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Preliteracy impairments in children with neurofibromatosis type 1

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ABBREVIATIONS

NF1	Neurofibromatosis type 1
RAN	Rapid automatic naming
SES	Socio-economic status

AIM This cross-sectional study aimed to examine the preliteracy abilities of young children with neurofibromatosis type 1 (NF1) and to identify which of these abilities best predicted conventional literacy (spelling).

METHOD Forty-two children with NF1 (23 males, 19 females; mean age [SD] 5y 6mo [6mo]) were compared with thirty-two unaffected children (15 males, 17 females; mean age [SD] 5y 4mo [6mo]). All children completed a comprehensive cognitive assessment including measures of phonological processing (phonological awareness, phonological memory, rapid automatic naming) and letter-sound knowledge.

RESULTS Children with NF1 performed significantly poorer than the comparison group across all cognitive and preliteracy domains, with specific weaknesses evident in phonological awareness ($F_{1,68}$=14.13, p<0.001, partial η^2=0.17), phonological memory ($F_{1,68}$=13.87, p<0.001, partial η^2=0.17), and letter-sound knowledge ($F_{1,71}$=5.65, p=0.020, partial η^2=0.07). Within the NF1 group, over a third of children demonstrated impairment in at least one phonological processing domain and the risk of phonological impairment was 5.60 times that of unaffected children. Children's letter–sound knowledge was the strongest predictor of conventional literacy (spelling).

INTERPRETATION This study establishes that preliteracy deficits are present and detectable in young children with NF1. As a result of the high incidence of preliteracy impairment, we recommend screening phonological awareness and letter-sound knowledge to identify risk of future learning disorders.

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What this paper adds

- Young children with neurofibromatosis type 1 are at elevated risk of preliteracy deficits.
- The most affected domains are phonological awareness and phonological memory.
- Letter-sound knowledge is the strongest predictor of conventional literacy (spelling).

[Main text]

Neurofibromatosis type 1 (NF1) is a common neurogenetic disorder that affects multiple systems throughout the body. It is primarily characterized by skin features including café au lait spots, axillary freckling, cutaneous neurofibromas, and iris hamartomas (Lisch nodules).[1] In addition to physical manifestations, children with NF1 frequently experience deficits in a range of cognitive domains including visuoperception, executive functioning, attention, and language.[2] Academic underachievement is also common in NF1,[3] with reading disabilities highly prevalent.[4] Up to 67% of school-aged children with NF1 demonstrate single-word reading impairments[5] and there are high rates of reading comprehension difficulties.[6] Despite the high incidence of reading impairment in school-aged children with NF1, little is known about the development of literacy precursor skills, such as phonological processing in younger children. So far, the only study that objectively measured preliteracy skills in young children with NF1 reported significantly poorer letter-word identification skills in 40-month-old children with NF1 compared with typically developing individuals.[7] While these initial findings suggest early signs of later literacy difficulties are present and identifiable in young children with NF1, the precise nature of these difficulties is unclear.

In the general population, reading difficulties often arise from a language-based impairment involving weaknesses in processing sounds of spoken language (i.e. phonological processing).[8] Research has identified three distinct yet related processes, each of which play important roles in the acquisition of literacy skills: (1) phonological awareness, the ability to recognize and manipulate sounds of oral language; (2) phonological memory, the ability to store and manipulate verbal information in short-term memory; and (3) phonological naming, the ability to efficiently retrieve information held in long-term memory (also known as rapid automatic naming [RAN]).[9] Combined with letter-sound knowledge, phonological skills are

important for achieving mastery of the alphabetic principle and, ultimately, successful reading and spelling development.[10]

Owing to the high incidence of reading problems in school-aged children with NF1 and the lifelong negative implications of literacy difficulties,[11] it is crucial that children with preliteracy difficulties be identified early so that they can receive timely intervention. To develop a better understanding of preliteracy abilities in children with NF1, the primary aims of this study were to (1) examine the preliteracy abilities of children with NF1 and (2) determine which preliteracy abilities are the strongest predictors of conventional literacy (in this study, spelling) in children with NF1. Research suggests spelling ability provides a good indication of mastery of the alphabetic principle[12] and reading ability,[13] and therefore was chosen as a measure of conventional literacy.

There are also risk and protective factors that affect the development of children's literacy skills.[14] Therefore, an exploratory aim of the study was to examine the relationship of preliteracy abilities with cognitive and demographic variables. Variables of interest included oral language abilities,[15] attention,[16] sex,[14] socio-economic status (SES),[14] IQ,[17] and visual–spatial skills as a result of the high incidence of this impairment observed in children with NF1.[2]

METHOD

Participants

Children aged between 5 and 6 years who met the National Institutes of Health diagnostic criteria for NF1 (National Institutes of Health Consensus Development Conference)[18] were recruited through the Neurogenetics Clinic, The Children's Hospital at Westmead, Sydney, Australia. An unaffected peer comparison group was recruited by four methods: a larger longitudinal study investigating cognitive development in children with NF1 compared with unaffected children;[19] local primary schools in the Sydney metropolitan area; advertisements placed in local community newspapers; and on noticeboards located throughout The Children's Hospital at Westmead. A developmental and medical history was taken from parents of participants with NF1 and relevant medical files were reviewed. Participants were excluded on the basis of (1) diagnosed intracranial pathology (i.e. symptomatic optic gliomas), (2) significant vision/hearing loss, or (3) inadequate English. Parents of comparison participants completed a detailed structured interview. No comparison participants had a history of neurological or psychological disorders, intellectual impairment, learning difficulties, or developmental delay. Parents were asked about their children's language status

(i.e. monolingual English, bilingual). Data were missing for some children, but their English was adequate to complete the assessment. Approval for this study was granted by the Sydney Children's Hospital Network (11/CHW/28) and The University of Sydney (15371) Human Research Ethics Committees, and written informed consent was obtained from the parents of all participants.

Procedure

All assessments occurred at The Children's Hospital at Westmead's clinical research facilities. After informed signed consent was obtained, children were individually assessed by a psychologist in a quiet room. Assessments lasted approximately 2 hours and breaks were provided as needed. Parents completed questionnaires about their child's development.

Measures

Preliteracy measures

Children completed the Comprehensive Test of Phonological Processing,[20] which comprises seven subtests (mean=10, SD=3) and generates three composite variables: phonological awareness, phonological memory, and RAN (mean=100, SD=15). The phonological awareness composite included the following subtests: elision (deleting a phoneme from a word); blending (blending phonemes together to make a word); and sound matching (identifying objects that begin with a specific sound). The phonological memory composite comprised memory for digits (repeating a string of numbers of increasing length) and non-word repetition (repeating nonsense words of increasing length and complexity). The RAN composite included the rapid colour and rapid object naming subtests (naming objects or colours as quickly as possible).

The Letter-Sound Test[21] was also administered and required children to name the sounds of single letters and letter combinations. Raw scores were converted to z-scores on the basis of the age of the child.

Conventional literacy measure

The spelling subtest of the Wechsler Individual Achievement Test, Second Edition[22] was administered.

General cognitive measures

General intellectual functioning was assessed with the Wechsler Preschool and Primary Scale of Intelligence, Third Edition, Australian Adaptation.[23] Expressive and receptive vocabularies were respectively assessed with the picture naming and receptive vocabulary subtests. The comprehension of instructions subtest from A Developmental Neuropsychological Assessment[24] was used to provide a broader measure of receptive language abilities. The visual-spatial subtest of the Test of Visual Perceptual Skills (Non-motor) – Revised[25] assessed children's ability to judge similarities and differences between visual objects. Attention abilities were assessed by the Conners' Kiddie Continuous Performance Test[26] or the Conners' Performance Test – Version II,[27] and symptoms of attention-deficit–hyperactivity disorder were rated by parents using the Conners' ADHD/DSM-IV Scales.[28] Detailed information about the measures is provided in Appendix S1 (online supporting information).

SES was estimated using the Index of Relative Socio-Economic Advantage and Disadvantage, which ranks geographical areas in terms of their socio-economic advantage and disadvantage.[29] Areas receive a decile score ranging between 1 and 10, with the lowest 10% of areas allocated a decile of 1 and the highest 10% of areas receiving a decile of 10.

Statistical analyses

Data were analyzed using SPSS version 23 (SPSS Inc., Chicago, IL, USA). Asymmetrically distributed data are reported as median with an interquartile range. As specified in the test manual,[20] children's performances on phonological processing composites (i.e. phonological awareness, phonological memory, RAN) were classified according to the following criteria: below average (standard score 80–89), poor (standard score 70–79), and very poor (standard score <70). A phonological processing impairment was defined as performance below 80 on any composite score. The relative risk of a phonological impairment occurring in each group (i.e. NF1 and typically developing) was calculated. Independent-samples *t*-tests were used to examine group differences in neuropsychological test scores, and effect sizes are reported as Cohen's *d* (with pooled SD). For non-normally distributed variables, the Mann–Whitney *U* statistic was used to determine between group differences. Effect sizes were calculated as *Z* divided by the square-root of the sample size (*r*) and then converted to Cohen's *d*.[30] As there was a significant difference between groups for SES, and previous research has indicated a significant association between SES and literacy abilities,[14] group differences on preliteracy and literacy (spelling) measures were examined using analysis of covariance with SES entered as the covariate. Effect sizes were calculated and reported as partial η^2. The Holm

procedure (a modification of the Bonferroni procedure) was used to control the type 1 error rate.

Pearson correlation (r) or Spearman's rho (ρ) coefficients for asymmetrically distributed data were conducted to examine the relationship between preliteracy variables and other cognitive and demographic variables in children with NF1, with a p value of 0.01 applied. A hierarchical multiple regression was conducted to identify which preliteracy variables were most strongly associated with the spelling abilities of children with NF1. A maximum of four predictors were included in the model owing to the sample size. To control for the potential influence of intelligence, a non-verbal estimate (performance IQ) was entered at step one of the regression. Preliteracy variables were entered into the regression model according to the strength of their correlation with the outcome variable. As the letter-sound knowledge variable was positively skewed, a logarithmic transformation was conducted so it could be included in the model.

RESULTS

Demographic and general cognitive data for both groups are displayed in Table I. The NF1 group consisted of 42 children, 30 of whom were sporadic cases. The comparison group consisted of 32 typically developing children. Within the NF1 group, 67% (n=28) of the participants were monolingual English speakers, 24% (n=10) of children were bilingual, and 9% (n=4) were able to understand and communicate adequately in English; however, their language status was not recorded. Within the comparison group, 88% (n=28) of children were monolingual English speakers, 3% (n=1) were bilingual, and 9% (n=3) of children were able to understand and communicate in English; however, their language status was not recorded. There were no significant group differences in sex, age, or months of formal education (Table I). The comparison group, however, had significantly higher SES.

Children with NF1 performed significantly poorer than unaffected children on all general cognitive measures (Table I). Analyses of covariance indicated that SES was only a significant covariate for phonological memory ($F_{1,68}$=4.98, p=0.03, partial η^2=0.07). After adjusting for SES, the NF1 group had significantly lower composite scores for phonological awareness and phonological memory than the comparison group (Table I). Approximately one-third of children with NF1 performed below average on the phonological awareness composite and over half performed below average on the phonological memory composite (Table II). Medium to large effect sizes were observed between groups for elision, blending, sound matching, memory for digits, and non-word repetition. Some children were unable to

complete prerequisite qualifying items for RAN subtests (i.e. they were unable to consistently identify colours [three children with NF1, two typically developing], objects [one typically developing child], or both [three children with NF1, one typically developing]); consequently, the tasks were discontinued and a score was not calculated. After adjusting for SES, children with NF1 demonstrated significantly poorer performance on the RAN composite; however, there was no significant difference on either of the RAN subtests. The number of children with impaired phonological processing is shown in Table III. The risk of a phonological processing deficit was 5.60 times greater (95% confidence interval 1.37–22.86) in children with NF1 compared with the typically developing group. Children with NF1 also exhibited significantly poorer letter-sound knowledge and spelling ability than the comparison group after controlling for SES (Table I).

Correlations between the Comprehensive Test of Phonological Processing composite scores, letter-sound knowledge, and key cognitive and demographic variables for the NF1 group are displayed in Table IV. There was a significant positive and strong relationship between phonological awareness and phonological memory composite scores. There were no significant relationships between RAN and other Comprehensive Test of Phonological Processing composite scores. Correlations between Comprehensive Test of Phonological Processing composite scores and cognitive and behavioural measures revealed significant positive relationships between phonological awareness and verbal IQ, performance IQ, Full-scale IQ, processing speed, and A Developmental Neuropsychological Assessment comprehension of instructions. Phonological memory was positively related to verbal IQ, performance IQ, Full-scale IQ, global language, and A Developmental Neuropsychological Assessment comprehension of instructions. There was a strong positive relationship between letter-sound knowledge and phonological awareness, and a moderate positive association between letter-sound knowledge and processing speed.

In the regression model, performance IQ was entered in step 1. Phonological awareness was entered in step 2 because it had the highest correlation with spelling. Letter-sound knowledge was entered at step 3 followed by phonological memory (Table V). While phonological awareness was a significant predictor at step 2, it was no longer significant once letter-sound knowledge was entered. There was no evidence of collinearity between the two variables. In the final model, performance IQ and letter-sound knowledge were significant predictors, accounting for 56% of the variance in spelling ability.

There were no significant differences between males and females on any of the preliteracy measures in the comparison group (all $p>0.11$). Within the NF1 cohort, there was

a trend for phonological awareness skills to be poorer in males (mean=90.45, SD=11.49) versus females (mean=99.21, SD=11.97), and the phonological memory skills of males (mean=85.14, SD=9.37) to be poorer than females (mean=92.17, SD=11.23). However, these differences were not significant once the Holm procedure was applied (t_{37}=−2.33, p=0.03, d=0.75; t_{37}=−2.13, p=0.04, d=0.68 respectively). Within the NF1 group there was no significant difference between males (mean=92.84, SD=10.70) and females (mean=90.25, SD=13.62) for RAN abilities (t_{33}=0.63, p=0.53, d=0.21), or between males (mean=−1.73, SD=0.98) and females (mean=−1.34, SD=1.12) for letter-sound knowledge (t_{40}=1.25, p=0.22, d=0.39).

DISCUSSION

In this study, we examined the preliteracy abilities of children with NF1 and found that they performed significantly poorer across all preliteracy domains assessed, including phonological awareness, phonological memory, RAN, and letter-sound knowledge, compared with typically developing children. Large effect sizes were observed for phonological memory and phonological awareness, both of which are critical precursor skills required for the development of adequate literacy abilities. Further, we found that children with NF1 had 5.60 times the risk of a phonological deficit occurring compared with typically developing children. The results of this study demonstrate that preliteracy impairments are identifiable in young children with NF1 and, as such, may serve as a screen for future reading deficits.

As reported in older school-age children,[31] our findings indicated that young children with NF1 are at increased risk of phonological awareness deficits, with one-third of children performing below the average range. Children with NF1 also demonstrated significant weaknesses in phonological memory, with over half of young children with NF1 performing below age expectations. Indeed, approximately 23% experienced significant deficits in storing phonological information in short-term memory, which is likely to affect their ability to accurately decode words. Although phonological memory deficits have been previously reported in NF1,[6] this is not a consistent finding, with a recent study reporting preserved phonological memory in French-speaking school-aged children with NF1.[31] The lack of consistency may be because of the variability in orthographic consistency between the French-based studies versus English-based studies. Alternatively, it may be related to developmental differences between the study cohorts. Previous studies suggest that although phonological memory deficits are particularly evident in younger children who later develop

reading difficulties, phonological awareness becomes a stronger predictor of literacy outcomes as children progress through school.[15]

Although children with NF1 displayed poorer overall RAN abilities than unaffected children, group differences were smaller than those observed for phonological awareness and memory. This may be because a quarter of unaffected children displayed difficulties on RAN measures. Further, there were several children in both groups who were unable to complete RAN tasks. It is possible that the children in our sample were too young to have their RAN skills reliably assessed. In addition, we found no relationship between RAN and other preliteracy skills, which adds to previous evidence that RAN abilities are relatively independent of other phonological processes.[32]

Our results also indicated that poor letter-sound knowledge is common in young children with NF1, suggesting a specific difficulty in learning the sounds that correspond to letters and letter combinations. We further demonstrated that letter-sound knowledge was the strongest preliteracy predictor of early spelling abilities in young children with NF1. This provides support for previous research that letter-sound knowledge plays a vital role in mastering the alphabetic principle[10] and is a significant predictor of spelling ability.[13,17] Contrary to previous findings in the general population,[13] phonological awareness was not a significant predictor of spelling abilities in the final model. However, it should be noted that before including letter-sound knowledge in the model, phonological awareness significantly predicted spelling, accounting for 47% of the variance. Of note, we found strong correlations between phonological awareness and letter-sound knowledge in our NF1 cohort, which suggests these two skills typically develop in parallel in NF1; or, at least, that when there is a delayed development in one of these skills, there is usually poor development in the other. Taken together, these findings suggest that weak letter-sound knowledge ultimately appears to be the most important predictor of early spelling ability in NF1, and that deficits in letter-sound knowledge in combination with phonological impairments are likely to significantly contribute to the literacy difficulties that are common in school-aged children with the condition.[5,6,33]

We further investigated the relationship between preliteracy skills and cognitive and demographic variables. Interestingly, we observed a significant relationship between children's spelling and non-verbal cognitive abilities, including perceptual reasoning and visuospatial skills, which provides some support for the hypothesis that the non-verbal deficits evident in NF1 may contribute to the increased frequency of literacy difficulties.[6] We also observed a significant positive relationship between language abilities (receptive and

expressive) and phonological awareness and memory, supporting previous findings in children without NF1 that oral language supports the development of preliteracy abilities.[34] Previous research has reported a high incidence of language delays in young children with NF1,[35] which raises the possibility that the high level of phonological processing deficits evident in our sample may have been related to the poorer language abilities reported in children with NF1.

Consistent with previous findings, our results indicate that children with NF1 are at an increased risk of attention deficits,[3] although these deficits appear to be relatively independent of the preliteracy difficulties observed. Despite the links between preliteracy skills and attention reported in the general population,[16] our findings suggest that the co-occurrence of preliteracy impairments and attention deficits are most appropriately viewed as independent outcomes of an NF1 mutation and, as such, screening for preliteracy deficits should be considered regardless of attention-deficit–hyperactivity disorder status.

Previous research[3] has indicated that males with NF1 and from the general population[14] are at greater risk of learning difficulties. We identified that, on average, males' performance on phonological awareness and memory tasks was lower than females. Despite these sex differences not reaching statistical significance after controlling for the familywise error rate, the moderate effect sizes suggest that these results may have some clinical relevance. Further investigation is needed to determine whether males with NF1 are at greater relative risk of poorer phonological outcomes than females.

Results from this study have important clinical implications. We recommend a brief screen of letter-sound knowledge and phonological awareness to identify the risk of literacy-based learning disorders in young children with NF1. Children who screen positively should be referred for a comprehensive language assessment and early intervention. We have previously demonstrated that systematic phonics instruction can significantly improve the reading abilities of older children with NF1.[33] It will be important for future randomized controlled studies to investigate whether early intervention in these areas can improve preliteracy abilities and reduce the high rates of literacy disorders evident in school-aged children with NF1.

Study limitations include the sample size and group differences in SES. Future research investigating preliteracy abilities in NF1 should consider using a larger sample size and including a comparison group matched by SES. We also note a slightly higher proportion of sporadic NF1 cases in our sample (71%) compared with expectations (50%). Unbiased study recruitment procedures suggest this was a chance occurrence and, given previous

evidence of no relationship between mode of NF1 inheritance and cognitive outcomes,[3] we believe our data are representative of the general NF1 population.

In conclusion, this study establishes the presence of detectable preliteracy impairments in young children with NF1. We found the risk of phonological deficits within the NF1 group was 5.60 times that of their typically developing peers and that letter-sound knowledge is the best preliteracy predictor of conventional literacy ability. Longitudinal research examining the progression of preliteracy-to-literacy skills in children with NF1 is needed to confirm predictors of future reading impairment providing early intervention targets.

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The authors have stated that they had no interest that could be perceived as posing a conflict or bias.

SUPPLEMENTARY INFORMATION

The following additional materials may be found online:

Appendix S1: Measures.

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Table I: Demographics, general cognitive and preliteracy measures

Measure	Neurofibromatosis type 1 (*n*=42)			Comparison (*n*=32)			ANCOVA			
	n	Mean	SD	*n*	Mean	SD	*F*	df	*p*	Effect size
Sex										
Male	23			15						
Female	19			17					0.50	
Age, y	42	5.50	0.51	32	5.34	0.48			0.26	
SEIFA[a]	42	8.00[b]	4.00[c]	32	10.00[b]	3.00[c]			0.005[d,e]	
Formal education, mo	42	7.88	7.57	32	6.19	7.71			0.34	
WPPSI-III										
Full-scale IQ	42	89.55	10.91	32	104.66	12.06			<0.001[d]	1.31[f]
Verbal IQ	42	95.07	13.85	32	105.13	10.59			0.001[d]	0.82[f]
Performance IQ	42	87.79	11.48	32	103.91	14.66			<0.001[d]	1.22[f]
Processing speed	42	90.71	15.70	32	106.69	14.82			<0.001[d]	1.05[f]
Global language	42	95.50[b]	21.00[c]	32	105.00[b]	20.00[c]			0.002[d,e]	0.77[f]
NEPSY										
Comprehension	41	10.00[b]	3.00[c]	32	11.00[b]	2.00[c]			0.001[d,e]	0.84[f]
CADS										

ADHD index	39	61.00[b]	11.00[c]	29	51.00[b]	14.00[c]			<0.001[d,e]	1.09[f]
CPT-II/KCPT										
Omissions[g]	35	64.00[b]	32.00[c]	31	50.00[b]	17.00[c]			<0.001[d,e]	1.03[f]
TVPS-R										
Visual–spatial relations	39	76.00[b]	30.00[c]	32	110.50[b]	22.00[c]			<0.001[d,e]	1.17[f]
CTOPP										
Phonological awareness	39	94.72	12.39	32	107.13	12.37	14.13	1, 68	<0.001[d]	0.17[h]
Elision	39	8.82	2.28	32	10.94	2.44	11.56	1, 68	0.001[d]	0.15[h]
Blending	40	9.90	2.55	32	11.38	2.42	4.30	1, 69	0.042[i]	0.06[h]
Sound matching	40	8.78	2.25	32	11.00	1.97	16.23	1, 69	<0.001[d]	0.19[h]
Phonological memory	40	88.45	10.60	32	99.81	11.28	13.87	1, 68	<0.001[d]	0.17[h]
Memory for digits	40	8.30	2.28	32	10.09	2.25	7.76	1, 69	0.007[d]	0.10[h]
Non-word repetition	40	8.00[b]	3.00[c]	32	10.00[b]	4.00[c]	11.76	1, 69	0.001[d]	0.15[h]
Rapid naming[j]	34	91.44	12.12	28	99.57	14.35	4.68	1, 59	0.035[i]	0.07[h]
Rapid colour naming	34	8.88	2.20	29	9.72	2.49	1.34	1, 60	0.252	0.02[h]
Rapid object naming	37	8.00[b]	4.00[c]	30	9.50[b]	3.00[c]	3.25	1, 64	0.076	0.05[h]
Letter-sound knowledge[k]	42	−1.55	1.05	32	−0.54	1.67	5.65	1, 71	0.020[i]	0.07[h,l]
WIAT-II										
Spelling	40	90.70	15.40	32	101.88	15.76	6.67	1, 69	0.012[i]	0.09[h]

Unadjusted means reported for ANCOVAs. [a]Decile ranking of areas in Australia according to relative socio-economic advantage and disadvantage: 1 is lowest socio-economic status, 10 is highest. [b]Median. [c]Interquartile range. [d]$p<0.01$. [e]Mann–Whitney *U*-test. [f]Cohen's *d*. [g]Missing KCPT data because of a computer hardware problem ($n=8$). [h]Partial η^2. [i]$p<0.05$. [j]Rapid naming data missing as some children were unable to complete prerequisite qualifying items and the task was not administered (i.e. they were unable to correctly identify colours [$n=5$], objects [$n=1$], or both [$n=4$]). [k]z-score. [l]Calculated using transformed data. ANCOVA, analysis of covariance; df, degrees of freedom; SEIFA, Socio-Economic Indexes for Areas; WPPSI-III, Wechsler Preschool and Primary Scale of Intelligence, Third Edition; NEPSY Comprehension, A Developmental Neuropsychological Assessment, comprehension of instructions; CADS, Conners' ADHD (attention-deficit–hyperactivity disorder)/DSM-IV (Diagnostic and Statistical Manual of Mental Disorders, 4th Edition) Scales; CPT-II, Continuous Performance Test-Version II; KCPT, Kiddie Continuous Performance Test; TVPS-R, Test of Visual Perceptual Skills (Non-Motor) – Revised; CTOPP, Comprehensive Test of Phonological Processing; WIAT-II, Wechsler Individual Achievement Test, Second Edition.

Table II: Classification of performance on phonological processing composite measures

Composite scores	*n*	Very poor, *n* (%)	Poor, *n* (%)	Below average, *n* (%)
Neurofibromatosis type 1				
Phonological awareness	39	2 (5)	0 (0)	11 (28)
Phonological memory	40	2 (5)	7 (18)	12 (30)
RAN	34	2 (6)	3 (9)	11 (32)
Comparison				
Phonological awareness	32	0 (0)	0 (0)	3 (9)
Phonological memory	32	0 (0)	1 (3)	5 (16)
RAN	28	0 (0)	1 (4)	6 (21)

Very poor, standard score <70; poor, standard score 70–79; below average, standard score 80–89. Data missing for neurofibromatosis type 1 group (*n*=2) as children did not complete the Comprehensive Test of Phonological Processing. Rapid naming data missing as some children were unable to complete prerequisite qualifying items and the task was not administered (i.e. they were unable to correctly identify colours [*n*=5], objects [*n*=1], or both [*n*=4]). RAN, rapid automatic naming.

Table III: Number of phonological processing deficits

Deficits	NF1	Comparison
	n (%)	*n* (%)
0	26 (65)	30 (94)
1	12 (30)	2 (6)
2	2 (5)	0 (0)

Relative risk of phonological processing deficit in neurofibromatosis type 1 (NF1) group =5.60 (95% confidence interval 1.37–22.86). Data missing for NF1 group (*n*=2) as children did not complete the Comprehensive Test of Phonological Processing.

Table IV: Correlations (*r*) between preliteracy variables and cognitive and demographic variables for neurofibromatosis type 1 group

Measure	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1. Phonological awareness[a]	—													
2. Phonological memory[b]	0.69[c]	–												
3. Rapid automatic naming[d]	−0.02	−0.10	–											
4. Letter-sound knowledge[e]	0.63[c]	0.37	0.17	–										
5. Socio-Economic Indexes for Areas[f]	0.20	0.35	0.13	0.15	–									
6. Full-scale IQ	0.61[c]	0.68[c]	−0.09	0.29	0.31	–								
7. Verbal IQ	0.50[c]	0.67[c]	−0.33	0.26	0.27	0.82[c]	–							
8. Performance IQ	0.50[c]	0.48[c]	0.12	0.15	0.24	0.82[c]	0.47[c]	–						
9. Processing speed	0.53[c]	0.37	0.16	0.45[c]	0.16	0.54[c]	0.27	0.54[c]	–					
10. Global language[f]	0.31	0.50[c]	−0.05	0.20	0.26	0.71[c]	0.76[c]	0.52[c]	0.38	–				
11. NEPSY comprehension[f,g]	0.43[c]	0.55[c]	0.13	0.23	0.33	0.73[c]	0.55[c]	0.60[c]	0.45[c]	0.45[c]	–			
12. Spelling[b]	0.68[c]	0.41	0.09	0.64[c]	0.29	0.53[c]	0.34	0.52[c]	0.64[c]	0.30	0.39	–		
13. CADS ADHD symptoms[a,f]	−0.27	−0.36	0.07	−0.16	−0.28	−0.24	−0.10	−0.30	−0.44[c]	−0.18	−0.35	−0.40	–	
14. CPT-II/KCPT[d,f]	−0.21	−0.31	−0.21	−0.10	−0.04	−0.16	−0.20	−0.04	−0.22	−0.29	−0.33	−0.14	0.39	–
15. TVPS-R[a,f]	0.38	0.34	0.30	0.14	0.28	0.45[c]	0.16	0.53[c]	0.42[c]	0.20	0.55[c]	0.46[c]	−0.26	−0.17

[a]*n*=39. [b]*n*=40. [c]*p*<0.01. [d]*n*=35. [e]Calculated using transformed data. [f]Spearman's ρ coefficient. [g]*n*=41. NEPSY comprehension, A Developmental Neuropsychological Assessment, comprehension of instructions; CADS, Conners' ADHD (attention-deficit–hyperactivity disorder)/DSM-IV (Diagnostic and Statistical Manual of Mental Disorders, 4th Edition) Scales; CPT-II, Continuous Performance Test-Version II; KCPT, Kiddie Continuous Performance Test; TVPS-R, Test of Visual Perceptual Skills (Non-Motor) – Revised.

Table V: Summary of hierarchical regression analysis for preliteracy variables predicting spelling ability in the neurofibromatosis type 1 group

Variable	*B*	SE of *B*	*β*	Adjusted R^2	ΔR^2
Step 1				0.19	0.21
Constant	34.47	19.16			
Performance IQ	0.64	0.21	0.46[a]		
Step 2				0.47	0.29
Constant	−9.13	18.41			
Performance IQ	0.27	0.19	0.19		
Phonological awareness	0.80	0.18	0.60[a]		
Step 3				0.57	0.10
Constant	6.49	17.58			
Performance IQ	0.45	0.18	0.32[b]		
Phonological awareness	0.31	0.24	0.23		
Letter-sound knowledge	39.97	14.06	0.46[a]		
Step 4				0.56	0.00
Constant	9.59	18.63			
Performance IQ	0.46	0.19	00.33[b]		
Phonological awareness	0.39	0.28	00.29		
Letter-sound knowledge	39.19	14.28	0.45[a]		
Phonological memory	−0.13	0.23	−0.08		

[a]$p<0.01$. [b]$p<0.05$. *B*, unstandardized beta; SE of *B*, standard error of *B; β,* standardized beta.