Research in Developmental Disabilities 139 (2023) 104540

Contents lists available at ScienceDirect

Research in Developmental Disabilities

journal homepage: www.elsevier.com/locate/redevdis

Trajectory assessments of cognitive, visuospatial, and academic profile in nonverbal learning disability (visuospatial developmental disorder)

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ARTICLE INFO

Keywords:
Visuospatial developmental disorder
Nonverbal learning disability
Longitudinal study
Visuospatial processing

ABSTRACT

Substantial progress has been made in defining children with nonverbal learning disability (NLD), but longitudinal studies are still lacking. To start filling this gap, we examined changes in general cognitive functioning, visuo-constructive skills, and academic profiles in a group of children with NLD, also taking into account any internalizing and externalizing symptom as transdiagnostic features.

A total of 30 participants (24 boys) diagnosed with NLD were tested twice, with a three-year gap between the two assessments (T1: at age 8–13; T2: at 11–16), on their cognitive profile, visuospatial abilities, and academic performance (i.e., reading, writing and arithmetic abilities). At T2, any internalizing and externalizing symptom was also investigated.

Statistically significant differences emerged between the two assessments in terms of the WISC-IV Perceptual Reasoning Index (PRI), handwriting speed and arithmetical fact retrieval.

The NLD profile seems to be characterized by a relative stability in its core features during a child's development, as regards both weaknesses (i.e., visuospatial processing) and strengths (i.e., verbal abilities). The presence of internalizing and externalizing symptoms also suggested the importance to analyze transdiagnostic features rather than only sharp boundaries between conditions.

1. Introduction

Children with a visuospatial developmental disorder, often termed nonverbal learning disability (NLD), are characterized by visuospatial processing deficits but average verbal abilities. NLD is often associated with academic difficulties and/or social perception or emotional deficits (Fisher et al., 2022), leading to a set of symptoms that it may share with other neurodevelopmental disorders (Mammarella et al., 2022).

A considerable effort has been made by researchers in recent years to study such children (Mammarella & Cornoldi, 2020), and to raise awareness about the importance of establishing shared and acknowledged diagnostic criteria (Fisher et al., 2022; Mammarella, 2020, 2022). In fact, NLD is still not recognized by the international diagnostic manuals. In a recent systematic review, Fisher and colleagues (Fisher et al., 2022) nonetheless concluded that there is now strong evidence available to pinpoint that an identifiable group

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https://doi.org/10.1016/j.ridd.2023.104540
Received 13 October 2022; Received in revised form 25 April 2023; Accepted 23 May 2023

of children differ from their typically-developing peers inasmuch as they have substantial visuospatial deficits. The Authors mentioned among the limitations of the studies they had reviewed that longitudinal data are still lacking. To the best of our knowledge, the present study is the first to have longitudinally assessed children with NLD in an effort to begin to fill this gap in the literature.

NLD was first described by Johnson and Myklebust (Johnson & Myklebust, 1967) in 1967. More than 50 years on, more evidence has been collected on the cognitive, neuropsychological, and academic profile of children with this disorder than on their emotional and socio-relational characteristics. It is worth noting that, in the absence of acknowledged diagnostic criteria, most published studies considered a discrepancy between verbal and visuospatial intelligence as the main criterion for identifying children with NLD (Fisher et al., 2022; Mammarella & Cornoldi, 2014), although recent research highlighted the crucial role of visuospatial processing skills. The visuospatial processing skills of children with NLD have been studied in depth, mainly to shed light on which specific abilities are impaired. For example, Semrud-Clikeman, Walkowiak, Wilkinson and Portman Minne (2010) compared children with NLD, Asperger syndrome or ADHD, and typically-developing (TD) peers on several neuropsychological tasks. They found children with NLD more severely impaired than either of the other groups on measures of visuo-constructive skills, and on measures of visual perception. Regarding fine motor skills, both the NLD and Asperger groups performed worse than the TD controls, and the ADHD group. Mammarella et al. (2019) compared children with NLD, or with autism spectrum disorder (ASD) but no intellectual disability, and TD controls, assessing them on visuo-constructive and visuospatial working memory tasks. They found that children with NLD performed less well in both types of task. It is important to note that the NLD and ASD groups examined in this study had statistically similar scores on the full-scale IQ and visuo-perceptual reasoning index of the Wechsler scales, so the differences in performance could not be attributable to the NLD group having a lower visuospatial intelligence. In previous studies, children with NLD have also revealed difficulties in graphically representing spatial descriptions (Mammarella et al., 2009), and in several measures of visuospatial working memory (Basso Garcia et al., 2015; Cardillo et al., 2017, 2020).

In terms of academic profiles, a discrepancy between good reading decoding skills and poor performance in mathematics has been used in the past as a criterion for diagnosing children with NLD (Chow & Skuy, 1999; Pelletier et al., 2001; Rourke, 1995). It has therefore generally been assumed that children with NLD perform well in reading and poorly in mathematics (Forrest, 2004). Several studies confirmed their difficulties specifically in mathematical tasks that involved visuospatial processing (Crollen et al., 2015; Mammarella et al., 2010, 2013). As for reading comprehension, Humphries et al. (2004) found difficulties with both narrative comprehension and retelling in a sample of children with NLD, specifically when they were asked to draw inferences. Other studies (Mammarella et al., 2009; Worling et al., 1999) suggested, on the other hand, that the reading comprehension difficulties seen in children with NLD related to the processing of spatial information in written passages. Handwriting has not been extensively studied in these children as yet: to the best of our knowledge, only Gross-Tsur et al. (1995) considered this aspect in children with NLD, reporting that 6 out of 20 children in their sample had graphomotor problems.

Finally, there are mixed findings regarding concurrent internalizing and externalizing symptoms in children with NLD. When Hendriksen et al. (2007) considered a group of children with NLD, a group with motor disabilities, and a group with verbal learning disability, they found that the former scored lower on externalizing symptoms than children with motor disabilities, and higher than children with verbal learning disability for inattention. Pelletier et al. (2001) reported that children with NLD had more severe internalizing symptoms than children with dyslexia, whereas Forrest (2004) found no difference on internalizing symptoms between groups with NLD as opposed to verbal learning disability. Mammarella et al. (2016) likewise found no differences between children with NLD and those with dyslexia when measured on generalized and social anxiety, though both groups scored higher than TD children. In this last study (Mammarella et al., 2016), children with NLD also did not differ from TD controls on depressive symptoms.

1.1. The present study

As mentioned earlier, the literature is fairly consistent as regards the cognitive and academic profile of children with NLD (Fisher et al., 2022), which has historically been characterized by a discrepancy between verbal and visuospatial intelligence, as well as poor visuospatial processing skills. Moreover, past descriptions on the profile shed light on mathematical difficulties, though the findings on reading comprehension and handwriting skills are scarce and rather more variable. For the time being, however, there is no evidence available on whether and how the profile of children with NLD changes as they develop. In other words, it is not clear whether their cognitive profile, visuospatial deficits, and academic performance become stable after a few years. In the present study, we consequently collected data on the general cognitive functioning, visuo-constructive skills, and academic profile (i.e., reading decoding, reading comprehension, mathematics, and handwriting) of a sample of children with a clinical diagnosis of NLD, assessing them at two different times (in 2018 and 2021) to see how their skills had developed as they grew older. We then considered the variables for which statistically significant differences emerged between the two time points to test whether the indices of their cognitive profiles, or any internalizing and externalizing symptoms, predicted the differences observed three years after the baseline assessment. At the second time point, we also investigated the children's internalizing and externalizing symptoms, to identify the proportion of children with different levels of impairment in these aspects. To be more specific, we considered the number of children exceeding a clinical cut-off (2SD beyond the normative sample) or revealing slight difficulties (1 SD beyond the normative sample) in said areas.

Summarizing, the main aims of the present study were to: (i) analyze the presence of any difference between T1 and T2 on the measures of general cognitive functioning, visuo-constructive skills, and academic performance of our children with NLD; (ii) test whether the cognitive indices at T1 might predict the performance observed three years later (only for the variables for which statistically significant differences emerged between the two time points), controlling for the same abilities at T1 and any internalizing and externalizing symptoms at T2; (iii) analyze the levels of internalizing and externalizing symptoms at T2, in order to observe whether internalizing or externalizing symptoms may occur, on varying levels of severity in NLD.

Table 1
Characteristics of the NLD group at T1.

Measures	Mean (*SD*) (n = 30)
Age (months)	128.80 (32.13)
VMI (standard scores)	78.12 (11.68)
VCI (standard scores)	113.17 (14.35)
ADI-R: A (Reciprocal social interaction)	6.40 (5.56)
ADI-R: B (Language/communication)	5.65 (3.83)
ADI-R: C (Repetitive behaviors/interests)	2.95 (3.35)

Note: VCI: Verbal Comprehension Index (WISC-IV); ADI-R: Autism Diagnostic Interview–Revised.

2. Method

2.1. Participants

A total of 30 participants (24 boys), with a clinical diagnosis of NLD took part in the study. They were tested twice on their cognitive and visuo-constructive functioning, and their academic profile, with a three-year interval between the two assessments. After 3 years (T2), additional measures were used to assess internalizing and externalizing symptoms, only 25 out to 30 participants agreed to complete the assessment with these additional measures.

At the baseline (T1; in 2018), participants were selected from among the database of a clinical center in north-east Italy that specializes in the diagnosis of neurodevelopmental disorders (total screened cases n = 458). Participants' inclusion in the study was subject to the agreement of all the authors of this manuscript, who adopted the following criteria to confirm a diagnosis of NLD: deficits in the processing of visual and spatial information (i.e., scores at least 1 SD below the norm in the developmental test of Visual–Motor Integration, VMI; Beery & Buktenica, 2000) and a history of visuospatial processing difficulties confirmed by interviewing the parents. Further inclusion criteria were as follows: a WISC-IV Verbal Comprehension Index (Wechsler, 2012) within or above the normal range (i.e., above 85); age between 8 and 13 years at T1; having not taken part to a rehabilitation program between T1 and T2; no other psychiatric, neurological, or genetic disorders. Children who were born pre-term were not excluded by our sample, however, only 2 of them were born pre-term (respectively at the 34 and 36 gestation week).

The Autism Diagnostic Interview-Revised (ADI-R; Rutter et al., 2005) was administered to rule out any autistic trait, and all participants scored below the cut-offs for each scale. All participants spoke Italian as their first language and attended regular classes at their school. Their characteristics are summarized in Table 1.

2.2. Materials

2.2.1. Intelligence

The *Wechsler Intelligence Scale* (WISC-IV; Wechsler, 2012) was administered, and the scores obtained on the factor indices (i.e., the verbal comprehension index [VCI], the perceptual reasoning index [PRI], the working memory index [WMI], and the processing speed index [PSI]) were analyzed. The Full-scale IQ was not considered because the marked discrepancy emerging between the various indices made the total score unreliable (Wechsler, 2012).

2.2.2. Visuo-constructive abilities

The Rey-Osterrieth Complex Figure Test (ROCFT; Rey, 1941) was administered, in both the copy and the recall conditions, the latter after a 3-minute break. The standard scoring system (Rey, 1941) was used, scoring each of the 18 elements from 0 to 2 points based on accuracy of reproduction, position in space, and maintenance of proportions. Z scores were obtained for both conditions.

2.2.3. Academic achievement

Reading decoding and comprehension. Reading decoding abilities were assessed administering standardized words and pseudo-words reading tasks. The DDE-2 (Sartori et al., 2007) was administered to children attending grades 3rd to 8th (approximately covering ages from 8 to 14), while the MT-3 Advanced Clinical Battery (Cornoldi et al., 2017) to children attending grades 9th and 10th (aged 14–16 years old). Reading times and errors were registered, and raw scores were converted into z scores using normative values. To assess text comprehension abilities the MT-3 Clinical (Cornoldi & Carretti, 2016) and MT-3 Advanced Clinical (Cornoldi et al., 2017) batteries were used, depending on children's attended grade at the time of the assessment (i.e., the MT-3 Clinical from grade 3 to grade 8, the MT-3 Advanced Clinical for grades 9th and 10th). Children were presented with a passage, and a silent reading was asked. Participants had to answer multiple-choice questions. Z scores were calculated based on the accuracy.

Handwriting speed. Handwriting speed tasks, drawn from the Battery for Handwriting Assessment (BVSCO-2; Cornoldi et al., 2013), (administered to children from grade 3rd to 8th) or the MT-3 Advanced Clinical Battery (Cornoldi et al., 2017) (administered to children attending grades 9th and 10th) were administered. Participants were asked to write as fast as they could: (i) the syllable "le", using a cursive writing; and (ii) number words using their preferred writing style. Participants had a minute of time to complete each task. Z scores based on the number of written graphemes were computed.

Table 2
Descriptive statistics and differences, in terms of Cohen's d, at T1 and T2 for the cognitive, visuospatial and academic achievement measures.

	T1 Mean (SD)	T2 Mean (SD)	*t*	*p*	*Cohen's d*
Intelligence					
Verbal Comprehension Index	113.17 (14.350)	114.70 (14.763)	.726	.474	.105
Perceptual Reasoning Index	83.47 (14.635)	88.97 (17.425)	2.090	**.045**	.342
Working Memory Index	91.47 (15.891)	94.67 (11.284)	1.422	.166	.235
Processing Speed Index	83.20 (11.825)	81.70 (10.863)	-.826	.416	.132
Visuo-constructive abilities					
ROCFT: copy accuracy	-3.92 (2.14)	-3.99 (2.389)	-.131	.897	.031
ROCFT: recall accuracy	-2.59 (0.935)	-2.25 (1.046)	1.563	.129	.343
Reading decoding and comprehension					
Words: time	-0.52 (1.034)	-0.61 (1.188)	-.562	.579	.081
Words: number of errors	0.37 (1.689)	0.53 (2.528)	.605	.550	.074
Pseudo-words: time	-0.39 (0.708)	- 0.59 (1.052)	-.929	.361	.223
Pseudo-words: number of errors	0.14 (1.022)	0.39 (1.928)	.909	.371	.162
Text comprehension: number of errors	-0.16 (0.997)	0.19 (1.014)	-.152	.880	.042
Handwriting					
"le"	-1.85 (1.189)	-1.53 (1.312)	1.525	.138	.256
Number words	-1.47 (0.954)	-0.89 (0.785)	2.881	**.007**	.667
Arithmetic					
Mental calculation: time	1.27 (2.081)	1.26 (2.389)	-.023	.982	.004
Mental calculation: number of errors	0.51 (1.208)	0.34 (1.308)	-.634	.531	.135
Arithmetical facts: number of errors	0.79 (1.196)	0.16 (1.328)	-2.632	**.010**	.497

Note: ROCFT: Rey Osterrieth Complex Figure Test (Rey, 1941).

Arithmetic. The AC-MT 6–11 (Cornoldi et al., 2012) (grades 3rd to 5th), AC-MT 11–14 (Cornoldi et al., 2007) (grades 6th to 8th) and the MT-3 Advanced Clinical (Cornoldi et al., 2017) (grades 9th and 10th) batteries were used to assess participants' arithmetical abilities. Mental calculations and arithmetical facts retrieval tasks were administered. For both tasks, participants were presented orally with a calculation at a time and asked to solve each mental calculation within 30 s and each arithmetical fact within 3 s. Total number of mistakes made in each task, and response time for the mental calculations were converted into z scores.

2.2.4. Internalizing and externalizing symptoms

The Revised Children's Manifest Anxiety Scale, Second Edition (RCMAS-2; Reynolds & Richmond, 2012) is a yes/no self-rating scale devised to assess anxiety in children and adolescents. The total anxiety score was considered for the purpose of the study. Raw scores were converted into T scores.

The Depression Self-Rating Scale (SAFA-D; Cianchetti & Sannio Fancello, 2001) is designed to assess depressive symptoms in children, using a 3-point Likert scale. The SAFA-D depressed mood score was considered. Raw scores were transformed into T scores.

The Conners Parent Rating Scale, Revised: Short Form (CPRS R:S; Conners et al., 1998) was used to assess participants' externalizing problems (on a 4-point Likert scale), based on the oppositional traits and hyperactivity subscales. Raw scores were converted into T scores.

We checked the reliability of all our measures with Cronbach's α_s or test-retest indices, and they all reached satisfactory standards.

2.3. Procedure

A longitudinal design method was adopted for the present study.

At T1 (2018), participants were selected among the diagnostic database of children who had been previously diagnosed with developmental disorders by expert clinicians in a specialized clinical centre in the North-Eastern area of Italy, and whose parents had given written consent to be contacted again for research purpose. Written informed consent was attained by parents or legal caretakers for each participant at T1 and T2. The study was approved by the research ethic board of the Authors' institution.

Children aged 8–13 were assessed on their cognitive profile, visuospatial abilities, and academic achievement (i.e., reading, writing and arithmetic abilities). Three years later (at T2, in 2021), the same assessment was repeated when the participants were between 11 and 16 years old. Additional measures obtained at T2 concerned the presence of internalizing (RCMAS-2; Reynolds & Richmond, 2012 and SAFA-D; Cianchetti & Sannio Fancello, 2001) and externalizing (CPRS R:S; Conners et al., 1998) symptoms.

2.4. Data analysis

2.4.1. Data analyses were conducted using R (R Core Team, 2021)

Firstly, cognitive, visuospatial and academic (i.e., reading, writing and arithmetic abilities) measures were considered. Several linear mixed-effects models were run, with the aim to detect the presence of statistically significant differences between T1 and T2. In these linear mixed-effect models time of assessment (wave) was entered as the predictor, while the scores at each task were considered as the dependent variables. Participants were included as random effects, aiming to take into account their variability. Post-hoc

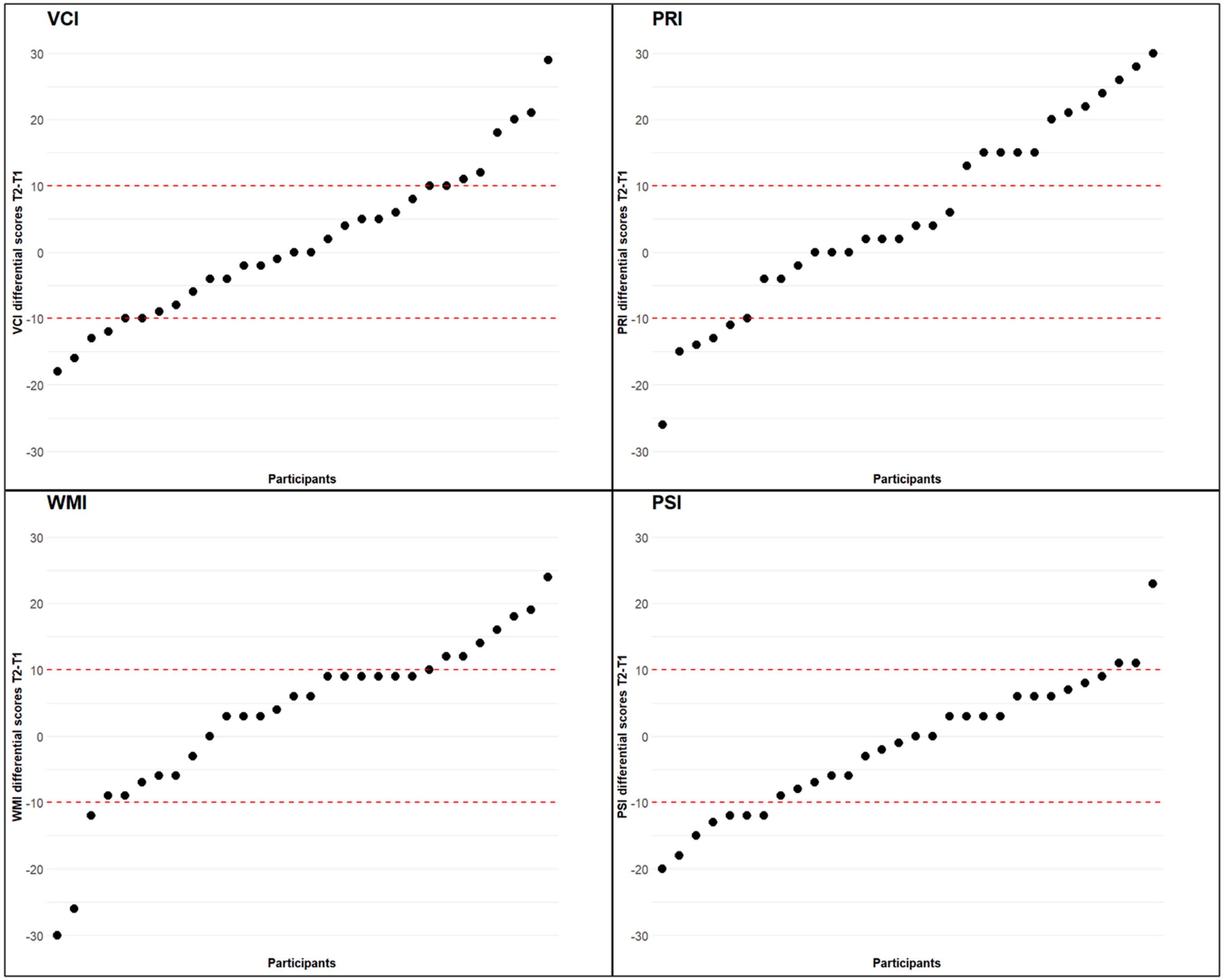

Fig. 1. *Differential scores for WISC-IV indices collected at T1 and T2 (upper left panel: Verbal Comprehension Index; upper right panel: Perceptual Reasoning Index; lower left panel: Working Memory Index; lower right panel: Processing Speed Index). A positive differential score indicates an improvement at T2, while a negative score reflects a worsening performance. Finally, near-zero differential scores represent a stable pattern at the two time points. Note:* VCI: Verbal Comprehension Index; PRI: Perceptual Reasoning Index; WMI: Working Memory Index; PSI: Processing Speed Index.

comparisons were performed when appropriate, and the False Discovery Rate method for multiple testing (Benjamini & Hochberg, 1995) was used to adjust the model coefficients for the number of comparisons.

Due to the relatively high number of variables administered for the assessment of academic achievement, internalizing and externalizing symptoms (see Table 2 for descriptive statistics), several principal component analyses (PCa) were conducted to extract factors and thus reduce the variables. PCa allowed explaining the same amount of variance with fewer variables (principal components) (Suhr, 2005). For the handwriting speed factor, the "le" and the number-words tasks were considered, while for the arithmetic abilities factor the mental calculation and arithmetical facts retrieval tasks were taken into account. As a result, two factors for handwriting abilities (Handwriting speed at T1 and at T2) and two factors for arithmetic abilities (Arithmetic abilities at T1 and at T2) were obtained, one for each timepoint. For the factor tapping internalizing symptoms, the total score of the RCMAS-2 and the depressed mood score of the SAFA-D questionnaires were entered. Finally, in the externalizing factor oppositional traits and hyperactivity subscales of the CPRS R:S were included. Such obtained factors were used for the subsequent regression analyses. Table S1 reported in the Appendix summarizes all the principal components' loadings.

Several linear regression analyses were run on the areas for which emerged statistically significant differences between T1 and T2. These analyses aimed to shed further light on the associations between measures collected at T1 and T2 regarding intelligence (e.g., PRI of the WISC-IV) and academic achievement (i.e., composite scores for handwriting speed and arithmetic abilities). In the first model, perceptual reasoning index at T2 was set as the dependent variable, while composite scores for handwriting speed and arithmetical abilities at T2 were set as dependent variables in the other two models, respectively. All the linear regression models consisted in two steps, with WISC-IV indices (VCI, PRI, WMI and PSI) collected at T1 entered in the first step. As concerns the second and the third linear regression models, in addition to WISC-IV indices, composite scores for handwriting speed or arithmetical abilities collected at T1 were included, alternatively, in the first step. In the second step were considered the ROCFT copy and recall accuracy z scores collected at T1, and internalizing and externalizing composite scores collected at T2. For each linear regression model, ANoVAs were conducted aiming to detect differences in the proportion of variance explained by each model (i.e., step 1 and step 2).

Finally, we considered the additional measures, concerning the presence of internalizing and externalizing symptoms. Those data were analysed computing the number of participants who scored respectively beyond 1 SD or 2 SD from the normative average, thus suggesting the presence of different levels of impairment. As for internalizing and externalizing measures we could only present the data at T2, because in the first assessment we were able to collect those measures only in a small sub-sample of 13 participants, and this numerosity do not allowed us to perform any reliable longitudinal comparison.

3. Results

Age was never considered in the analyses because all measures were converted in relation to normative data.

3.1. Longitudinal differences

Table 2 summarizes the descriptive statistics for the measures of cognitive and visuospatial abilities, and academic achievement recorded at T1 and T2, together with the results of the linear mixed-effects models.

3.1.1. Intelligence

At both time points, participants scored within or above the normal range (above 85) in the VCI and WMI, while they scored below average in the PSI. No significant differences emerged for these indices between T1 and T2 (Table 2). In the PRI, participants scored below average at T1, while their mean scores were higher at T2, $t(29) = 2.09$, $p = .045$, $AIC = 488.79$, with a medium effect size (*Cohen's* $d = .34$).

The differences between the scores obtained in the WISC-IV indices at T1 and T2 were computed (Fig. 1).

3.1.2. Visuo-constructive abilities

The children's scores revealed severe impairments in both the copy and the recall phases of Rey's Complex Figure Task (Table 2), but no significant differences emerged between T1 and T2 in either phase of task.

3.1.3. Academic achievement

Reading decoding and comprehension. Participants scored within normal range in all tasks, at both time points (Table 2). No significant differences emerged between T1 and T2, neither for reading speed or accuracy in the word and pseudo-word tasks, or for the reading comprehension task.

Handwriting speed. Overall, the children's performance was below average in all tasks and at both time points (Table 2). Notably, the children scored below average (i.e., −1.5 SD) in the "le" cursive writing task, which demands good fine motor coordination abilities, with no significant differences emerging between T1 and T2. On the other hand, they wrote significantly more graphemes at T2 than at T1 in the "number word" writing task, when they could choose their preferred writing style $t(29) = 2.881$, $p = .007$, $AIC = 162.38$.

Arithmetic. In the mental calculation task, participants' scores for accuracy were within normal range at both time points, though their performance was slower than expected (i.e., −1 SD below the norm; Table 2). No significant differences emerged between T1 and T2 in the children's mental calculation abilities, neither for accuracy nor for speed, although the children fared significantly better at T2 when tested on arithmetical facts, $t(29) = -2.632$, $p = .013$, $AIC = 199.44$.

Table 3
Regression analyses with the perceptual reasoning index (PRI), handwriting speed and arithmetical abilities at T2 as dependent variables.

Predictors	*β*	Std. Error	*t*	*p*
PRI at T2				
Model 1				
PRI at T1	0.433	0.254	2.437	0.025
VCI at T1	0.100	0.324	0.419	0.680
WMI at T1	-.013	0.169	-0.062	0.951
PSI at T1	0.453	0.193	2.361	0.030
Handwriting speed at T2				
Model 1				
Handwriting at T1	0.454	0.170	2.669	0.016
VCI at T1	-0.150	0.309	-0.628	0.538
PRI at T1	0.523	0.245	2.911	0.010
WMI at T1	0.161	0.163	0.784	0.444
PSI at T1	0.257	0.184	1.335	0.199
Arithmetical abilities at T2				
Model 1				
Arithmetic at T1	0.525	0.217	2.418	0.027
VCI at T1	0.054	0.392	0.178	0.861
PRI at T1	-0.025	0.299	-0.115	0.910
WMI at T1	-0.110	0.198	-0.441	0.665
PSI at T1	0.003	0.227	0.014	0.989

Note: VCI: Verbal Comprehension Index; PRI: Perceptual Reasoning Index; WMI: Working Memory Index; PSI: Processing Speed Index.

Table 4
Descriptive statistics (M, and SD) and number of children scoring 1 SD or 2 SD beyond average for internalizing symptoms (anxiety and depression) and externalizing symptoms (oppositional traits and hyperactivity).

Measure	Mean (SD)	N beyond 1 SD	N beyond 2 SD
Internalizing symptoms			
RCMAS-2 total score	51.56 (11.663)	6	3
SAFA-D total score	54.93 (9.300)	6	3
Externalizing symptoms			
CPRS R:S oppositional traits	61.00 (14.270)	12	9
CPRS R:S hyperactivity	55.70 (15.479)	9	5

Note: RCMAS-2: Revised Children's Manifest Anxiety Scale, Second Edition; SAFA-D: Self-Report Psychiatric Scales for Children and Adolescents, Depression subscale; CPRS R:S: Conners Parent Rating Scale, Revised: Short Form.

3.2. Regression analysis

In the first linear regression model, taking the PRI from the WISC-IV at T2 as the dependent variable, the hypothesized predictors accounted for 40% of the variance, $F(4, 18) = 4.62$, $p = .010$, calculated using the adjusted R^2. Among the predictors, PRI at T1 ($\beta = .43$, $t = 2.44$, $p = .025$) and PSI at T1 ($\beta = .45$, $t = 2.36$, $p = .030$) were significantly and positively associated with the PRI score at T2 (Table 3).

In the second model, run on handwriting speed at T2, the predictors accounted for 40% of the variance (adjusted R^2), $F(5, 17) = 3.89$, $p = .016$. Specifically, PRI at T1 ($\beta = .52$, $t = 2.91$, $p = .010$), and handwriting speed at T1 ($\beta = .45$, $t = 2.67$, $p = .016$) were significantly and positively associated with handwriting speed at T2 (Table 3).

Finally, the results obtained with the third model, concerning arithmetical abilities at T2, were not significant, $F(5, 17) = 1.43$, $p = .263$, reflecting the lack of any significant predictive associations between the variables considered (Table 3).

More details about the regression analyses and models are provided in the Appendix.

3.3. Additional measures

Table 4 contains the descriptive statistics for the measures assessing internalizing and externalizing symptoms, together with the number of participants whose scores diverged from the average by more than 1 SD (i.e., indicating a difficulty in the area examined) or 2 SD (the clinical cut-off).

Anxiety and depression were considered as internalizing symptoms, and the sample as a whole scored within normal range on these dimensions. Almost a quarter of the sample (n = 6) had scores diverging more than 1 SD from the average on both anxiety and depression scales, while relatively few of the children (n = 3) had scores that were more than 2 SD above the average on the same scales.

Finally, as concerns externalizing problems, there was a marked variability, but nearly half of the parents (i.e., n = 12 for oppositional traits, and n = 9 for hyperactivity) reported more oppositional behavior in their children that might have been expected (i.

e.,>1 SD). A relevant number of parents (n = 9) judged that their child's oppositional traits were clinically significant (Table 4). Considering the hyperactivity traits, a milder pattern emerged with parents revealing clinical (n = 5) difficulties in this area.

4. Discussion

In this longitudinal study, 30 children aged between 8 and 13 years with a clinical diagnosis of NLD were tested at the baseline (T1) and again three years later (at T2) to assess any changes of their cognitive and visuo-constructive functioning, and their academic profiles. Linear regression analyses were run on the variables revealing statistically significant differences between the two time points to identify which of the other variables considered might predict such changes. Internalizing and externalizing symptoms were also examined at T2 in a subsample of 25 participants drawn from the initial sample.

Our findings confirm that children with NLD have a cognitive profile characterized by a greater verbal than visuospatial intelligence (Fisher et al., 2022; Mammarella & Cornoldi, 2014). Our sample's scores on the PSI were lower than expected in a typically-developing population, and remained much the same after three years. Their scores on the PRI improved after three years but indicated a persistent weakness in the children's general cognitive profile. As for their visuo-constructive abilities, our findings point to a persistently poor performance of children with NLD in this area (Mammarella et al., 2019; Semrud-Clikeman, Walkowiak, Wilkinson & Christopher, 2010). These findings suggested that the split between verbal and visuospatial intelligence is not stable, as PRI improved in our sample after three years. Thus, it seems not a good criterion for diagnosing children with NLD. Differently, performances on the Rey's complex figure remained poor and stable three years later, offering further evidence for the importance of visuospatial processing deficits in the NLD profile (Fisher et al., 2022; Mammarella et al., 2019; Semrud-Clikeman, Walkowiak, Wilkinson & Christopher, 2010).

The results of a linear regression conducted to see if any of the variables considered was associated with the improvement on the PRI seen at T2 suggested that higher scores on the PRI and PSI at T1 were positively related with higher scores on the PRI three years later. It is worth noting that the subtests comprising the PSI in the Wechsler scales (coding and symbol search) may measure not only processing speed but also visuospatial processing (Decker et al., 2006). The children in our sample who could process visuospatial information more quickly seemed to be at an advantage when it came to completing perceptual reasoning subtests three years later. It is worth noting that, however, the Rey's complex figure was not a significant predictor of the PRI, which indirectly strengthen the idea that visuospatial intelligence is not a synonym of visuospatial processing, and that visuospatial processing impairments may be not necessarily associated with visuospatial intelligence.

As for the academic profile of children with NLD, our findings indicate that they do not have reading decoding difficulties (Gross-Tsur et al., 1995; Rourke, 1995; Semrud-Clikeman, Walkowiak, Wilkinson & Christopher, 2010), and this pattern of results was confirmed after three years. The same could be said of their reading comprehension skills. Past research on reading comprehension in children with NLD had suggested that they struggle to draw inferences (Humphries et al., 2004), especially relating to visuospatial information (Mammarella et al., 2009; Worling et al., 1999). We used standardized text passages to assess reading comprehension, which contained no descriptions of visuospatial environments, though some questions involved drawing inferences, and the performance of our children with NLD was adequate in this condition. Our findings regarding handwriting also seem intriguing. We administered two tasks, one of which demanded greater visuo-motor coordination skills (repeatedly writing "le" in cursive script), while children could choose their preferred writing style for the "number words" task. The children with NLD performed poorly in both tasks at T1, but their performance in the "number words" task improved at T2. As mentioned earlier, handwriting has not been studied extensively in children with NLD. Previous research has shown that visuo-motor skills are positively associated with handwriting in children (Marr & Cermak, 2002; Weintraub & Graham, 2000). Our findings suggest that, while the children's performance remained poor after three years in the purer visuo-motor task (i.e., the "le" task), their speed improved when they could use the writing style of their choice. This impression is strengthened by the results of the linear regression, in which handwriting at T2 positively correlated with PRI and handwriting at T1 – a finding consistent with previous research on adolescents diagnosed with other neurodevelopmental disorders (Fuentes et al., 2010). In short, children who scored higher on the PRI at T1 managed to improve their handwriting speed at T2. The PRI represents the ability to organize and reason through problems with visually-presented, nonverbal material. The better PRI seen in our children with NLD after three years (during which time they would have gained more experience in writing) may reflect their ability to use compensatory strategies to overcome their graphomotor impairments.

When we measured our sample of children with NLD on mental calculation and arithmetical fact retrieval, their performance was average in terms of accuracy, while they were slightly slower compared with the normative data at both the time points considered. Tested on arithmetical fact retrieval, the children with NLD improved at T2 in terms of accuracy. The linear regression model identified no measures capable of predicting their performance, and this came as no surprise. The mathematical difficulties seen in this population may relate to their visuospatial processing difficulties, and thus emerge in tasks in which visuospatial abilities are more involved, such as written calculation, symbolic and non-symbolic comparison, or mental number line representation (Crollen et al., 2015; Mammarella et al., 2010, 2013; Venneri et al., 2003), whereas previous studies showed that mental calculation and arithmetical fact retrieval both engage more verbal than visuospatial processes (De Smedt et al., 2010; Noël et al., 2001).

A further aim of our study was to focus on transdiagnostic features, indeed, we wondered whether internalizing and externalizing symptoms may be observed in NLD. Thus, at T2 internalizing and externalizing symptoms were measured. It is worth noting that the missing measures of such symptoms at T1 is a limitation of our study as we were unable to see whether any of such difficulties remained stable or changed over three years.

Some interesting results nonetheless emerged. As for internalizing symptoms, such as anxiety and depression (Mammarella et al., 2016), only a small number of children with NLD obtained clinically-relevant scores. This is consistent with previous reports, which

Table S1
Principal Component analysis' loadings for each dimension considered.

Principal components	Measures considered	Loadings	Sum of squared loadings	Proportion of variance explained
Handwriting speed at T1	"le" at T1	.77	1.92	0.60
	Number-words at T1	.77		
Handwriting speed at T2	"le" at T2	0.84	1.37	0.69
	Number-words at T2	0.83		
Arithmetic abilities at T1	Mental calculation: time	0.85	2.11	0.70
	Mental calculation: errors	0.83		
	Arithmetical facts retrieval: errors	0.83		
Arithmetic abilities at T1	Mental calculation: time	0.80	2.20	0.73
	Mental calculation: errors	0.85		
	Arithmetical facts retrieval: errors	0.91		
Internalizing symptoms	Total score RCMAS-2	.90	1.63	0.82
	Depressed mood	.90		
Externalizing symptoms	Oppositional traits	.91	1.67	0.84
	Hyperactivity	.92		

Note: RCMAS-2: Revised Children's Manifest Anxiety Scale, Second Edition.

argued that, although some children with NLD may obtain clinical scores when measured on anxiety or depression measures, this does not seem to be a characteristic specific to NLD (Mammarella et al., 2022). The picture changes for externalizing symptoms. Parents identified more children in our sample as having clinical symptoms of hyperactivity, and oppositional traits, compared to those revealing internalizing symptoms. Semrud-Clikeman, Walkowiak, Wilkinson, and Christopher (2010) found that, when externalizing symptoms were rated by parents, only children with the combined ADHD subtype scored higher than children with NLD or ASD, while children with the inattentive subtype of ADHD did not differ from those with ASD or NLD. The comorbidity between ADHD and NLD should therefore be further investigated in subsequent studies. In Scandinavia, the concept of DAMP (deficits in attention, motor control, and perception) has been used since the 1980 s (Kadesjö & Gillberg, 1998) to describe children with a combination of attention difficulties and impairments in gross and/or fine motor skills, and/or perception. Such children are often at high risk of problems (Kadesjö & Gillberg, 1998). Children described as cases of DAMP might be similar to our children with NLD who have comorbid symptoms of ADHD. If so, researchers and practitioners in different countries have probably long been trying to prove the existence of a diagnostic entity distinct from other neurodevelopmental disorders, that – judging from recent evidence (Fisher et al., 2022) - could be labelled visuospatial developmental disorder.

Although the present research offers novel evidence, some limitations need to be mentioned. First, children aged between 8 and 13 were initially enrolled to our study. Although participants' scores were standardized based on the normative sample of the tasks administered, the presence of a broad age range may have obscured some information. Future studies might consider more restrictive age ranges in order to analyze longitudinal trajectories. A further limitation concerns the small sample of participants we were able to include in our study. Further studies should nonetheless try to replicate our findings in larger samples of children. This might further improve our understanding of the NLD profile and help practitioners with their diagnosis. Finally, in addition to these two limitations, a third potential issue occurs. In our study, data on potential changing factors that may have occurred between the two waves were not available. These data should include, for instance, information on school programs children took part in, or the intervention programs they attended. Future studies may address this issue by keeping track of the main events in participants' lives in order to clarify the results of longitudinal analyses.

To conclude, our descriptive longitudinal study found that the main characteristics of children with NLD remained stable after three years (i.e., they had persistent visuospatial processing deficits, mainly in visuo-constructive tasks). These children also remained stable in certain strengths (verbal intelligence, reading decoding and comprehension), while they improved over time in arithmetical fact retrieval and perceptual reasoning. This latter improvement was predicted by a higher speed of visuospatial information processing three years before. Finally, we noted a higher percentage of comorbidity at T2, in externalizing compared to internalizing symptoms. Taken together, our findings add further evidence to contribute to a better understanding of the NLD profile.

CRediT authorship contribution statement

Irene C. Mammarella: Conceptualization, Writing – original draft preparation. **Ramona Cardillo:** Data curation, Formal analysis, Writing – review & editing. **Camilla Orefice:** Metodology, Writing – review & editing.

Data availability

Data will be made available on request.

Table S2
Regression analyses with perceptual reasoning index (PRI), handwriting speed and arithmetic abilities at T2 as dependent variables.

Predictors	*β*	Std. Error	*t*	*p*
PRI at T2				
Model 1				
PRI at **T1**	0.433	0.254	2.437	**0.025**
VCI at **T1**	0.100	0.324	0.419	0.680
WMI at **T1**	-.013	0.169	-0.062	0.951
PSI at **T1**	0.453	0.193	2.361	**0.030**
Model 2				
PRI at **T1**	0.340	0.271	1.793	0.095
VCI at **T1**	0.022	0.314	0.096	0.925
WMI at **T1**	0.169	0.171	0.824	0.424
PSI at **T1**	0.450	0.181	2.496	**0.026**
ROCFT copy at **T1**	-0.120	0.208	-0.614	0.549
ROCFT recall at **T1**	-0.057	0.202	-0.295	0.772
Internalizing symptoms at **T2**	-0.467	0.212	-2.307	**0.037**
Externalizing symptoms at **T2**	-0.243	0.178	-1.436	0.173
Handwriting speed at T2				
Model 1				
Handwriting speed at **T1**	0.454	0.170	2.669	**0.016**
VCI at **T1**	-0.150	0.309	-0.628	0.538
PRI at **T1**	0.523	0.245	2.911	**0.010**
WMI at **T1**	0.161	0.163	0.784	0.444
PSI at **T1**	0.256	0.184	1.335	0.199
Model 2				
Handwriting speed at **T1**	0.674	0.176	3.822	**0.002**
VCI at **T1**	-0.303	0.285	-1.368	0.195
PRI at **T1**	0.662	0.264	3.419	**0.005**
WMI at **T1**	0.106	0.150	0.561	0.584
PSI at **T1**	0.229	0.160	1.372	0.193
ROCFT copy at **T1**	-0.159	0.219	-0.737	0.474
ROCFT recall at **T1**	-0.019	0.184	-0.102	0.921
Internalizing symptoms at **T2**	0.300	0.187	1.607	0.132
Externalizing symptoms at **T2**	0.502	0.159	3.157	**0.008**
Arithmetic abilities at T2				
Model 1				
Arithmetic abilities at **T1**	0.525	0.217	2.418	**0.027**
VCI at **T1**	0.054	0.392	0.178	0.861
PRI at **T1**	-0.025	0.299	-0.115	0.910
WMI at **T1**	-0.110	0.198	-0.441	0.665
PSI at **T1**	0.003	0.227	0.014	0.989
Model 2				
Arithmetic abilities at **T1**	0.700	0.243	2.882	**0.013**
VCI at **T1**	0.163	0.432	0.485	0.636
PRI at **T1**	-0.073	0.350	-0.285	0.780
WMI at **T1**	0.019	0.215	0.070	0.946
PSI at **T1**	-0.137	0.229	-0.571	0.578
ROCFT copy at **T1**	0.048	0.276	0.178	0.862
ROCFT recall at **T1**	0.375	0.254	1.473	0.165
Internalizing symptoms at **T2**	-0.495	0.269	-1.844	0.088
Externalizing symptoms at **T2**	-0.248	0.238	-1.040	0.317

Note: VCI: Verbal Comprehension Index; PRI: Perceptual Reasoning Index; WMI: Working Memory Index; PSI: Processing Speed Index; ROCFT: Rey Osterrieth Complex Figure Test.

Appendix

PCa loadings

A series of principal component analyses (PCa) were conducted to extract factors and reduce our variables. For the handwriting speed factor, the “le” and the number-words tasks were considered, while for the arithmetic abilities factor the mental calculation and arithmetical facts retrieval tasks were taken into account. As a result, two factors for handwriting abilities (Handwriting speed at T1 and at T2) and two factors for arithmetic abilities (Arithmetic abilities at T1 and at T2) were obtained, one for each time-point. For the factor tapping internalizing symptoms, the total score of the RCMAS-2 and the depressed mood score of the SAFA-D questionnaires were entered. Finally, in the externalizing factor oppositional traits and hyperactivity subscales of the CPRS R:S were included. Table S1 summarizes all the principal components’ loadings.

Regression analyses

Table S2 summarizes the regression analysis models, ran considering PRI, handwriting speed and arithmetic abilities at T2 as the dependent variable, respectively.

For each of the regression analysis model, the differences between the variances explained by the first and the second step were non-significant, with $F(4)= 2.121$, $p = .132$ for the first (i.e., PRI at T2 as dependent variable), $F(4)= 3.01$, $p = .058$ for the second (i.e., handwriting speed at T2 as dependent variable), and $F(4)= 1.367$, $p = .299$ for the third regression (i.e., arithmetic skills at T2 as dependent variable) ran. Thus, for each model, due to second steps not explaining a higher proportion of variance as compared to first steps, the latter have been discussed in the manuscript, while second steps will be detailed below.

In the second step of the first linear regression model, taking the PRI from the WISC-IV at T2 as the dependent variable, the hypothesized predictors accounted for 52% of the variance, $F(8, 14)= 3.95$, $p = .012$, calculated using the Adjusted R^2. Among the predictors, however, only PSI at T1 ($\beta = .450$, $t = 2.50$, $p = .026$) and internalizing symptoms at T2 ($\beta = -.467$, $t = -2.31$, $p = .037$) were significantly associated with the PRI score at T2 (Table S2). In particular, PSI at T1 was positively associated with PRI at T2, while internalizing symptoms at T2 were found to be negatively associated with PRI at the same time. In the second step of the second regression model, ran on handwriting speed at T2, the predictors accounted for 59% of the variance (Adjusted R^2), $F(9, 13)= 4.52$, $p = .007$. Specifically, handwriting speed at T1 ($\beta = .674$, $t = 3.82$, $p = .002$), PRI at T1 ($\beta = .662$, $t = 3.42$, $p = .005$) and externalizing symptoms at T2 ($\beta = .502$, $t = 3.16$, $p = .008$) were significantly and positively associated with handwriting speed at T2 (Table S2).

Finally, as seen in the manuscript for the third model, conducted on arithmetic abilities at T2, the second step was non-significant as well, $F(9, 13)= 1.47$, $p = .255$ (Table S2), suggesting the absence of predictive significant associations between variables.

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