). The present study's correlation analyses are partially in line with this interpretation. More tokens of space-related words were produced by parents of children with weaker EF and a lower IQ. Unexpectedly, parents' education level was not related to their verbal production categories. Considering past research demonstrating mothers with higher SES using longer utterances and more types of words when they talk to their children (Hoff, 2003), we expected significant correlations of parents' verbal production with this variable. However, the production of terms within the categories considered in the present study seems to be linked to children-level variables, more than to parents' education.

Many studies investigating time-related difficulties in children with ADHD used wide age-ranges and included only school-aged and older children (e.g., Houghton et al., 2011; Smith et al., 2002). The present study is the first investigation of temporal cognition, in terms of time-related verbal production, in preschoolers with ADHD. This responds to the need to clarify time periods for reliable assessments of specific deficits associated with ADHD (Pauli-Pott & Becker, 2011). In fact, our results suggest that the preschool years are an optimal developmental period for investigating time-related difficulties. Beyond the assessment of such time-related difficulties, time processing skills should be taken into consideration when planning early interventions to facilitate everyday functioning for children with cognitive impairments (Janeslätt et al., 2009). The individuation of time-related difficulties in children with ADHD as young as 4, suggests preschoolers may benefit from interventions aimed at improving time processing skills. This can be done, for example, by explicitly helping parents teach their children the meaning and appropriate use of time-related words and concepts, and by suggesting strategies for planning and time estimation, as bases of time management (e.g., Leech et al., 2019; Marlowe, 2000).

This study has some limitations. First, the use of a unique measure for assessing time-related difficulties, namely the verbal production within the time category, needs further validation. Indeed, future studies should include multiple measures of temporal cognition of preschoolers, such as targeted questionnaires for parents and teachers (e.g., Sense of time questionnaire; Tobia et al., 2018) as well as behavioral measures suitable for young children (e.g., temporal bisection tasks; Droit-Volet & Zélanti, 2013). Obtaining such a multi-method assessment is critical towards validating the role of time-related words produced by children as an index of their temporal cognition. Second, the small sample size of the study and the higher percentage of males in the ADHD compared to the TD group are significant limitations. Future studies should include a larger number of children per group, as well as samples properly matched for sex, to maximize power. Furthermore, a larger sample would allow to analyze possible differences in time-related skills in subgroups of children with ADHD, such as those with only-ADHD or ADHD *and* ODD, and to confirm effects that we found as only marginal (i.e., higher use of space-related words by parents of children with ADHD). Also, larger samples would allow to examine how contextual factors influence various aspects of parent–child interactions, included the use of temporal terms. Third, the majority of the sample was Hispanic/Latinx, which limits the generalizability of the results. To examine the extent to which our findings are applicable to non-Hispanic/non-Latinx children, these should be replicated in samples of preschoolers that differ in ethnicity. However, most studies on time-related impairments in school-aged children with ADHD involve non-Hispanic/Latinx white (Noreika et al., 2013); therefore, results of the present study offer some new evidence on time impairments in Hispanic/Latinx children with ADHD. Finally, to disentangle the direction of time related impairment and associated variables (ADHD symptoms and EF), a longitudinal study would be needed.

Despite these limitations, the current study has strengths. This study is the first to identify time related impairments in preschoolers with ADHD based upon expressed language. It is also the first to detect these deficits within the context of parent–child interactions, previously not investigated for this purpose within ADHD populations. Additionally, our study showed that significant associations between temporal cognition, attentional skills and EF can be identified in children as early as preschool. More work is needed, with future directions examining whether time-related deficits can be identified in preschoolers using multiple methods and exploring the developmental path of time processing impairment. Lastly, it will be important to examine whether multimodal early intervention programs that are effective with preschoolers with ADHD and their parents, such as the Summer Treatment Program for Pre-Kindergarteners (STP-Prek; Graziano & Hart, 2016), can also indirectly improve children's time-related skills, or whether focused ancillary interventions are needed to address this underlying impairment.

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Compliance with Ethical Standards

Conflict of Interest The authors declare no competing interests.

Ethical Approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional research committee (Florida International University) and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

References

Alloway, T. P., & Stein, A. (2014). Investigating the link between cognitive skills and learning in non-comorbid samples of ADHD and SLI. *International Journal of Educational Research*, *64*, 26–31. https://doi.org/10.1016/j.ijer.2013.10.003.

American Psychiatric Association. (2013). *Diagnostic and Statistical Manual of Mental Disorders (DSM-5®)*. American Psychiatric Pub.

Anderson, A. (1997). Families and mathematics: a study of parent–child interactions. *Journal for Research in Mathematics Education*, *28*, 484–511. https://doi.org/10.2307/749684.

Barkley, R. A. (1998). *It's About Time*. Unpublished manuscript, University of Massachusetts, USA.

Barry, T. D., Lyman, R. D., & Klinger, L. G. (2002). Academic underachievement and attention-deficit/hyperactivity disorder: the negative impact of symptom severity on school performance. *Journal of School Psychology*, *40*, 259–283. https://doi.org/10.1016/S0022-4405(02)00100-0.

Bindman, S. W., Hindman, A. H., Bowles, R. P., & Morrison, F. J. (2013). The contributions of parental management language to executive function in preschool children. *Early Childhood Research Quarterly*, *28*, 529–539. https://doi.org/10.1016/j.ecresq.2013.03.003.

Blevins-Knabe, B., & Musun-Miller, L. (1996). Number use at home by children and their parents and its relationship to early mathematical performance. *Early Development and Parenting: An International Journal of Research and Practice*, *5*, 35–45. https://doi.org/10.1002/(SICI)1099-0917(199603)5:1<35::AID-EDP113>3.0.CO;2-0.

Bonafina, M. A., Newcorn, J. H., McKay, K. E., Koda, V. H., & Halperin, J. M. (2000). ADHD and reading disabilities: a cluster analytic approach for distinguishing subgroups. *Journal of Learning Disabilities*, *33*, 297–307. https://doi.org/10.1177/002221940003300307.

Brown, L. N., & Vickers, J. N. (2004). Temporal judgments, hemispheric equivalence, and interhemispheric transfer in adolescents with attention deficit hyperactivity disorder. *Experimental Brain Research*, *154*, 76–84. https://doi.org/10.1007/s00221-003-1641-z.

Busby Grant, J., & Suddendorf, T. (2011). Production of temporal terms by 3-, 4-, and 5-year-old children. *Early Childhood Research Quarterly*, *26*, 87–95. https://doi.org/10.1016/j.ecresq.2010.05.002.

Camarata, S. M., & Gibson, T. (1999). Pragmatic language deficits in attention-deficit hyperactivity disorder (ADHD). *Mental Retardation and Developmental Disabilities Research Reviews*, *5*, 207–214. https://doi.org/10.1002/(SICI)1098-2779(1999)5:3<207::AID-MRDD7>3.0.CO;2-O.

Cornu, V., Schiltz, C., Martin, R., & Hornung, C. (2018). Visuospatial abilities are key for young children's verbal number skills. *Journal of Experimental Child Psychology*, *166*, 604–620. https://doi.org/10.1016/j.jecp.2017.09.006.

Currie, J., & Stabile, M. (2006). Child mental health and human capital accumulation: the case of ADHD. *Journal of Health Economics*, *25*, 1094–1118. https://doi.org/10.1016/j.jhealeco.2006.03.001.

Danforth, J. S., Anderson, L. P., Barkley, R. A., & Stokes, T. F. (1991). Observations of parent–child interactions with hyperactive children: research and clinical implications. *Clinical Psychology Review*, *11*, 703–727. https://doi.org/10.1016/0272-7358(91)90127-G.

Droit-Volet, S. (2013). Time perception in children: a neurodevelopmental approach. *Neuropsychologia*, *51*, 220–234. https://doi.org/10.1016/j.neuropsychologia.2012.09.023.

Droit-Volet, S., & Zélanti, P. S. (2013). Development of time sensitivity and information processing speed. *PloS ONE*, *8*, e71424 https://doi.org/10.1371/journal.pone.0071424.

Ferrara, K., Silva, M., Wilson, C., & Landau, B. (2016). Spatial language and the embedded listener model in parents' input to children. *Cognitive Science*, *40*, 1877–1910. https://doi.org/10.1111/cogs.12328.

Friedman, W. (1990a). Children's representations to the daily activities. *Child Development*, *61*, 1399–1412. https://doi.org/10.1111/j.1467-8624.1990.tb02870.x.

Gioia, G. A., Espy, K. A., & Isquith, P. K. (2003). *The behavior rating inventory of executive function—Preschool version*. Odessa, FL: Psychological Assessment Resources.

Gioia, G. A., Isquith, P. K., Kenworthy, L., & Barton, R. M. (2002). Profiles of everyday executive function in acquired and developmental disorders. *Child Neuropsychology*, *8*, 121–137. https://doi.org/10.1076/chin.8.2.121.8727.

Graziano, P. A., & Hart, K. (2016). Beyond behavior modification: benefits of social–emotional/self-regulation training for preschoolers with behavior problems. *Journal of School Psychology*, *58*, 91–111. https://doi.org/10.1016/j.jsp.2016.07.004.

Graziano, P. A., Slavec, J., Hart, K., Garcia, A., & Pelham, W. E. (2014). Improving school readiness in preschoolers with behavior problems: results from a summer treatment program. *Journal of Psychopathology and Behavioral Assessment*, *36*, 555–569. https://doi.org/10.1007/s10862-014-9418-1.

Graziano, P. A., Slavec, J., Ros, R., Garb, L., Hart, K., & Garcia, A. (2015). Self-regulation assessment among preschoolers with externalizing behavior problems. *Psychological Assessment*, *27*, 1337–1348. https://doi.org/10.1037/pas0000113.

Grondin, S. (2010). Timing and time perception: a review of recent behavioral and neuroscience findings and theoretical directions. *Attention, Perception, & Psychophysics*, *72*, 561–582. https://doi.org/10.3758/APP.72.3.561.

Hart, H., Radua, J., Mataix-Cols, D., & Rubia, K. (2012). Meta-analysis of fMRI studies of timing in attention-deficit hyperactivity disorder (ADHD). *Neuroscience & Biobehavioral Reviews*, *36*, 2248–2256. https://doi.org/10.1016/j.neubiorev.2012.08.003.

Hembree-Kigin, T. L., & McNeil, C. B. (2013). *Parent–child Interaction Therapy*. Springer Science & Business Media.

Hoff, E. (2003a). The specificity of environmental influence: socioeconomic status affects early vocabulary development via maternal speech. *Child Development*, *74*, 1368–1378. https://doi.org/10.1111/1467-8624.00612.

Houghton, S., Durkin, K., Ang, R. P., Taylor, M. F., & Brandtman, M. (2011). Measuring temporal self-regulation in children with and without attention deficit hyperactivity disorder. *European Journal of Psychological Assessment*, *27*, 88–94. https://doi.org/10.1027/1015-5759/a000048.

Huang, J., Yang, B. R., Zou, X. B., Jing, J., Pen, G., McAlonan, G. M., & Chan, R. C. (2012). Temporal processing impairment in children with attention-deficit-hyperactivity disorder. *Research in Developmental Disabilities*, *33*, 538–548. https://doi.org/10.1016/j.ridd.2011.10.021.

Hudson, J. A. (2006). The development of future time concepts through mother–child conversation. *Merrill-Palmer Quarterly*, *52*, 70–95. https://doi.org/10.1353/mpq.2006.0005.

Hwang-Gu, S. L., & Gau, S. S. F. (2015). Interval timing deficits assessed by time reproduction dual tasks as cognitive endophenotypes for attention-deficit/hyperactivity disorder. *PloS one*, *10*(5), e0127157. https://doi.org/10.1371/journal.pone.0127157.

Janeslätt, G., Granlund, M., & Kottorp, A. (2009). Measurement of time processing ability and daily time management in children with disabilities. *Disability and Health Journal*, *2*, 15–19. https://doi.org/10.1016/j.dhjo.2008.09.002.

Johnston, C., & Mash, E. J. (2001). Families of children with attention-deficit/hyperactivity disorder: review and recommendations for future research. *Clinical Child and Family Psychology Review*, *4*, 183–207. https://doi.org/10.1023/A:1017592030434.

Kalff, A. C., De Sonneville, L. M., Hurks, P. P., Hendriksen, J. G., Kroes, M., Feron, F. J., Steyaert, J., van Zeben, T. M. C. B., Vles, J. S. H., & Jolles, J. (2005). Speed, speed variability, and accuracy of information processing in 5 to 6-year-old children at risk of ADHD. *Journal of the International Neuropsychological Society*, *11*, 173–183. https://doi.org/10.1017/S1355617705050216.

Klibanoff, R. S., Levine, S. C., Huttenlocher, J., Vasilyeva, M., & Hedges, L. V. (2006). Preschool children's mathematical knowledge: the effect of teacher" math talk. *Developmental Psychology*, *42*, 59–69. https://doi.org/10.1037/0012-1649.42.1.59.

Leech, K. A., Leimgruber, K., Warneken, F., & Rowe, M. L. (2019). Conversation about the future self improves preschoolers' prospection abilities. *Journal of Experimental Child Psychology*, *181*, 110–120. https://doi.org/10.1016/j.jecp.2018.12.008.

Levy, E., & Nelson, K. (1994). Words in discourse: a dialectical approach to the acquisition of meaning and use. *Journal of Child Language*, *21*, 367–389. https://doi.org/10.1017/S0305000900009314.

MacWhinney, B. (2000). *The CHILDES project: Tools for analyzing talk* (*3rd ed.*). Mahwah, NJ: Erlbaum.

Mahone, E. M., & Hoffman, J. (2007). Behavior ratings of executive function among preschoolers with ADHD. *The Clinical Neuropsychologist*, *21*, 569–586. https://doi.org/10.1080/13854040600762724.

Marks, D. J., Berwid, O. G., Santra, A., Kera, E. C., Cyrulnik, S. E., & Halperin, J. M. (2005). Neuropsychological correlates of ADHD symptoms in preschoolers. *Neuropsychology*, *19*, 446–455. https://doi.org/10.1037/0894-4105.19.4.446.

Marlowe, W. B. (2000). An intervention for children with disorders of executive functions. *Developmental Neuropsychology*, *18*, 445–454. https://doi.org/10.1207/S1532694209Marlowe.

Meaux, J. B., & Chelonis, J. J. (2003). Time perception differences in children with and without ADHD. *Journal of Pediatric Health Care*, *17*, 64–71. https://doi.org/10.1067/mph.2003.26.

Mix, K. S., & Cheng, Y. L. (2012). The relation between space and math: developmental and educational implications. *Advances in Child Development and Behavior*, *42*, 197–243. https://doi.org/10.1016/B978-0-12-394388-0.00006-X.

Noreika, V., Falter, C. M., & Rubia, K. (2013). Timing deficits in attention-deficit/hyperactivity disorder (ADHD): evidence from neurocognitive and neuroimaging studies. *Neuropsychologia*, *51*, 235–266. https://doi.org/10.1016/j.neuropsychologia.2012.09.036.

Nussbaum, N. L., Grant, M. L., Roman, M. J., Poole, J. H., & Bigler, E. D. (1990). Attention deficit disorder and the mediating effect of age on academic and behavioral variables. *Journal of Developmental and Behavioral Pediatrics*, *11*, 22–26. https://doi.org/10.1097/00004703-199002000-00005.

Pauli-Pott, U., & Becker, K. (2011). Neuropsychological basic deficits in preschoolers at risk for ADHD: a meta-analysis. *Clinical Psychology Review*, *31*, 626–637. https://doi.org/10.1016/j.cpr.2011.02.005.

Pelham, Jr, W. E., Fabiano, G. A., & Massetti, G. M. (2005). Evidence-based assessment of attention deficit hyperactivity disorder in children and adolescents. *Journal of Clinical Child and Adolescent Psychology*, *34*, 449–476. https://doi.org/10.1207/s15374424jccp3403_5.

Pelham, Jr, W. E., Gnagy, E. M., Greenslade, K. E., & Milich, R. (1992). Teacher ratings of DSM-III-R symptoms for the disruptive behavior disorders. *Journal of the American Academy of*

Child & Adolescent Psychiatry, *31*, 210–218. https://doi.org/10.1097/00004583-199203000-00006.

Plummer, C., & Humphrey, N. (2009). Time perception in children with ADHD: the effects of task modality and duration. *Child Neuropsychology*, *15*, 147–162. https://doi.org/10.1080/09297040802403690.

Ponitz, C. C., McClelland, M. M., Matthews, J. S., & Morrison, F. J. (2009). A structured observation of behavioral self-regulation and its contribution to kindergarten outcomes. *Developmental Psychology*, *45*, 605–619. https://doi.org/10.1037/a0015365.

Ponitz, C. E., McClelland, M. M., Jewkes, A. M., Connor, C. M., Farris, C. L., & Morrison, F. J. (2008). Touch your toes! Developing a direct measure of behavioral regulation in early childhood. *Early Childhood Research Quarterly*, *23*, 141–158. https://doi.org/10.1016/j.ecresq.2007.01.004.

Raiford, S. E., Dorzidick, L., & Zhang, O. (2015). *Q-interactive special group studies: The WISC-V and children with autism spectrum disorder and accompanying language impairment or attention-deficit/hyperactivity disorder (Q-interactive Technical Report 11)*. Bloomington, MN: Pearson.

Reynolds, C., & Kamphaus, R. (2004). Behavior Assessment System for Children - Second Edition, (BASC-2). Bloomington, MN: Pearson.

Ros, R., & Graziano, P. A. (2018). Social functioning in children with or at risk for attention deficit/hyperactivity disorder: a meta-analytic review. *Journal of Clinical Child & Adolescent Psychology*, *47*, 213–235. https://doi.org/10.1080/15374416.2016.1266644.

Rosemberg, C. R., Alam, F., & Stein, A. (2014). Factors reflecting children's use of temporal terms as a function of social group. *Language, Interaction and Acquisition*, *5*, 38–61. https://doi.org/10.1075/lia.5.1.02ros.

Shaffer, D., Fisher, P., Lucas, C. P., Dulcan, M. K., & Schwab-Stone, M. E. (2000). NIMH Diagnostic Interview Schedule for Children Version IV (NIMH DISC-IV): description, differences from previous versions, and reliability of some common diagnoses. *Journal of the American Academy of Child & Adolescent Psychiatry*, *39*, 28–38. https://doi.org/10.1097/00004583-200001000-00014.

Smith, A., Taylor, E., Warner Rogers, J., Newman, S., & Rubia, K. (2002). Evidence for a pure time perception deficit in children with ADHD. *Journal of Child Psychology and Psychiatry*, *43*, 529–542. https://doi.org/10.1111/1469-7610.00043.

Sonuga-Barke, E., Bitsakou, P., & Thompson, M. (2010). Beyond the dual pathway model: evidence for the dissociation of timing, inhibitory, and delay-related impairments in attention-deficit/hyperactivity disorder. *Journal of the American Academy of Child & Adolescent Psychiatry*, *49*, 345–355. https://doi.org/10.1016/j.jaac.2009.12.018.

Spiegel, J. A., Lonigan, C. J., & Phillips, B. M. (2017). Factor structure and utility of the Behavior Rating Inventory of Executive Function—Preschool Version. *Psychological Assessment*, *29*, 172–185. https://doi.org/10.1037/pas0000324.

Syed, M., & Nelson, S. C. (2015). Guidelines for establishing reliability when coding narrative data. *Emerging Adulthood*, *3*, 375–387.

Syeda, M. M., & Climie, E. A. (2014). Test review: wechsler preschool and primary scale of intelligence–fourth edition. *Journal of Psychoeducational Assessment*, *32*, 265–272. https://doi.org/10.1177/0734282913508620.

Tillman, K. A. (2019). What time words teach us about children's acquisition of the temporal reasoning system. *Behavioral and Brain Sciences*, 42. https://doi.org/10.1017/S0140525X19000578

Tillman, K. A., Marghetis, T., Barner, D., & Srinivasan, M. (2017). Today is tomorrow's yesterday: children's acquisition of deictic time words. *Cognitive Psychology*, *92*, 87–100. https://doi.org/10.1016/j.cogpsych.2016.10.003.

Tirosh, E., & Cohen, A. (1998). Language deficit with attention-deficit disorder: a prevalent comorbidity. *Journal of Child Neurology*, *13*, 493–497. https://doi.org/10.1177/088307389801301005.

Tobia, V., Bonifacci, P., Bernabini, L., & Marzocchi, G. M. (2019). Teachers, not parents, are able to predict time processing skills in preschoolers. *British Journal of Developmental Psychology*, *37*, 519–534. https://doi.org/10.1111/bjdp.12294.

Tobia, V., Rinaldi, L., & Marzocchi, G. M. (2018). Time processing impairments in preschoolers at risk of developing difficulties in mathematics. *Developmental Science*, *21*, e12526. https://doi.org/10.1111/desc.12526.

Tomasello, M. (2009). The usage-based theory of language acquisition. In E.L. Bavin (ed.), *The Cambridge Handbook of Child Language* (pp. 69–87). Cambridge: Cambridge University Press.

Toplak, M. E., Dockstader, C., & Tannock, R. (2006). Temporal information processing in ADHD: findings to date and new methods. *Journal of Neuroscience Methods*, *151*, 15–29. https://doi.org/10.1016/j.jneumeth.2005.09.018.

Verdine, B. N., Irwin, C. M., Golinkoff, R. M., & Hirsh-Pasek, K. (2014). Contributions of executive function and spatial skills to preschool mathematics achievement. *Journal of Experimental Child Psychology*, *126*, 37–51. https://doi.org/10.1016/j.jecp.2014.02.012.

Walg, M., Hapfelmeier, G., El-Wahsch, D., & Prior, H. (2017). The faster internal clock in ADHD is related to lower processing speed: WISC-IV profile analyses and time estimation tasks facilitate the distinction between real ADHD and pseudo-ADHD. *European Child & Adolescent Psychiatry*, *26*, 1177–1186. https://doi.org/10.1007/s00787-017-0971-5.

Walg, M., Oepen, J., & Prior, H. (2015). Adjustment of time perception in the range of seconds and milliseconds: the nature of time-processing alterations in children with ADHD. *Journal of Attention Disorders*, *19*, 755–763. https://doi.org/10.1177/1087054712454570.

Wechsler, D. (2012). *Wechsler Preschool and Primary Scale of Intelligence*—Fourth Edition. San Antonio, TX: The Psychological Corporation.

Westerberg, H., Hirvikoski, T., Forssberg, H., & Klingberg, T. (2004). Visuo-spatial working memory span: a sensitive measure of cognitive deficits in children with ADHD. *Child Neuropsychology*, *10*, 155–161. https://doi.org/10.1080/09297040409609806.

Woodcock, R., McGrew, K., & Mather, N. (2001). *Woodcock-Johnson R III NU Tests of Achievement*. Itasca, IL: Riverside Publishing.

Zakay, D., & Block, R. A. (1997). Temporal cognition. *Current Directions in Psychological Science*, *6*, 12–16.

Zentall, S. S. (2007). Math performance of students with ADHD: Cognitive and behavioral contributors and interventions. In D. B. Berch & M. M. M. Mazzocco (Eds.), *Why is math so hard for some children? The nature and origins of mathematical learning difficulties and disabilities* (pp. 219-243). Baltimore: Paul H. Brookes.

Zmyj, N. (2018). The relationship of delay of gratification and time comprehension in 4-year-old children. *International Journal of Behavioral Development*, *42*, 434–438. https://doi.org/10.1177/0165025417727870.

Zélanti, P. S., & Droit-Volet, S. (2011). Cognitive abilities explaining age-related changes in time perception of short and long durations. *Journal of Experimental Child Psychology*, *109*, 143–157. https://doi.org/10.1016/j.jecp.2011.01.003.