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Cognitive Profiles in Preschool Children at Risk for Co-Occurring Dyslexia and ADHD

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Abstract: Developmental dyslexia and attention-deficit/hyperactivity disorder (ADHD) co-occur in 15–40% of individuals diagnosed with one disorder. Despite substantial research on the cognitive profiles of preschoolers at risk for either dyslexia or ADHD, studies have neglected children at risk for co-occurring dyslexia and ADHD. Thus, our study compared the cognitive profile of preschoolers at risk for dyslexia with the profile of children at risk for co-occurring dyslexia and ADHD. We assessed 50 preschoolers at dyslexia risk (DR), 50 at dyslexia + ADHD risk (DAR), and 48 without risk (NR) (M_{age} = 67 months). Our assessment encompassed phonological processing, executive functioning (EF), receptive vocabulary, and processing speed. Principal component analysis revealed two distinct components within the measures of EF, a verbal short-term memory and an EF component. ANOVA revealed that the NR group outperformed risk groups across measures, except for cognitive flexibility and delay of gratification. Notably, the DR and DAR groups did not differ in most measures but showed near-significant differences on the EF component, with the DR group having higher composite scores than the DAR group. In conclusion, ADHD risk did not impact the cognitive performance of children at risk for dyslexia but might amplify EF problems that at-risk preschoolers encounter.

Keywords: dyslexia; ADHD; preschool; cognition; executive function; phonological processing; processing speed

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1. Introduction

Dyslexia and attention-deficit/hyperactivity disorder (ADHD) frequently co-occur, as approximately 15–40% of children with one diagnosis also have symptoms of the other [1–3] This co-occurrence is more than expected by chance since the prevalence of each disorder lies at around 7% [4–6]. In the DSM-5, the American Psychiatric Association [7] defines dyslexia (i.e., specific learning disorder) as "having problems with accurate or fluent word recognition, poor decoding and poor spelling abilities" (p. 67). ADHD, on the other hand, is a behavioral disorder characterized by two behavioral symptom dimensions, i.e., inattention and hyperactivity/impulsivity ([7], p. 59).

Multiple studies have indicated that dyslexia and ADHD negatively impact more than cognitive and academic outcomes [8,9]. Both disorders are also associated with internalizing and externalizing problems [9,10]. Therefore, early identification of at-risk children, before receiving the respective diagnoses, is crucial to mitigate the risk of poor school performance and socio-emotional problems [11–13]. Still, in prospective research, preschoolers at risk for co-occurring dyslexia and ADHD are often neglected. Despite the extensive body of studies exploring cognition (in diagnosed children) and predictors (in preschoolers) of dyslexia and ADHD separately, our understanding of the cognitive strengths and weaknesses of co-occurring dyslexia and ADHD is limited, making it challenging to identify and provide adequate support. Therefore, in this study, we compared preschool groups of children at risk for dyslexia and/or ADHD on domain-specific correlates of dyslexia (i.e., phonological processing) and ADHD (i.e., executive functioning), as well as on domain-general skills (i.e., processing speed and vocabulary).

1.1. Dyslexia

At the cognitive level, the predominant deficit in dyslexia is a phonological processing deficit [14,15], encompassing phonological awareness (PA), verbal short-term memory (vSTM), and rapid automatic naming (RAN). However, beyond these phonological issues, dyslexia is also associated with deficits in executive functions (EFs). One meta-analysis shows that children with dyslexia have EF deficits, even when co-occurring ADHD is taken into account [16]. However, two meta-analyses did not report on ADHD status. It is therefore possible that those children with dyslexia could have undiagnosed ADHD [17,18]. EFs, or executive functions, are a group of cognitive processes necessary for carrying out goal-oriented actions and managing thoughts, behavior, and emotions [19,20]. The consensus is that there are three related but separate EFs as follows: working memory/updating, inhibition, and cognitive flexibility/shifting [20,21]. Nevertheless, because of differences in how studies are conducted, the definition of critical concepts, and the selection of measurement methods, these EF deficits are not typically regarded as core deficits in dyslexia, unlike phonological processing [17].

In the Dutch-speaking part of Belgium, dyslexia diagnosis typically occurs after second grade, requiring six months of formal reading instruction, persistent reading challenges, and resistance to remedial efforts. However, phonological deficit issues may surface in preschoolers (around five years old) before formal reading education begins in primary school (at approximately six years old). Longitudinal studies have identified three cognitive predictors of dyslexia in preschoolers—phonological awareness, RAN, and letter knowledge—next to family risk of dyslexia. These deficits are accepted as the core predictors of dyslexia [22–27].

1.2. ADHD

For a long time, an EF impairment was proposed as the key cognitive deficit in ADHD, involving inhibition challenges, such as delaying responses, resisting impulses, and interrupting ongoing actions [28]. Next, ADHD is often associated with compromised working memory [28,29]. Baddeley and Hitch's original working memory model distinguishes three components, i.e., phonological loop (or verbal short-term memory), visuospatial sketchpad (or visuospatial short-term memory), and central executive [30,31]. ADHD mainly affects visuospatial working memory, involving visuospatial short-term memory and the central executive [29,32,33]. However, a meta-analysis has also shown modest deficits in the phonological loop [34]. Beyond the EF deficit theory, the motivational–affective theory suggests that ADHD correlates with a more rapid decline in the perceived value of future rewards, resulting in individuals with ADHD discounting future rewards at a higher rate compared to typically developing controls [35,36].

Much like in the case of dyslexia, a clinical diagnosis of ADHD is rarely made before the start of primary school, even though preschool impairments have been demonstrated at the cognitive and behavioral level [37–40]. More specifically, the studies mentioned above found that preschoolers already show inhibition deficits and delay aversion, which made independent contributions to the prediction of ADHD.

For both dyslexia and ADHD separately, it has been widely accepted that the core cognitive deficits were found at the group level. However, not all children with dyslexia will show a phonological processing deficit [41,42], and not all children with ADHD will exhibit executive functioning deficits or delay aversion [13,43,44]. Additionally, these deficits are not powerful enough to fully explain dyslexia (i.e., reading and/or spelling problems) and ADHD (i.e., inattention and/or hyperactivity/impulsivity) symptoms.

1.3. Co-Occurring Dyslexia and ADHD

Several comorbidity hypotheses exist about the neuropsychological underpinnings of co-occurring dyslexia and ADHD, all based on children with a diagnosis of dyslexia and ADHD. For instance, a group of studies concluded that children with co-occurring dyslexia and ADHD display the sum of deficits related to dyslexia and ADHD in an additive fashion, resulting in a perfect double dissociation between the two disorders. More specifically, these studies have found that children with co-occurring dyslexia and ADHD have both a phonological processing and an inhibition deficit [12,45,46]. Another group of studies similarly have found this additive effect of deficits but included specific deficits in the double disorder group. This cognitive subtype hypothesis marks co-occurring dyslexia and ADHD as a third disorder and points to specific neuropsychological deficits in children with both disorders [47]. For instance, studies have found that children displaying both dyslexia and ADHD show unique deficits in naming speed and have worse verbal working memory deficits [29,48–50]. Analogously, some studies provided evidence that children with the combination of dyslexia and ADHD have a cognitive profile consistent with the sum of deficits related to dyslexia and ADHD but with more severe deficits and worse academic and behavioral outcomes compared to children diagnosed with only dyslexia or ADHD [11,51]. Finally, most studies have found evidence for a shared deficit between children displaying co-occurring dyslexia and ADHD and children with either single disorder. More specifically, processing speed deficits are believed to be common to dyslexia, ADHD, and co-occurring dyslexia and ADHD [49,52–55].

According to the Multiple Deficit Model, the overlap of shared factors produces comorbidity. Co-occurrence can thus be expected due to common risk factors, which are assumed to result from the interaction of partially overlapping genetic, neurobiological, cognitive, and/or environmental factors [56]. Indeed, the latest studies on co-occurring dyslexia and ADHD found similar deficits in the dyslexia-only and co-occurring dyslexia and ADHD groups [16,57,58]. However, these studies have all investigated children with a diagnosis, leaving the question about the neuropsychological underpinnings of dyslexia and ADHD unresolved, especially in preschoolers at risk.

1.4. Current Study

In the present study, we compared the cognitive profile of preschoolers at cognitive risk for dyslexia and behavioral risk for ADHD to that of a group of preschoolers at risk for only dyslexia. In addition, we compared these risk groups to a group of average-to-high-performing preschoolers, the no-risk group. We were interested in their EFs, given the associations with dyslexia and ADHD separately. However, due to inconsistent findings and to our knowledge, the lack of studies in preschoolers (at-risk children), we expanded our scope to encompass other cognitive functions associated with both disorders, such as processing speed and receptive vocabulary.

First, as we had many tasks measuring EFs, we aimed to reduce the amount of variables with a principal component analysis. Second, we looked at risk group differences on the extracted components and the remaining variables. We hypothesized that the no-risk group would have significantly higher scores on EFs (i.e., behavioral inhibition and working memory, but not cognitive inhibition), phonological skills (by design), processing speed, and receptive vocabulary than the two at-risk groups. Considering the present knowledge of preschool cognition in children who continue to develop dyslexia, we hypothesized that the dyslexia risk group would score poorly on phonological skills (by design), receptive vocabulary, and processing speed. Lastly, we hypothesized that children with a double risk for dyslexia and ADHD would show impairments on EFs (i.e., behavioral inhibition and working memory, but not cognitive inhibition), phonological skills (by design), processing speed, and receptive vocabulary.

2. Materials and Methods

2.1. Participants

2.1.1. Selection

In Flanders (Belgium), we distributed an information letter to 8000 four-year-old children in 227 regular kindergarten schools. After written consent was obtained from 1900 parents, they received an online questionnaire concerning family demographics, family risk for dyslexia and/or ADHD, and behavioral risk for ADHD (cf. infra). Children with a native tongue other than Dutch, autism spectrum disorder, specific language impairment, neurological or sensory problems, or children who received speech therapy were excluded from the screening to ensure that further study would accurately identify the cognitive profile and developmental trajectories specific to dyslexia and/or ADHD without being influenced by confounding processes or other problems. This first selection resulted in a sample of 1225 children (597 boys) being screened for a cognitive risk for dyslexia (M_{age} = 5 years and 3 months; SD_{age} = 3 months and 11 days). For a complete description of the screening procedure, see [59].

2.1.2. Group Designation

To identify preschoolers at risk for developing ADHD, the online questionnaire included the Preschool Behaviour Questionnaire (PBQ) [60]. The PBQ consists of 61 items, which converge into 5 scales (i.e., inattention, hyperactivity, impulsivity, oppositional defiant/conduct disorder, and total externalizing behavior). Earlier research has shown that preschoolers who exhibit atypically high levels of inattention have an increased likelihood of developing psychopathology [61,62]. Additionally, recent research into the co-occurrence of dyslexia and ADHD in children and adolescents has shown that dyslexia is mainly related to the predominantly inattentive presentation of ADHD, rather than the predominantly hyperactive/impulsive or combined presentation [3,9]. However, it has also been demonstrated that preschool ADHD symptoms are not developmentally stable [63,64]. In conclusion, to grasp the full scale of ADHD behaviors, we identified children who showed high levels of inattention and/or hyperactivity and/or impulsivity. Following the manual's instructions, this comprised the top 20% in these symptom domains or those with a norm score of 15 or higher. While a score of 15 is considered subclinical, a score of 16 is deemed clinically significant on the questionnaire. Test–retest reliability ranges from 0.81 to 0.92, for boys and girls, on all three scales, when the questionnaire is filled out by parents [60]. In addition, the Dutch Commission for Test Materials (COTAN) reviewed this questionnaire as sufficient in terms of validity and reliability [65] and the predictive validity of parental questionnaires has been demonstrated by research [66].

Children were tested in schools to assess the cognitive risk for dyslexia, with tasks measuring letter knowledge (LK), phonological awareness (PA), and rapid automatic naming (RAN). We conducted three separate principal component analyses for every expected predictor of dyslexia (i.e., LK, PA, and RAN). Each predictor was subjected to an individual principal component analysis without rotation, based on the different tasks assumed to measure these predictors, obtaining weighted scores of each variable per factor. After the standardization of these weighted scores, percentiles were calculated subsequently. Based on earlier longitudinal studies in this research group and in order to obtain a large enough sample, we categorized participants as at risk for dyslexia when they performed below percentile 25 on LK, PA, or RAN, but did not perform above percentile 50 on any of these measurements [22,67–70]. Children scoring below percentile 25 on one of the three cognitive predictors of dyslexia and above or equal to norm score 15 on one of the three scales of the PBQ, were categorized as being at double risk for dyslexia and ADHD. For this study, children who scored above percentile 40 on all three preliteracy measures, but below 15 on the PBQ, were considered as controls, or the no-risk group. We opted for a cognitive risk approach concerning dyslexia risk and a behavioral risk approach for ADHD risk, based on prior findings from longitudinal studies. Letter knowledge, phonological awareness, and RAN were indeed seen as the most consistent predictors of dyslexia. Specifically, letter knowledge, phonological awareness, and RAN emerged as the most reliable predictors of dyslexia. Moreover, when children have not yet started formal reading instruction in the preschool stage, letter knowledge could be perceived as a behavioral proxy for reading ability. For ADHD, given the cognitive heterogeneity, we chose a behavioral risk assessment using a validated questionnaire.

After the cognitive screening in the schools, unreliable scores (e.g., the child refusing to do the task or the tablet crashing) were removed (n = 21). Additionally, the lowest 10% of scores on a nonverbal IQ measure, the Raven Colored Progressive Matrices [71], were removed as low intellectual ability might influence results on prereading and preliteracy tasks.

This corresponded to IQ scores below 76 (n = 113), which ensured the exclusion of children with mild intellectual disability (i.e., IQ scores between 65 and 75) (p. 37, [7]). The final data sample comprised 1059 screened children who also had complete PBQ information (501 boys and 558 girls; M_{IQ} = 101.05; SD_{IQ} = 14.73). The final selection of participants for this study happened randomly, and the number of girls versus boys was kept equal in all groups. A detailed overview of participant selection and group designation can be found in Figure 1.

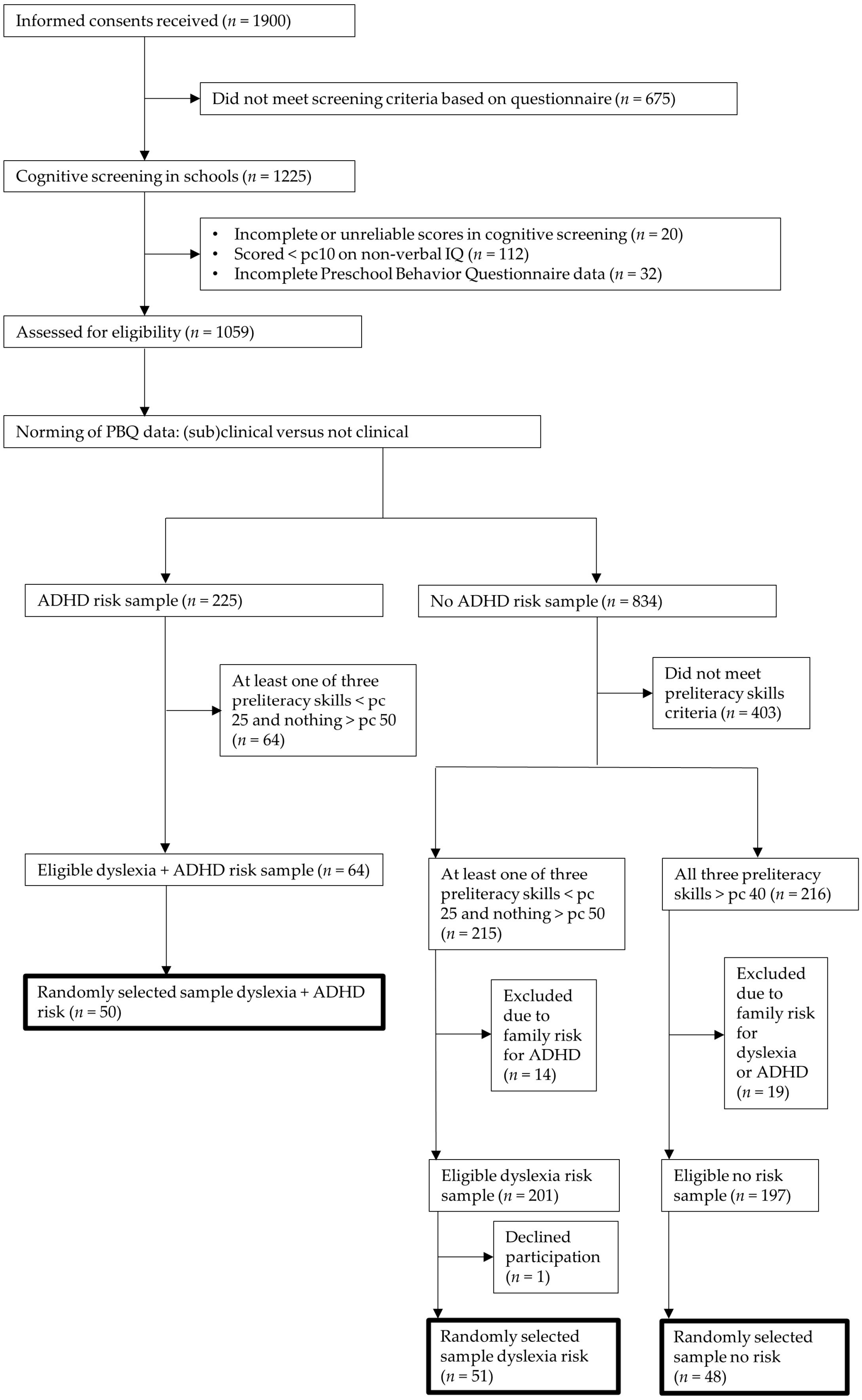

Figure 1. Flowchart of participant selection from recruitment to group designation and random selection of participants.

2.1.3. Demographic Characteristics of Sample

In total, our sample consisted of 149 children (77 boys) with a mean age of 67 months (*SD* = 3.1) (Table 1). All children were in their last year of preschool, and none had a formal diagnosis of ADHD or dyslexia. This sample comprised children with a cognitive risk for dyslexia and a behavioral risk for ADHD, although some also had a family risk (FR) for dyslexia or ADHD, defined by having at least one first-degree relative with dyslexia or ADHD. To ensure comparable group composition, we matched biological sex on the group-level. Indeed, no differences in biological sex were found across the groups, $\chi^2(2) = 0.16$, $p = 0.92$. Concerning age, there was a significant difference in age between groups, $F(2, 146) = 5.172$, $p < 0.01$, as the NR group was significantly older than the two risk groups (both p's < 0.05). However, descriptive statistics revealed that in reality, they only differed by almost two months. There was also a significant group difference on nonverbal IQ, $F(2, 145) = 4.232$, $p < 0.05$. Tukey post hoc tests revealed that this significant result was driven by a difference between the DAR and the NR group ($p = 0.016$). In accordance with the International Standard Classification of Education (ISCED) guidelines, the SES (maternal education level) was recoded into three categories—low, middle, and high SES—corresponding to mothers with a primary education degree, those with a secondary education degree or those with at least a bachelor's degree (or master's degree or PhD), respectively [72,73]. A Fisher's exact test of independence was conducted between risk group and maternal education level (SES), due to limited observations in the low-SES category. While most children came from middle- and high-SES backgrounds [74], there was no statistically significant association between risk group and maternal education level, $p = 0.20$.

Table 1. Demographic characteristics of participants.

		Risk Group	
	Dyslexia Risk (*n* = 51)	Dyslexia + ADHD Risk (*n* = 50)	No Risk (*n* = 48)
Age in months (*SD*)	66.6 (3.0)	66.3 (2.9)	68.1 (3.0)
Biological sex (%)			
Male	27 (52.9%)	26 (52.0%)	24 (50.0%)
Nonverbal IQ (*SD*)	95.9 (13.2)	94.0 (13.1)	102 (15.1)
SES (%)			
Low	1 (2.0%)	1 (2.0%)	0 (0%)
Middle	12 (23.5%)	13 (26.0%)	6 (12.5%)
High	35 (68.6%)	34 (68.0%)	42 (87.5%)
Unknown	2 (3.9%)	2 (4.0%)	-
Clinical ADHD symptom domains (%)			
Attention	-	12 (24.0%)	-
Hyperactivity	-	10 (20.0%)	-
Impulsivity	-	8 (16.0%)	-
Combined	-	20 (40.0%)	-
Mean normed scores on PBQ (range)			
Attention	9.2 (3–14)	13.9 (7–19)	9.4 (5–14)
Hyperactivity	9.6 (6–14)	14.3 (6–19)	9.7 (6–14)
Impulsivity	9.3 (5–14)	14.1 (6–19)	9.4 (3–14)
Family risk dyslexia (%)	9 (17.6%)	5 (10.0%)	-
Family risk ADHD (%)	-	4 (8.0%)	-

Note. ADHD subtype refers to the number of children scoring (sub)clinically on this subscale; low SES refers to mothers with a primary education degree, middle SES refers to mothers with a secondary education degree, and high SES signifies mothers having at least a bachelor's degree. The percentage represents the ratio within a specific group.

2.2. Procedure

In the middle of the school year (January, February, and March), spanning over a maximum of eight weeks, all children were tested. This period was chosen to avoid the post-holiday drop in performance, which occurs in the months of September and October [75]. Testing took place in a quiet room in the children's schools unless otherwise requested by their parents. Only one child opted to undergo testing at our office.

To minimize bias, all tasks were administered in a fixed order, and the entire battery took around 90 min for each child, split into three times 30 min to reduce impact and mitigate fatigue. Additionally, the whole day was embedded in a game of pirates, lost letters, and a treasure hunt to motivate children to complete all tasks.

2.3. Materials

2.3.1. Preliteracy Measures

Letter knowledge was assessed via receptive (passive) and productive (active) letter knowledge tasks. For the receptive letter knowledge task, the child was asked to choose the letter corresponding to an aurally presented sound. Each trial had five possibilities; all presented visually to the child. There were 16 items, and the final score was the number of correctly selected items. Productive letter knowledge was assessed on a card that showed 16 of the most frequently used letters in Dutch books. The child was asked to name or sound out each letter [22]. The dependent variable was the number of correct letter names or sounds, with a maximum score of 16. This task is an age-appropriate assessment and a reliable longitudinal predictor of reading [22,27].

For phonological awareness, we used the same begin and end sound identification task in kindergarten as aforementioned, but in a paper–pencil version and individually instead of in groups. These paper–pencil versions have reliability coefficients of $\alpha = 0.59$ for begin sound identification, and $\alpha = 63$ for end sound identification [76].

Rapid automatic naming was assessed via a paper–pencil task in which the child was presented with one card with 50 randomly arranged stimuli, and each stimulus appeared 10 times [77]. The stimuli were either objects (tree, duck, chair, scissors, and bicycle) or colors (black, blue, red, yellow, and green). The child was asked to name the stimuli as fast and accurately as possible. For each card, the number of errors and time necessary to complete the card were logged. Final scores were calculated by dividing the number of correctly named stimuli by the time necessary to complete the full card.

2.3.2. Executive Functioning

As we not only wanted to tap the neuropsychological domains of the dual pathway model [43], but additionally obtain the full particulars of executive functioning of the children, we assessed all three core EFs (working memory, inhibition, and cognitive flexibility) [78], and delay aversion. All tasks were age-appropriate and valid measures of EF [79].

To assess *cognitive inhibition*, we used a flanker task [79]. On a laptop screen, the child was presented with a horizontal row of 5 fish swimming in a direction (i.e., facing left or right). The child was asked to assess in which direction the middle fish swam and indicate this direction by pressing the corresponding button on the keyboard. Stickers with arrows were adhered to the correct keys on the keyboard to prevent children from pressing the wrong buttons. In congruent trials, all fish swim in the same direction, but in incongruent trials, the 4 outer fish swim in the opposite direction from the middle fish. The task started with 16 practice trials, of which 2 were with feedback. In total, there were 176 trials. Accuracy on all trials was recorded, and the difference between congruent and incongruent trials was calculated as a measure of conflict processing [80]. Vandenbroucke, Verschueren [79] found this task to be reliable in kindergarten and first grade, in both congruent ($\alpha = 0.96$, and $\alpha = 0.88$) and incongruent ($\alpha = 0.88$, and $\alpha = 0.85$) conditions, in a sample of typically developing children of the same age. The split-half correlation for this task was $r = 0.88$ in kindergarten and $r = 0.76$ in first grade.

Behavioral inhibition was measured using a traditional go/no-go task. During this task, the child had to press the space button on a laptop keyboard when a visually presented O occurred on the laptop screen (75% of trials) but inhibit their response to a rare X (25% of trials) [79,81,82]. We used an inter-stimulus interval (ISI) of 4000 ms and 6000 ms, as it has been shown that children with ADHD perform worse in longer ISIs [83]. Reaction time variability was analyzed as a measure of sustained attention, as well as no-go accuracy [84–88]. Similar to the previous task, Vandenbroucke, Verschueren [79] demonstrated the go/no-go task's reliability, as they reported a high internal consistency for the no-go-trials (α = 0.78–0.82) and high split-half correlation (r = 0.69–0.88).

For working memory, we measured each of the three subcomponents [30,31,89]. Phonological short-term memory was assessed by means of a Digit Span Forwards [90] and a Nonword Repetition Task (adapted from [91]), which required a child to immediately recall an aurally presented (via the headphone) list of digits and pseudowords, respectively. Both tests were preceded by two practice trials with feedback. The total score was the number of correctly recalled digit lists (maximum 21) and nonwords (maximum 24). The reliability measures were provided by De Smedt, Janssen [90], and both tests were proven to have acceptable and good reliability (α = 0.71 for Digit Span Forwards; α = 0.81 for NRT). Visuospatial short-term memory was tested by Block Recall Forwards [90]. On a wooden 23 cm × 26 cm board, nine blocks of 1 cm were glued at random places. For every trial, the researcher tapped a sequence of blocks, and the child was asked to indicate (an increasing number of) blocks in the same order as the researcher had previously tapped. The test was again preceded by two practice trials with feedback. The number of correctly recalled sequences was the final score (maximum 48). Block Recall Forwards has acceptable reliability (α = 0.77). Additionally, Digit Span Backwards and Block Recall Backwards were used to evaluate phonological and visuospatial working memory (i.e., phonological loop + central executive and visuospatial sketchpad + central executive), respectively [90]. For these tasks, the same procedures applied, but the child was asked to recall the digit lists and block sequences in reverse order. Before conducting these tasks, the child was asked the meaning of 'reverse', to ensure that he or she understood the task. If this was not the case, the child was given appropriate feedback and explanation in the practice trials. Digit Span Backwards has an internal consistency of 0.55 [90]. Due to the lack of evidence and the lack of reliable measures, we did not operationalize the fourth component of working memory, i.e., episodic buffer [92,93].

To investigate the development of cognitive flexibility, we assessed both fluency and shifting. A semantic fluency task was administered to the children, asking them to name as many animals and food or drinks as possible in one minute [94,95]. Reliability for this task is acceptable, α = 0.68 [95]. Shifting was assessed using a task developed in this research unit. Evidence and experience show that this is a developmentally appropriate task with good reliability [79]. For the first condition, the child was presented with a card with 40 randomly arranged stimuli (i.e., cat, dog, and fish, each appearing approximately 13 times) and was asked to rapidly name the stimuli. The second condition was similar, but only with shapes (i.e., circle, star, square). Again, the child was asked to rapidly name the stimuli. In the third condition, the child received a card with the animals of the first condition, in the shapes of the second condition. The child was asked to look at the color of the shape (i.e., blue or yellow) and was then required to name the shape if it is blue, but name the animal if the shape is yellow. For all conditions, accuracy and time were retained, which were used to calculate the number of stimuli recalled per second. The difference between the average accuracy, time, and accuracy/time on the first two conditions versus the last condition were used as measures of shifting.

2.3.3. Vocabulary

The Peabody Picture Vocabulary Test-III-NL was used to assess receptive vocabulary [96]. The task requires the child to choose one of 4 pictures that correspond in meaning with an aurally presented word, said by the researcher. The age of the child defined with which item to start. The final score was the total number of correctly chosen pictures, with the addition of all pictures that were part of the test for younger children (i.e., this test assumes that if children can complete a certain number of trials, they also would have known the previous trials). This raw score was then converted into a norm score (mean = 100, *SD* = 15). As for reliability, the Guttman's lambda-2 coefficients (λ) for internal consistency in this study's age groups were high (λ = 0.95 for 5;0–5;5 years and λ = 0.94 for 5:6–5:11 years).

2.3.4. Processing Speed

Processing speed measures were split up into domain-specific reading-related measures, using symbols (similar to letters and digits) and domain-general measures, being nonverbal in content and requiring no reading ability. The tasks to evaluate reading-related processing speed included the Symbol Search and Coding subtest of the Wechsler Preschool and Primary Scale of Intelligence (WPPSI-III-NL). Symbol search required the child to evaluate whether a given shape occurred in an array. For the coding subtest, the child was asked to copy symbols paired with geometric shapes [97]. A composite score was derived from the norm scores of each subtest, resulting in the processing speed quotient (PSQ). This PSQ was found to be a reliable measure, with reliability coefficients of 0.84 for ages 5:6–5:11 and 0.86 for ages 6:0–6:5.

2.4. Statistical Analyses

All analyses were conducted using RStudio [98]. Missing data were observed in the three following tasks: shifting (three participants), delay of gratification (thirteen participants), and flanker (four participants). The reasons for these missing data were the child's refusal to participate in the task, absence of parental consent, and computer issues, respectively. Outliers in the available data were identified by considering values below or above three standard deviations from the mean of each risk group. Applying this criterion led to the removal of 10 values (i.e., score on a specific task) from the analytical sample. Analyses were completed with and without outliers, and when the pattern of results was similar with and without outliers, only those with outliers were reported.

First, by means of analysis of variance, we validated the group designation based on the preliteracy measures that were tested (i.e., letter knowledge, phonological awareness, and rapid automatic naming). Given that children had to score below percentile 25 on at least one of these preliteracy measures to be considered at risk for dyslexia (irrespective of ADHD risk), we tested in these analyses if we could find the expected group differences. To do so, we summed scores from correlated tasks (i.e., passive and active letter knowledge ($r = 0.92$, $p < 0.001$) and phonological awareness ($r = 0.65$, $p < 0.001$)) to create the dependent variables. For the rapid naming task, we used the average score (items per second) of the object and color conditions as the dependent variable. These three variables demonstrated a reasonably normal distribution (skewness ≤ 1 and kurtosis ≤ 3). Subsequent post hoc analyses were adjusted for multiple comparisons using Benjamini–Hochberg FDR. Second, we evaluated the component structure of tasks measuring executive functions. Therefore, we conducted a principal components analysis with oblimin rotation. We used related factors because of the theoretical foundation that EFs in children form a unitary construct with separate, dissociable parts [21,99]. Third, after the component analysis, we assessed group differences between the remaining variables that were not included in the component analyses and the extracted components using an analysis of variance or Kruskal–Wallis test, depending on the distribution of the variable.

3. Results

3.1. Validity of Group Designation

Table 2 summarizes the descriptive statistics for each group and F-tests to detect group differences. Statistically significant lower performance for the DR and DAR groups was found across the three different preliteracy measures compared to the NR group, confirming the initial group selection. Notably, while the DR and DAR groups differed significantly from the NR group on all preliteracy measures, no differences were observed between the DR and DAR groups.

Table 2. Mean scores and standard deviations of preliteracy measures.

	Risk Group				
	DR M (SD)	**DAR M (SD)**	**NR M (SD)**	**F-Statistic All p's < 0.001**	**Post Hoc All p's < 0.001**
Letter knowledge total score	9.0 (6.1)	7.1 (3.7)	22.1 (8.0)	$F(2, 146) = 86.07, \eta^2 = 0.54$	NR > DR = DAR
Active letter knowledge	3.9 (3.2)	2.9 (2.2)	10.6 (4.2)	$F(2, 146) = 79.87, \eta^2 = 0.52$	NR > DR = DAR
Passive letter knowledge	5.1 (3.3)	4.2(2.1)	11.5 (4.0)	$F(2, 146) = 74.37, \eta^2 = 0.50$	NR > DR = DAR
Phonological awareness total score	6.8 (3.6)	6.3 (2.8)	13.0 (5.1)	$F(2, 146) = 43.55, \eta^2 = 0.37$	NR > DR = DAR
Begin phoneme identification	3.6 (2.4)	3.2 (2.2)	6.9 (2.8)	$F(2, 146) = 32.41, \eta^2 = 0.31$	NR > DR = DAR
End phoneme identification	3.3 (1.9)	3.1 (1.7)	6.1 (2.6)	$F(2, 146) = 32.87, \eta^2 = 0.31$	NR > DR = DAR
RAN average score	0.6 (0.1)	0.6 (0.1)	0.8 (0.2)	$F(2, 146) = 49.89, \eta^2 = 0.41$	NR > DR = DAR
RAN colors score	0.6 (0.1)	0.6 (0.1)	0.8 (0.2)	$F(2, 146) = 41.41, \eta^2 = 0.36$	NR > DR = DAR
RAN objects score	0.6 (0.1)	0.6 (0.2)	0.8 (0.1)	$F(2, 146) = 40.62, \eta^2 = 0.36$	NR > DR = DAR

Note. RAN = rapid automatic naming; NR = no risk; DR = dyslexia risk; DAR = dyslexia + ADHD risk.

As for ADHD risk, the children's teachers completed the Preschool Behaviour Questionnaire during data collection. Despite only half of the teachers filling out the questionnaire, the results showed that 60% of those identified children in the DAR group were at clinical risk for ADHD. Additionally, 88.23% of the teachers identified children in the DR and NR groups as not being at risk.

3.2. Component Structure of Executive Functioning Tasks

In order to reduce the number of variables measuring executive functions, we used a PCA with oblimin rotation. Initially, we assessed the Pearson correlations among all executive functioning tasks, discarding variables with low correlations ($r < 0.3$). As a result, we eliminated the shifting task (accuracy/time difference), the go/no-go task (no-go accuracy), the delay of gratification task (number of delayed rewards), and the flanker task (accuracy/time difference). The overall Kaiser–Meyer–Olkin (KMO) measure was 0.81 with individual KMO measures all greater than 0.72. Bartlett's test of sphericity, $\chi^2(21) = 288.28$, $p < 0.001$, suggested that the correlations between variables were large enough to proceed with PCA. Applying the eigenvalue criterion (eigenvalue > 1), we identified two components. We aggregated these tasks into two composite constructs, explaining 62% of the variance in children's performance (Table 3). There was a moderate correlation between the two components, $r = 0.4$.

Table 3. Principal component analysis of executive functioning.

	Loadings	
	Component 1: Verbal Short-Term Memory	**Component 2: Executive Functioning**
Digit span forward	0.857	
Nonword repetition task	0.891	
Digit span backward		0.523
Block recall forward		0.823
Block recall backward		0.797
Semantic fluency		0.698
Reaction time variability (go/no-go)		−0.737

Note. Only factor loadings above 0.25 are shown.

3.3. Group Differences

The following analyses will answer our research questions about group differences between the risk groups. First, we performed separate ANOVAs to detect any group differences on specific components or variables, with Benjamini–Hochberg FDR to account for multiple comparisons. All variables demonstrated a reasonably normal distribution per group (skewness ≤ 1 and kurtosis ranging between 2–5), except for the number of delayed rewards in the delay of gratification task. For this last task, we used the Kruskal–Wallis test to assess group differences. Table 4 shows the means and standard deviations per group and the results of the ANOVAs and post hoc tests. In all measured tests, except for the flanker and delay of gratification tasks, the NR group outperformed the risk groups. Only in the EF composite did the DR group show a trend ($p = 0.057$) of performing significantly better than the DAR group. However, when outliers were removed from the sample ($n = 3$), there was a significant post hoc group difference between the DR and the DAR group ($p = 0.026$).

Table 4. Descriptive statistics of groups on measures of executive functioning, processing speed, and vocabulary.

	Risk Group				
	DR M (*SD*)	**DAR M (*SD*)**	**NR M (*SD*)**	**Statistic**	**Post Hoc**
Verbal short-term memory component	−0.27 (0.76)	−0.40 (0.88)	0.7 (0.99)	$F(2, 146) = 22.92, p < 0.001, \eta^2 = 0.24$	NR > DR = DAR
Executive functioning component	−0.24 (0.85)	−0.55 (0.83)	0.82 (0.77)	$F(2, 146) = 37.43, p < 0.001, \eta^2 = 0.34$	NR > DR ≥ DAR
No-go accuracy (go/no-go)	0.72 (0.20)	0.70 (0.17)	0.78 (0.13)	$F(2, 146) = 3.082, p = 0.048, \eta^2 = 0.04$	NR = DR DR = DAR NR > DAR
Number of delayed rewards (delay of gratification)	2.59 (0.88)	2.47 (0.92)	2.56 (0.89)	$\chi^2(2) = 0.896, p = 0.639$	
Shifting accuracy/difference	0.30 (0.11)	0.28 (0.11)	0.40 (0.11)	$F(2, 143) = 16.84, p < 0.001, \eta^2 = 0.19$	NR > DR = DAR
Flanker accuracy difference	0.22 (0.18)	0.17 (0.13)	0.21 (0.13)	$F(2, 142) = 1.581, p = 0.209, \eta^2 = 0.02$	
Processing speed index score	99.53 (11.79)	96.38 (13.65)	107.88 (12.89)	$F(2, 146) = 10.52, p < 0.001, \eta^2 = 0.13$	NR > DR = DAR
Receptive vocabulary	103.63 (17.62)	100.90 (16.74)	111.52 (11.50)	$F(2, 146) = 6.11, p < 0.01, \eta^2 = 0.08$	NR > DR = DAR

Note. NR = no risk; DR = dyslexia risk; DAR = dyslexia + ADHD risk.

An important feature of our sample was that the groups differed on nonverbal IQ, i.e., the NR group significantly outperformed the DAR group. Additionally, the NR group was significantly older than the DR and DAR groups. Despite conventional advice against incorporating a covariate on which groups differ, especially (nonverbal) IQ [100,101], an ANCOVA yielded the same results as the ANOVA, with group differences remaining, even after controlling for nonverbal IQ and age. This indicates that nonverbal IQ and age did not influence group differences. Further details of this analysis are reported in the Supplementary Materials (Tables S1 and S2).

Second, we also looked more closely at some of the tasks. For the go/no-go task, there are three different conditions: a no-go following one, three, and five preceding go trials. Considering the number of preceding go trials, we performed a mixed-design ANOVA with a group as the between-subjects factor, the no-go condition as a repeated measure, and accuracy as a dependent variable [102]. There were main effects of group, $F(2, 438) = 7.403$, $p < 0.01$, and no-go condition, $F(2, 438) = 3.901$, $p < 0.05$, but no interaction effect. Benjamini–Hochberg FDR revealed significant differences between the DR and the NR group ($p < 0.01$) and between the DAR and NR group ($p < 0.001$) and significant differences between trials with one and three preceding gos ($p = 0.02$) and trials with one and five preceding gos ($p = 0.02$) (Figure 2).

As for the shifting task, the ANOVA of accuracy divided by time showed a significant group effect, as shown in Table 4. However, when examining accuracy and time differences in separate ANOVAs, we found no significant group differences: $F(2, 143) = 1.745$, $p = 0.178$ for the accuracy difference, and $F(2, 143) = 1.179$, $p = 0.31$ for the time difference.

Concerning the processing speed index score, which is derived from the symbol search and substitution tasks, there were significant group differences on the symbol search, $F(2, 146) = 10.37$, $p < 0.001$, and substitution tasks, $F(2, 146) = 5.258$, $p < 0.01$. Benjamini–Hochberg FDR showed that for both tasks, the DAR and DR groups differed significantly from the NR group (all p's < 0.05). However, there was no difference between the DR and DAR groups ($p = 0.23$ for the symbol search task, and $p = 0.38$ for the substitution task).

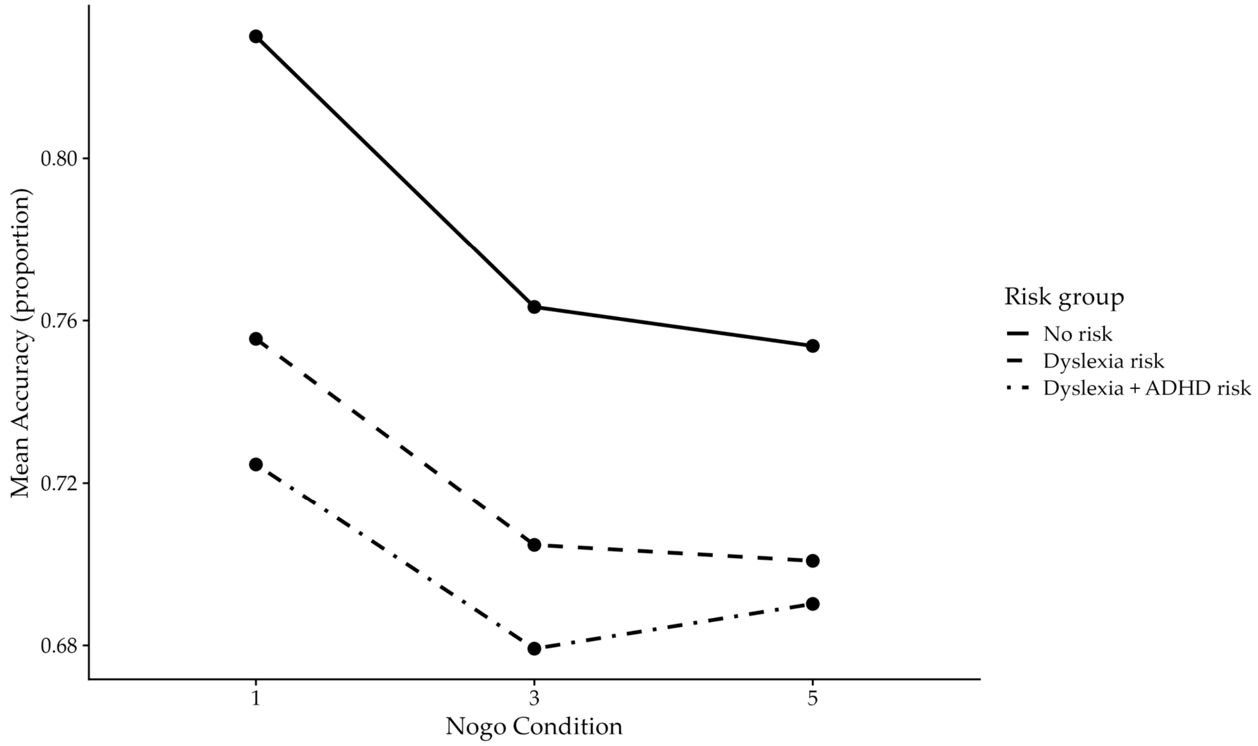

Figure 2. No-go accuracy scores per condition. Note. 1, 3, and 5 refer to one, three, and five preceding go trials before a no-go trial.

4. Discussion

In this study, we examined the cognitive profiles of preschoolers who were at risk for developing dyslexia (dyslexia risk, DR) or dyslexia + ADHD (dyslexia + ADHD risk, DAR). We compared these to the profile of preschoolers without risk (no risk, NR). First, our results confirmed the stability of our group categorization. Indeed, group differences in preliteracy measures (letter knowledge, phonological awareness, and rapid automatic naming) persisted when re-evaluated using the same tasks as when the children were initially selected for the study, approximately five months prior. As expected, the NR group performed significantly better on the preliteracy measures than the DR and DAR groups, who did not show significant differences between themselves. Second, we aimed to reduce the amount of variables measuring executive functions (EFs) by means of a principal component analysis (PCA). The results showed two distinct components, a verbal short-term memory component and an EF component. Third, analyses of risk group differences showed that both risk groups performed significantly lower than the NR group on all abovementioned tasks except for the flanker task. Only in the EF component did the DR and DAR groups show a trend to a significant difference, while there was no difference between these two risk groups on any of the other tasks.

Our first research question aimed to investigate the component structure of a large battery of EF tasks. Several studies found similar results concerning the composition of EFs. For instance, Garon, Bryson [99] showed that EFs remain nonspecific at this age. Studies have shown that EFs continue to differentiate during childhood, due to cortical maturation and cognitive challenges [99,103]. Also, much like the Unity/Diversity model of EFs, our data show that EFs appear to be a unitary construct [21]. Various tasks measuring distinct core EFs, such as verbal and visuo-spatial working memory (backwards digit span and block recall), visuo-spatial short-term memory (forwards block recall), generativity (semantic fluency), and task engagement or effort allocation (reaction time variability), correlated, forming the EF component. However, the flanker and shifting task did not correlate with the other EF tasks. This also agrees with Miyake's model, stating that EFs correlate with each other, but are also clearly separable (i.e., diverse).

While a recent review showed evidence for preschool EF as a single-factor construct, it is important to note that the studies in this review did not involve measures of verbal short-term memory [103]. However, because our test battery was built on Baddeley and Hitch's working memory model, we included verbal and visuo-spatial short-term memory measurements in the PCA. Consequently, the PCA showed a distinct component for verbal short-term memory alongside a separate EF component, which then included the visuo-spatial short-term memory. Since the same task is used in each component (digit span forwards in the verbal short-term memory component and digit span backwards in the EF component), the moderate correlation between the two components aligned with our expectations.

In short, our findings show a nonspecific, unitary EF component stemming from tasks theoretically measuring different core EFs. Additionally, a moderate correlation between the verbal short-term memory and EF components underscores their relatedness, showing unity. On the other hand, the lack of correlation among the flanker, shifting, and go/no-go tasks highlights diversity already at a preschool age.

Our second research question aimed to investigate group differences between the risk groups on the extracted components and on remaining variables (i.e., no-go accuracy, flanker and shifting difference scores, receptive vocabulary, and processing speed). Our main finding was that the NR group performed significantly better than the DR and DAR groups on all tasks, except for the flanker task. This finding agrees with results from a meta-analytic study that showed that older children diagnosed with learning disorders in reading and/or mathematics have poorer EF performance, specifically on working memory and short-term memory [18]. Concerning the two at-risk groups, one of our most notable results was that the DR and DAR groups did not differ on any measures, except for a trend towards a significant difference on the EF composite. These results contrast with previous studies suggesting that EF deficits align more with ADHD rather than with dyslexia (or broader, learning disorders) [13,50]. In conclusion, our findings show there was an impact of dyslexia risk on EF deficits, and that the presence of ADHD risk might amplify these EF deficits, beyond dyslexia risk alone.

The group differences in the verbal short-term memory composite were not unexpected, considering that verbal short-term memory is commonly regarded as a phonological skill [15,104]. Indeed, in older children with a diagnosis of dyslexia, verbal short-term memory seems impaired. Despite its relatively lower predictive power compared to phonological awareness, rapid automatic naming (RAN), or letter knowledge, our study shows that children identified as being at risk based on these latter preliteracy measures also encounter challenges with verbal short-term memory [25].

We also found group differences in the no-go accuracy of the go/no-go task, which measured response inhibition. As expected, all children's accuracy on the no-go trials dropped with more preceding go trials [105]. Our results also showed that the group difference was driven by trials with one preceding go trial, but not with three or five. Our interpretation suggests that this difference emerged because the demands of inhibitory control in trials with three or five preceding go trials proved challenging for all children, irrespective of their risk status. This implies that while basic inhibitory demands could distinguish between children at this age, the task's increased complexity proved difficult even for those not at risk. We also found a post hoc group difference only between the NR and the DAR group. The DR group did not differ from either the NR or the DAR group. This was expected, as response inhibition is a core neuropsychological difficulty for children with ADHD, reflecting their impulsiveness [81,102,106]. It is important to mention that another measure of the go/no-go task, reaction time variability, was a part of the EF composite. Reaction time variability is a reflection of children's sustained attention, or the effort they are able to allocate to the task, and is one of the most consistently found deficits in children with ADHD [83,87,88]. As expected, in our study, it becomes evident that children from the DAR group have significantly more difficulties allocating effort to the task than children from the DR and NR groups.

As expected, there was no group difference in accuracy or the reaction time conflict score on the flanker test. Indeed, the literature also does not mention a cognitive inhibition deficit in children with dyslexia and/or ADHD. However, as we aimed to obtain a full picture of the EFs of preschoolers (at risk), we included this measure in our battery.

There were also no group differences in the chosen number of delayed rewards. Other studies did find that children at risk for ADHD chose more often the immediate reward in a similar choice-delay task [39,40]. However, these studies used more trials compared to ours, which likely provided more variability to detect group differences. Consequently, it remains possible that our groups differ on the task, given the lower mean number of delayed choices; however, our study lacked the statistical power to detect these differences. Alternatively, in our study, children were not instructed to wait and sit still when choosing the delayed reward. Instead, we continued with test administrations and children received their candy after completing a new task. As a result, it is possible that distractions and the absence of a genuine waiting period influenced more children to choose the delayed reward.

Furthermore, there were no group differences between the DAR and DR groups on processing speed. This was expected, as processing speed is seen as a shared cognitive deficit between dyslexia and ADHD, and thus children with (a risk for) dyslexia and/or ADHD might have difficulties with this [49,52–55]. Indeed, the two at-risk groups performed significantly lower than our NR group.

We did not hypothesize about differences in cognitive flexibility, as shifting has not been consistently linked to ADHD or the effect sizes were small [88,107,108]. However, our study did reveal group differences, with the NR group outperforming the DR and DAR groups on the shifting measure. This might be because, at the group level, our sample of children at risk for dyslexia (irrespective of ADHD risk) had rapid naming deficits compared to the NR group. Since this switching task required rapidly retrieving words (animals and shapes), the significant group difference is not surprising and might drive this group difference. Similarly, another component of cognitive flexibility, semantic fluency, had inconsistent results in previous studies regarding the total produced words [108–110]. In our study, however, the semantic fluency task was loaded on the overarching EF component, which showed group differences. This again demonstrates the greater unity of EFs in preschoolers, compared to older children.

In conclusion, the cognitive profile of at-risk preschoolers aligns most with the findings from studies showing shared cognitive deficits between dyslexia and ADHD [16,57,58]. However, in our sample, the at-risk group showed deficits across a broader range of cognitive functions, compared to those studies. Additionally, the DAR group showed more difficulties with an overall EF-component, agreeing with studies that individuals with co-occurring dyslexia and ADHD experience similar, but worse, cognitive deficits as children with one diagnosis (i.e., dyslexia or ADHD) [11,51].

Strengths, Limitations, and Implications

The current study investigated the cognitive profiles of preschoolers at risk for developing dyslexia (and ADHD), compared to the cognitive profile of preschoolers without risk. This study is an important start in understanding the cognitive challenges these children encounter, which could possibly make their transition to primary school more difficult. For instance, knowing that children at risk for dyslexia, compared to children at risk for co-occurring dyslexia and ADHD, have similar cognitive difficulties, provides a valuable foundation for interventions targeting at-risk children. Importantly, our study revealed that EF difficulties can differentiate between the single risk for dyslexia and the co-occurring risk for dyslexia and ADHD, and thus highlights the importance of considering this when developing strategies for these children. As the transition to primary school itself affects EF development, these children are at greater risk for future school problems [111]. Considering that poor EFs in preschool correlate with problems in emergent literacy and numeracy skills [112,113] and subsequent academic struggles such as with reading, writing, science, and mathematics [79,114–116], the vulnerability of the children within our risk groups becomes evident. These groups are already predisposed to a higher chance of developing reading and writing problems, which might further escalate due to their executive function challenges.

We recognize several limitations within our study. First, it is important to remember that our groups differed on nonverbal IQ and age. Specifically, the risk groups were significantly younger than the no-risk group, and the DAR group scored significantly lower than the NR group. This discrepancy might influence the observed group differences, especially between the DAR group and the NR group.

Second, the principal component analysis was conducted across our whole sample, not per risk group. Unfortunately, comparing component structures between groups was not feasible due to sample size constraints. However, our findings align closely with studies on typically developing children. Given that a significant portion (66%) of our sample comprised children at risk for dyslexia (and ADHD), we can assume that the identified components would remain consistent across these groups.

Third, the absence of an ADHD-only risk group prevented us from isolating the impact of ADHD specifically on the cognitive profiles of these children, while our design did allow us to explore the amplifying influence of ADHD on preschool cognition in children at risk for dyslexia. It is important to note that with this sample, we were not able to attribute cognitive deficits to dyslexia or ADHD. We recommend that future research incorporate this (risk) group to broaden understanding and provide a more comprehensive cognitive assessment.

Fourth, the absence or presence of a post hoc group difference between the DR and the DAR groups, depending on the analytic sample, shows that our study might lack statistical power to detect small effects. Even though the effect size of the overall ANOVA ranged from small to large [117], the specific post hoc group differences might be small. Future studies with larger samples might offer more definitive insights into whether differences in EFs play a pivotal role in the onset of dyslexia and/or ADHD.

A last point of discussion revolves around the process of selecting the at-risk preschoolers. While our cut-off of performing below percentile 25 on the preliteracy measures for the at-risk preschoolers was based on previous research, we arbitrarily decided that the NR group had to score above percentile 40 on all of these preliteracy measures. In doing so, we eliminated a large variation in preliteracy scores between the 40th and 50th percentile (as at-risk children were not allowed to score above percentile 50). Consequently, the observed group differences may be influenced by the choice to specifically select the highest achievers in the typically developing population. Indeed, the NR group scored higher than expected on normed tasks of processing speed and receptive vocabulary. Given that the at-risk groups (mostly DAR) nearly consistently underperformed the NR group across measures, including nonverbal IQ, it is plausible that we unintentionally chose two extreme groups, one vulnerable group selected for their preliteracy difficulties and one high-achieving typically developing group.

5. Conclusions

In summary, our findings show that children at risk for developing dyslexia (and ADHD) have broader cognitive difficulties than those directly linked to preliteracy and future reading or spelling problems. While dyslexia risk was based on cognitive predictors [22–26,118], ADHD risk was assessed based on behavioral criteria [60], and our findings indicate a cognitive profile in children at risk for dyslexia (and ADHD) that shows difficulties beyond those for which the children were selected. Specifically, EFs also seem to be implicated in these children. Considering EFs are fundamental to future well-being and academic success, these results highlight the importance of comprehensive cognitive screening in preschool for children at risk for developing dyslexia and/or ADHD. Future studies should elaborate and deepen these findings by setting up a longitudinal study to see how children's cognitive profiles develop over time. It is, for instance, critical to assess whether the group differences of this study persist over time and whether all children develop at similar rates, fall behind, or catch up. Including an ADHD-only group in this future study is essential to elucidate the cognitive profile associated with co-occurring dyslexia and ADHD, compared to dyslexia or ADHD alone. Early detection and follow-up assessments of difficulties are also vital to clinical practice, in order to investigate the reciprocal relationship between persisting negative cognitive impacts and school achievement.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/educsci14040435/s1, Table S1. Group differences when including nonverbal IQ as a covariate; Table S2. Group differences when including age as a covariate.

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