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RESEARCH REPORT

The association of cognitive abilities with language disorder in 8-year-old children: A population-based clinical sample

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Abstract

Background: Despite accumulated evidence that language development depends on basic cognitive processes, the balance in contributions of verbal and non-verbal cognitive skills to language abilities is still underexplored. Little is known about which cognitive measures best predict the degree of severity in children with language disorder (LD).

Aims: To examine the association between verbal and non-verbal cognitive abilities with language abilities in typically developing and language impaired 8-year-old children, as well as which cognitive abilities are most effective in distinguishing LD severity levels.

Methods & Procedures: Children ($N = 509$) from the Language-8 Study, which oversampled probable cases of children with LD from a population-based cohort in Norway, were assessed at 8 years. Language skills were assessed using the Norwegian Clinical Evaluation of Language Fundamentals—4 (CELF-4). Children's verbal and non-verbal cognitive abilities were assessed via standardized cognitive measures. An exploratory factor analysis (EFA) was first conducted to uncover the underlying factor structure of the cognitive variables. Using a hierarchical multiple regression analysis, we then examined to what extent the non-verbal cognition factor explained language abilities above and beyond verbal cognition factors. Lastly, multinomial logistic regression was used to examine which cognitive measures best predicted the degree of severity in the children with LD.

Outcomes & Results: The EFA resulted in three factors (Verbal Cognition, Processing Speed and Memory, and Non-Verbal Cognition). The hierarchical multiple regression analysis revealed that all three cognitive factors contributed significantly to individual variation in language abilities. Non-Verbal Cognition explained 5.4% variance in language abilities above and beyond that accounted for by Verbal Cognition and Processing Speed and Memory. Results from the multinomial logistic regression analysis indicated that cognitive subtests, including Familiar Sequences, WASI Vocabulary and WASI Similarities, not only distinguished LD from typically developing children, but were also efficient in distinguishing severity of LD symptoms.

Conclusions & Implications: This study confirms concurrent links between language and non-verbal cognitive skills above and beyond the contribution of verbal cognitive skills. The results provide further evidence that children with LD experience both language and cognitive problems in mid-childhood. Our findings suggest implications for LD intervention and diagnosis. The findings support the importance of measuring both verbal and non-verbal cognitive skills when making an LD diagnosis, and point to the potential of targeting underlying cognitive skills as one strategy to support language abilities.

KEYWORDS
children, cognition, language disorder, symptom severity

WHAT THIS PAPER ADDS

What is already known on the subject

Language development is dependent on basic cognitive processes. These include both verbal and non-verbal cognitive abilities. Children with LD often experience both language and cognitive problems. There is evidence that performance on cognitive tests may be associated with the degree of severity of LD.

What this paper adds to existing knowledge

The current results from a large population-based cohort establish that a number of verbal and non-verbal cognitive abilities are tightly linked to variation in language abilities and the degree of severity of LD. Our study confirms concurrent links between language and non-verbal cognitive abilities above and beyond the contribution of verbal cognitive abilities. We also identify specific verbal and non-verbal cognitive tests that distinguish between typical children and children with LD, as well as LD severity.

What are the potential or actual clinical implications of this work?

Our findings support the importance of measuring both verbal and non-verbal cognitive skills when making an LD diagnosis. Our findings also point to the potential of targeting underlying cognitive skills as one strategy to support language abilities. We suggest that future intervention studies focus on the impact of non-verbal cognitive skills on language development in children with LD.

INTRODUCTION

Language disorder (LD)[1] is a condition that adversely affects the child's ability to acquire language, leading to poor outcomes in receptive and/or expressive language skills. Affected children are likely to have language problems enduring into middle childhood and beyond, with a significant impact on everyday social interactions and/or educational progress (Bishop et al., 2017). Earlier conceptualizations of the disorder assumed that language was selectively affected, with no identifiable cause, since the child's cognitive abilities would be within the normal range (Leonard, 1998; Stark & Tallal, 1981). Evidence in later research, however, suggests that the aetiology of LD is more complex, and may involve the interaction of a number of factors, thus shifting the focus to the underlying mechanisms which support language acquisition and use (Archibald, 2017; Archibald & Gathercole, 2006; Bishop, 2006, 2013). Despite accumulated evidence that language development depends on basic cognitive processes, the balance in contributions of verbal and non-verbal cognitive skills to language abilities is still underexplored.

Furthermore, little is known regarding which cognitive measures best predict the degree of severity in children with LD. The main aim of the present paper is to investigate the potential of non-verbal cognitive skills to predict poor language outcomes in a representative sample of 8-year-old Norwegian children and to establish to what extent they predict the degree of LD severity in that sample. It thus contributes to a better understanding of the cognitive mechanism underlying language, the knowledge of which may further inform intervention and LD diagnosis.

Associations between non-verbal cognitive skills and LD

Few studies have specifically addressed the association between non-verbal cognitive abilities and language skills in children with LD, largely as a result of the traditional existence of exclusionary criteria and assumptions thereof. Restrepo et al. (1992) provide evidence of significant differences in the relationship between non-verbal and verbal cognitive skills between LD and typical children in a sample of 4;2–5;11-year-old children, and specifically the relationship between non-verbal rule-induction and novel bound-morpheme learning. The authors suggest that a 'qualitative-differences' model of LD better accounts for the co-occurrence of poor verbal and non-verbal cognitive skills in children with LD than a 'low-normal' model. A meta-analysis of studies published between 1995 and 2012 provides further evidence of differences in non-verbal cognitive skills between children with LD and their age-matched typical controls (Gallinat & Spaulding, 2014). This analysis of 138 samples from 131 studies shows that, on average, children with LD performed 0.69 SD below their controls. In the paper the systematic, and often significantly lower, performance on non-verbal cognitive tests by children with LD is discussed in light of its theoretical implications for the characterization of this population. The results are taken as evidence of the complex bidirectional relationship between language and non-verbal cognitive skills across development. This meta-study also documents a wide heterogeneity in effect sizes between studies, and highlights that the magnitude of the difference between children with LD and typical children depends on the IQ test selected. Furthermore, in a comprehensive review of research between 2000 and 2012, Earle et al. (2017) suggest that the practice of matching LD children to controls on non-verbal cognitive performance may have unintended consequences for the generalization of research findings to the broader LD population. This review indicates that, in studies where children with LD were matched to controls on non-verbal IQ, they systematically performed better on non-verbal cognitive tests in comparison with participants in studies where the children with LD and typical controls were not matched.

Further evidence of the complex bidirectional relationship between language and non-verbal cognitive skills is provided in the long-term follow-up study by Botting (2005) and Griffiths et al. (2022). Botting investigated a cohort of 82 children whose IQ scores were measured at 7, 8, 11 and 14 years. Analyses revealed a significant fall in IQ scores between 7 and 14 years by 20 points, at the same time as different developmental trajectories were observed in different subgroups of children. Griffith et al. followed a cohort of 501 children across three waves of measurements of receptive vocabulary and block design from 7 to 13 years. The results provided evidence that language and non-verbal cognition had mutual influence on the rates of growth of each skill. These findings are interpreted as suggesting a dynamic relationship between language and cognitive mechanisms, which interact to produce the specific language impaired profile of those children. The developmental interaction between language and cognition and the brain systems that support language is further highlighted in Bishop's proposal that weak lateralization (for language) in LD children may be a consequence of impaired language learning, rather than its cause (Bishop, 2013).

While the research reviewed above provides important insights into the complexity of LD and its dynamic nature, the exact factors involved remain obscured due to the nature of omnibus tests and the tasks which are used to tap specific non-verbal constructs. Thus, studies that focus on specific underlying cognitive mechanisms and their role in LD are of special interest. Some studies provide evidence from typical development, which in turn can be used to make predictions about the relevance of these factors also in the case of LD. A series of meta-analyses reported in Hamrick et al. (2018) provide compelling evidence of strong associations between lexical ability and declarative memory, and between grammar learning and both declarative and procedural memory in typical first language acquisition, as well as in adult second language acquisition. LD is strongly associated with impairments of procedural memory leading to the proposal of the Procedural Deficit Hypothesis as an explanatory account of developmental LD (Ullman, 2004; Ullman & Pierpont, 2005). In addition, language acquisition may be linked to other generic cognitive skills. Thus, the ability to detect abstract patterns in visual stimuli, as measured by performance on non-verbal tasks, such as Block Design and Matrix Reasoning, has been implicated in the ability to learn second languages with ease in gifted individuals on the autism spectrum, and specifically, in enhanced morphology sensitivity in the first language (Vulchanova et al., 2012a, 2012b). Archibald (2013) provides compelling evidence of a factor comprised of tasks which tap fluid reasoning (Block Design and Mazes Reasoning) which predicts verbal skills in an epidemiological sample of typically developing school children. It may thus be the case that fluid reasoning may be particularly relevant for the acquisition of specific (rule-based) aspects of language.

A meta-analysis of statistical learning in LD and autism documents that children with LD perform more poorly on statistical learning tasks than typical language learners (Obeid et al., 2016). The link between statistical learning and language acquisition has long been demonstrated for typical language development (Saffran et al., 1996; Saffran & Kirkham, 2018). It can be argued that children with LD exhibit difficulty in tracking sequential patterns that are both linguistic and non-linguistic, supporting the view that the deficits observed in LI are not specific to language (Saffran & Kirkham, 2018). This is further confirmed by a meta-analysis of visuo-spatial skills and LD (Vugs et al., 2013). This analysis, based on 21 studies, established significant impairment in both visuo-spatial storage and visuo-spatial executive skills in children with LD, suggesting that the disorder is more of a generic nature. However, the evidence concerning visuo-spatial skills in children with LD is controversial, depending on the skills assessed and task(s) used. Visuo-spatial short-term memory, for instance, has received less attention. The study by Archibald and Gathercole (2006) does not provide evidence of a deficit in visuo-spatial memory in a sample of twenty 7–11-year-old children with LD. The children in that study performed appropriately for language age on three tasks (i.e., block recall, mazes memory and visual patterns) whose scores formed a composite measure of visuo-spatial skills. As a bidirectional relationship between spatial language and spatial ability has been established in pre-school development (Wu et al., 2022), and given that an association between reduced shape bias in word learning and visual associative learning has been documented in children with LD (Collisson et al., 2015), it is expected that visuo-spatial skills may also impact on language skills in children with LD. It is thus important to include visuo-spatial tasks in studies whose aim is to investigate the contribution of non-verbal cognition to language in these children.

There is compelling evidence from studies of both typically developing children and children with LD of associations between non-verbal cognitive skills and language profiles and outcomes. Importantly, this evidence suggests that domain-general mechanisms might play a role in language development and potentially compromise language learning. Performance in the domain of the memory system and its components, and specifically visuo-spatial storage and procedural memory, visuo-spatial skills, fluid reasoning can thus reveal the potential source of atypical acquisition of the language system.

Associations between verbal cognitive skills and LD

The phonological loop component of the memory system and working memory have been identified as core mechanisms in language learning (Baddeley et al., 1998; Baddeley, 2003), and impaired working and short-term memory capacity, as measured on non-word and sentence repetition tasks, has been shown to accompany language deficits (Conti-Ramsden & Botting, 2001). Lower performance on working memory and short-term memory tasks has been systematically associated with language deficits (Archibald, 2017; Gathercole, 1993). Impairments of verbal memory are also considered a central risk marker of the condition (Archibald & Gathercole, 2006; Botting & Conti-Ramsden, 2001; Conti-Ramsden et al., 2001; Hesketh & Conti-Ramsden, 2013). A working memory deficit in children with LD may be argued to be not only co-occurring with the deficit, but also to be the underlying cause (Marton et al., 2016). According to this view, we should expect to find working memory deficits in all children with LD. In a study of French children with LD in comparison with controls, Delage and Frauenfelder (2020) identified predictive relationships between working memory and the comprehension and repetition of complex sentences in both groups. These results provide evidence of a robust relationship between working memory and syntactic complexity, with clinical implications for the treatment of children with LD. However, Archibald and Joanisse (2009) found a subgroup with LI that did not appear to have working memory deficits. Importantly, and of relevance for the current study, Archibald (2017) suggests that every child with language problems may not have working memory deficits, but when they do and when the deficits are (sufficiently) severe, they may be an underlying cause of LD.

Consistent with the influential model of the memory system originally proposed by Baddeley and Hitch (1974) which was refined in later work, several components need to be considered in regard to demands posed by language learning and language use. Short-term memory and working memory have both been implicated as playing an essential role. While both involve temporary storage, they differ in whether additional processing and manipulation is necessary. Archibald and Gathercole (2006) provide evidence of deficits in both verbal short-term memory and working memory in a sample of twenty 7–11-year-old children with LD. The study by Archibald (2013) highlights the importance of distinguishing among tasks and the extent to which they can be conceived as pure measures of a specific construct. This is specifically relevant for memory tasks. Traditionally, verbal short-term memory is tested by tasks involving immediate repetition of auditory material (forward digit span; non-word repetition). This component of the memory system poses minimal demands and is assumed to be supported by the phonological loop. In contrast, working memory requires not only the temporary storage of material, but also its manipulation and may recruit for this purpose additional executive resources. Even though both components may be involved in the processing of auditory material, they differ in what resources they recruit. Thus, short-term phonological memory is more closely associated with language and depends on language, while working memory relies more heavily on the interaction with other, non-verbal processes (Baddeley, 1998).

Cognitive skills and degree of severity of LD

There is evidence that performance on non-verbal cognitive tests may be associated with the degree of severity of language problems, for example, consistent relationships between severity of LD and lower non-verbal IQ have been documented (Conti-Ramsden et al., 2012; Gallinat & Spaulding, 2014). In a longitudinal cohort study of language and non-verbal ability in children with LD, Conti-Ramsden et al. (2012) demonstrated that non-verbal ability largely covaries with verbal ability, albeit not to the same degree across subgroups defined on the basis of the severity of LD. This study provides evidence of co-occurring impairments in language and non-verbal cognition. It is worth noting, however, that the study employed a single composite measure of non-verbal ability for the analyses. In a more recent study, Saar et al. (2018) established that weaker non-verbal reasoning skills are associated with severe problems in verbal comprehension and verbal short-term memory in two groups of Finnish pre-school children diagnosed with LD, one group with impaired expressive skills, the other with impaired receptive skills. This study also documented that children with receptive LD, relative to those with only expressive LD, had more severe and widespread problems in both verbal and non-verbal reasoning. This underscores the importance of evaluating non-verbal cognitive skills, in order to understand the whole range of processing demands linked to language learning. Interestingly, both groups performed poorly on two of the non-verbal cognitive tests, Picture Concepts and Matrices, indicating impairments common to both receptive and expressive language difficulties. The authors further suggest that non-verbal IQ in the normal range may not always represent an intact general non-verbal capacity previously assumed in LD diagnostics.

Literature gaps and the need for the current study

The studies mentioned above highlight the role of non-verbal cognitive abilities and mechanisms in language acquisition, learning and disorder. They further suggest that specific non-verbal skills may selectively affect specific aspects of the language system (e.g., expressive and receptive; vocabulary and narrative skills). Despite the recognition of the role of cognitive skills in the manifestation of LD, to the best of our knowledge, no study has addressed the extent to which performance on cognitive tasks can distinguish between degrees of severity of impaired language skills in affected children.

An important caveat concerns the way cognitive skills are measured. Standardized intelligence tests distinguish between verbal and non-verbal tasks, also reflected in the norms and quotients. However, many of the verbal tasks of traditional IQ tests, along with measuring verbal cognitive skills, measure conceptual and categorization skills. For instance, the Similarities subtest in WASI along with verbal expression also measures an examinee's verbal concept formation, crystallized intelligence, abstract reasoning, associative and categorical thinking. The WASI Vocabulary subtest, along with degree of language development, also measures an examinee's word knowledge, verbal concept formation, fund of knowledge and crystallized intelligence (McCrimmon & Smith, 2012). Thus, such measures appear to be closely related to language development and may be useful in predicting language status and degree of severity in children with LD.

Another important caveat here is that cognitive capacity is often measured and reported as a composite, making it difficult to assess the independent contribution of specific factors, such as working memory, processing speed, ability to detect patterns and regularities in abstract visual stimuli. As pointed out by Saar et al. (2018), non-verbal IQ in the normal range measured as a composite may not always represent an intact general non-verbal capacity in children with LD. In that study, short-term memory, non-verbal reasoning, and several non-verbal subtests correlated significantly with the composite verbal index in a sample of children with LD. In addition, Restrepo et al. (1992) documented a correlation between performance on a rule-induction task and a novel morpheme learning task in the children with LD in their sample. This calls for identifying specific (and independent) mechanisms underlying cognitive capacity and their corresponding conceptual and behavioural manifestations, which, in turn, may correlate with and support specific language skills.

An important final remark concerns the way in which constructs are measured. As pointed out above, many tasks included in standardized tests measure more than one ability. Often, performance on non-verbal measures may rely on verbal ability. The results of a significant drop in non-verbal scores in the cohort of children with LD (Botting, 2005) suggest that the association between measures assumed to be purely non-verbal and language processing is bidirectional and more complex, which in turn makes testing non-verbal cognition particularly demanding. For the purposes of the current work, we have selected specific tasks which have been systematically demonstrated to tap non-verbal intelligence and whose status has also been addressed extensively on theoretical grounds (Archibald, 2017).

THE PRESENT STUDY

The specific role of cognitive mechanisms supporting a child's language acquisition, and their impact on LD, including the degree of severity, were the focus of the current study. Specifically, we were interested in the interrelatedness of the cognitive measures, as little is known about the relationship of the cognitive abilities in 8-year-old children. As for prediction of LD severity, previous studies have typically used composite scores for IQ and working memory, making it difficult to assess the independent contribution of skills underlying performance on specific tasks. Thus, in the present study, we consider the individual cognitive measures with their respective conceptualizations as independent predictors, with the aim of highlighting the contribution of individual skills and mechanisms to language ability. The following research questions were addressed:

- What is the interrelationship between cognitive and language abilities in 8-year-old Norwegian children?
- To what extent do non-verbal cognitive abilities contribute to language abilities above and beyond verbal cognitive abilities?
- Which, among these cognitive abilities, are most effective in distinguishing LD severity?

METHODS

Participants

The present study included children participating in the Language-8 Study, a clinical substudy of the Norwegian Mother, Father, and Child Cohort Study (MoBa). This study was approved by the Regional Committee for Medical Research Ethics in Norway.

The MoBa is a prospective population-based pregnancy cohort study conducted by the Norwegian Institute of Public Health. Participants were recruited from all over Norway from 1999 to 2008. There was a 41% consent rate for women approached to participate. Consenting women received three questionnaires during pregnancy: in gestational weeks 17, 22 and 30. They later received questionnaires after delivery, when their child was 6 and 18 months old, and 3, 5, 7 and 8 years old. Data collection is still ongoing. The cohort now includes 114,500 children, 95,200 mothers and 75,200 fathers (Magnus et al., 2016). The MoBa data are linked to the Medical Birth Registry of Norway which contains standardized data regarding all pregnancies and births in Norway from 12 weeks of gestation (Irgens, 2000).

The Language-8 Study aims to examine environmental and heritable causes for LD. Recruitment of children to cognitive and language assessment was done when they were between 8;5 and 8;9 years of age. Due to limitations in terms of study financial resources, only children living in the six nearby counties of Oslo were invited to participate. Consistent with current advice on identification of LD (Bishop & McDonald, 2009; Plante, 1998), selection of eligible children involved multiple sources of information. See details of inclusionary and exclusionary criteria in Appendix A for both *possible cases* (i.e., a child with possible LD) and *controls*. Accordingly, invitations to clinical assessment were sent to 1515 families (1056 probable cases and 459 controls), with the expected participation of 400 probable cases and 200 controls (based on participation rates in similar clinical studies in the MoBa). All invited families, who signed and returned a written consent for participating in the study ($N = 806$), were contacted for a 35-min telephone interview. The purpose of this interview was to ensure that children with any of the exclusionary criteria present were not invited to the clinical assessment. Due to logistic challenges, the final number of children assessed in the study was 509, including 359 probable cases and 150 controls. The remaining 297 consenting families who were not seen in the clinic provided data through the phone interview and responding to questionnaires. Appendix B provides demographic data comparing the clinic sample with the children who were (1) consented to participation but were not seen in the clinic, (2) invited but were not consented and (3) were not invited. The data indicate significant differences between the subgroups in maternal education, paternal education, and family income (all $p < 0.001$), suggesting that the clinic sample is more highly educated and more affluent than families in the other subgroups.

Clinical assessments

All 509 children participated in a comprehensive evaluation including assessment of language and cognition at a research clinic of the Norwegian Institute of Public Health. While the children were tested, the parents completed a short study-specific questionnaire. Two research-trained examiners with a master's degree, respectively in linguistics and psychology, administered the tests. The entire assessment required 3.5 h, including short breaks when needed and a planned 30-min break for refreshments, rest and completion of a spit sample both from child and mother. All individual sessions were videotaped for quality control (i.e., protocol compliance, selected reliability checking and case discussions). The research-trained staff coded each other's testing on site at regular intervals (i.e., every 20 assessments) to ensure assessment procedure fidelity.

Measures

For the purposes of the current study, we only consider measures of cognitive skills and some measures of language abilities. Language skills were measured using the Core Language Index (CLI) from the Norwegian version of Clinical Evaluation of Language Fundamentals—4 (CELF-4; Semel et al., 2013). The CLI is derived from four subtests of CELF-4 (Table 1). The Norwegian standardization of CELF-4 has been shown to have reliable sensitivity and specificity properties (Akselberg et al., 2021). For (verbal and non-verbal) cognitive skills, our assessment includes nine standardized tests. Details of the tests used are included in Table 1.

Defining LD and symptom severity

The present study used the CLI score from CELF-4 to identify LD and establish symptom severity. The norm referenced CLI score has a mean of 100 and a standard deviation (SD) of 15. Among the sample of children in this study, two had missing CLI scores and were excluded from further analyses. For the remaining 507 children, the CLI score showed wide variability, ranging from 52 to 137, with a mean of 97.25 and a SD of 14.98. Despite a complex process of case identification and oversampling, our study sample appears to be highly representative of the expected population distribution. This was further indicated by skewness (-0.28) and Kurtosis (0.01) measures. Sample descriptives and a histogram visually showing the sample distribution are provided in Appendix C. For severity intervals, we followed the guidelines provided in Semel et al. (2003) for identification of LD and classification of symptom severity. Children who scored 85 or lower were deemed to present with LD (N = 107). Initially, we divided LD status into three symptom severity levels: *mild* (those who scored 78–85; N = 63), *moderate* (those who scored 71–77; N = 19), and *severe* (those who scored 70 and lower; N = 5). However, after checking the validity of the LD severity group allocation from performance on each of the four CLI subtests (Figure 1), we found that the mild and moderate LD groups displayed a certain degree of overlap on the understanding-of-instructions, and the formulation-of-sentences tasks. We thus collapsed the mild and moderate LD groups, resulting in three comparison groups, namely, non-LD, mild/moderate LD (hereafter referred to as mild LD for simplicity), and severe LD. Descriptive statistics for cognitive measures shown for the two LD groups and the non-LD group, as well as the whole clinic sample are presented in Appendix D.

Table 2 presents key characteristics of the three groups and whether there were significant differences between them. The proportion of male gender appeared to be larger in the *severe* LD group than among the other two groups. However, results from the Chi-square test indicated no significant difference for gender among the three groups, χ^2 (2507) = 3.15, p = 0.123. Maternal education and child age at the time of clinical assessment showed significant differences between the non-LD and the severe LD group (one-way analysis of variance—ANOVA).

Statistical analysis

All statistical analyses were conducted using IBM SPSS, version 27. No missing values were observed in the main variables. For the covariates, maternal education had a missing percentage of 2.59%, and the missing values were replaced with the mean value. There were no missing values for gender or child age.

Pearson correlations were calculated to examine the interrelationships among the cognitive variables and their relationship with the language abilities. An exploratory factor analysis (EFA) was used to uncover the underlying factor structure of the nine cognitive variables, using maximum likelihood extraction technique and an oblique rotation. Then regression-based factor scores were obtained, mean factor scores for each factor were calculated and used in the regression analyses. A hierarchical method was adopted, and the non-verbal cognition factor was entered in the last step to explore whether non-verbal cognition explained language abilities above and beyond verbal cognition. Multinomial logistic regression was used to examine which cognitive measures best predicted degree of severity in the language impaired children.

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TABLE 1 Measures of cognitive and language skills with assessment instrument used

Instrument	Test	Task
Cognitive skills		
WASI-II Norwegian version (Wechsler, 2011)	Block Design	While viewing a constructed model, the student uses red-and-white blocks to re-create the design within a specified time limit
	Matrix Reasoning	The student views an incomplete matrix or series and selects the response option that completes the matrix or series
	Vocabulary	The student defines words that are presented visually and orally
	Similarities	The student is presented two words that represent common objects/concepts and describes how they are similar
CELF-4 Norwegian version (Semel et al., 2013)		
	Backward Digit Span	The student repeats a series of numbers backwards
	Familiar Sequences	The student names days of the week, counts backward and orders other information while being timed
	Rapid Automatized Naming	The student names colours, shapes and colour–shape combinations while being timed
NEPSY (Korkman et al., 1998)	Non-Word Repetition	The student repeats non-words of increasing complexity presented through a headphone
Knox Cube (Knox, 1913)	Knox Cube	The test administrator tapes each cube in order from left to right. The student copies the sequence
Core language index		
CELF-4 Norwegian version (Semel et al., 2013)	Understanding of instructions	The student points to pictured objects in response to oral directions
	Grammatical structures	
	The student completes sentences using the targeted structure(s)	
	Repetition of sentences	The student imitates sentences presented by the examiner
	Formulation of sentences	The student formulates a sentence about visual stimuli using a targeted word or phrase

In all regression analyses, child gender and maternal education were entered as control variables.

RESULTS

As can be seen in Table 3, the only non-significant correlation was between Non-Word Repetition and Rapid Automatized Naming; all intercorrelations between other cognitive measures were significant at 0.01 level, with values ranging from 0.129 (between Rapid Automatized Naming and WASI Matrix Reasoning) to 0.571 (between WASI Similarities and WASI Vocabulary). There were weak to moderate relationships between cognitive variables and CLI, with coefficient values ranging from−0.243 (between Rapid Automatized Naming and CLI) to 0.590 (between WASI Similarities and CLI).

To identify clear and distinct factors, data from the nine individual cognitive subtests were first entered in an EFA. This analysis resulted in three factors (all with eigenvalues greater than 1). Cumulative variance explained by the extraction was 69.3%. WASI Similarities, WASI Vocabulary and NEPSY Non-Word Repetition loaded on the expected verbal cognition construct; WASI Block Design, WASI Matrix Reasoning and Knox Cube loaded on the expected non-verbal cognition construct. The three CELF cognitive tests, namely, Rapid Automatized Naming, Backward Digit Span and Familiar Sequences, loaded on a distinct third factor. Rapid Automatized Naming requires rapid responding and is thought to tap, among other things, phonological processing, while the latter two tests recruit memory resources (short-term and working memory). The third factor can thus be labelled Processing Speed and Memory. With the present sample size, all measurement

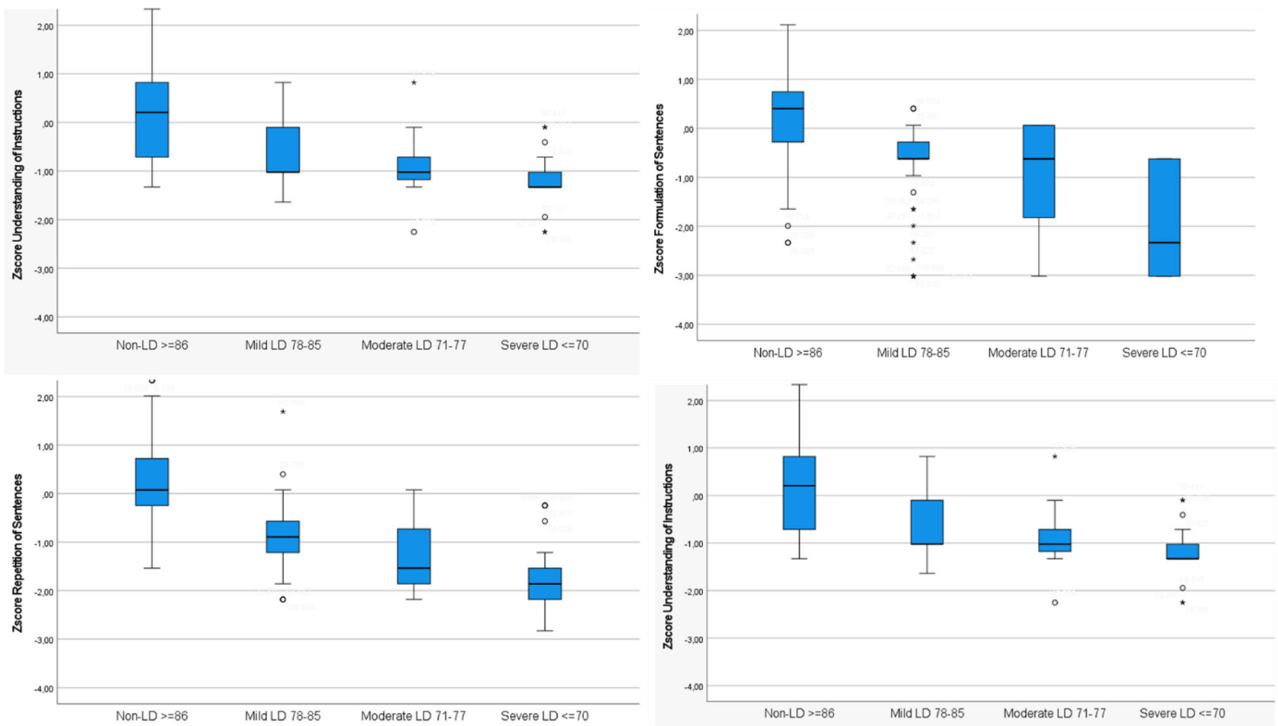

FIGURE 1 Box plots of performance z-scores on CELF-4 CLI subtests by LD severity group [Colour figure can be viewed at wileyonlinelibrary.com]

TABLE 2 Key characteristics by language disorder (LD) severity group

LD severity level	No. of male gender	Maternal education (scale 1–6)[a]	Child age (years)	CELF CLI score
Non-LD ($N = 397$)	223 (55.9%)	5.02 (0.97)	8.74 (0.13)	102.88 (10.74)
Mild LD ($N = 80$)	50 (61.2%)	4.65 (1.17)	8.71 (0.14)	80.21 (3.71)
Severe LD ($N = 25$)	18 (72.0%)	4.56 (1.16)	8.69 (0.11)	63.00 (5.09)
p-value	0.123	0.002	0.021	< 0.001

Note:
[a]Maternal education scale: 1 = 9-year elementary, 2 = further education 1–2 years, 3 = further education vocational, 4 = further education, 3 years (general studies), 5 = higher education (university/college) up to and including 4 years, and 6 = higher education over 4 years.
CLI, CELF core language index.

items had proper loadings exceeding the threshold of 0.30 (Hair et al., 1998). Familiar Sequences cross-loaded at 0.408 on the Verbal Cognition; no other tests loaded at 0.30 or higher on two or more factors. Regarding the reliability, all factors had acceptable internal consistency with a Cronbach's alpha above 0.70. The discriminate validity of the factors was assessed using the average variance extracted (AVE). The AVE values ranged between 0.46 and 0.58, which are near or above the recommended level of 0.50 (Segars, 1997). In conclusion, measurement model demonstrated good reliability, convergent validity and discriminant validity. These values are summarized in Table 4.

Before performing the regression analyses, we checked the data for collinearity. Tolerance (ranging from 0.64 to 0.99) and variance inflation factors (VIF; ranging from 1.00 to 1.56) showed no violation of the multicollinearity assumptions. Furthermore, residual and scatter plots indicated that the assumption of normality, linearity and homoscedasticity were all satisfied. The hierarchical multiple regression (see Table 5 for regression statistics) revealed that Verbal Cognition contributed significantly to the regression model ($F[4461] = 392.11$, $p < 0.001$) and accounted for 41.8% of the variation in language abilities. Processing Speed and Memory also made a unique contribution, explaining 4.0% of the variation in language abilities above and beyond that accounted for by

TABLE 3 Pearson correlations among major variables ($N = 507$)

	2	3	4	5	6	7	8	9	CLI
1. CELF Rapid Automatized Naming	−0.073	−0.224**	−0.318**	−0.205**	−0.191**	−0.140**	−0.129**	−0.194**	−0.243**
2. NEPSY Non-Word Repetition		0.184**	0.368**	0.273**	0.276**	0.208**	0.237**	0.195**	0.498**
3. CELF Backward Digit Span			0.404**	0.221**	0.193**	0.201**	0.211**	0.319**	0.333**
4. CELF Familiar Sequences				0.422**	0.394**	0.283**	0.290**	0.333**	0.569**
5. WASI Vocabulary					0.571**	0.367**	0.374**	0.241**	0.553**
6. WASI Similarities						0.347**	0.389**	0.205**	0.590**
7. WASI Block Design							0.521**	0.374**	0.476**
8. WASI Matrix Reasoning								0.353**	0.471**
9. Knox Cube									0.358**

Note: CLI = CELF Core Language Index.
**Significant at the 0.01 level.

TABLE 4 Latent cognitive factors and the measurement values

Factor	Task	Loadings	AVE	CR
Verbal cognition	WASI Similarities	0.808	0.53	0.77
	WASI Vocabulary	0.765		
	NEPSY Non-Word Repetition	0.587		
Processing speed and memory	CELF Rapid Automatized Naming	0.551	0.46	0.71
	CELF Backward Digit Span	0.688		
	CELF Familiar Sequences	0.767		
Non-verbal cognition	WASI Block Design	0.796	0.58	0.81
	WASI Matrix Reasoning	0.724		
	Knox Cube	0.771		

Note: AVE = Average Variance Extracted; CR =Cronbach's alpha.

Verbal Cognition. The Non-Verbal Cognition accounted for additional 5.4% variance in language abilities (above and beyond that accounted for by Verbal Cognition and Processing Speed and Memory), as indicated by a significant *F* for the increment in R^2 in Step 4. We then repeated the analysis, reversing the order of the Verbal Cognition and Non-Verbal Cognition. Non-Verbal Cognition predicted 23.9% of the variance associated with language abilities; Processing Speed and Memory added 5.4% and Verbal Cognition added another 22.0%. Together the three cognitive factors and control variables accounted for 55.9% of the variance in language abilities (detailed regression statistics are presented in Appendix E).

Finally, a multinomial logistic regression was performed to model the relationship between the cognitive measures and membership in the three groups (non-LD, mild LD and severe LD). Rapid Automatized Naming, Backward Digit Span, Knox Cube and Maternal Education were excluded from these analyses because a preliminary analysis indicated relatively low predictive power. Before conducting the multinomial logistic regression analysis, scores on each of the remaining cognitive variables were standardized to a mean of 0 and SD of 1, in order to facilitate interpretation. The scores were then reversed, so that higher scores indicated poorer skills. Addition of the predictors to a model that contained only the intercept significantly improved the fit between model and data, $x^2(14,490) = 248.49$, Nagelkerke $R^2 = 57.2$, $p < 0.001$. Goodness-of-fit was examined by conducting Hosmer–Lemeshow tests for each pair of groups. In no case was this test significant, indicating the model was a good fit. In the first analysis, the reference group was children without LD (non-LD).

TABLE 5 Hierarchical multiple regression predicting language abilities from the cognitive factors

Variable	β	t	R^2	ΔR^2	F for ΔR^2
Step 1			0.046	0.046	12.14, $p < 0.001$
Gender	0.13	2.95, $p = 0.003$			
Maternal education	0.17	3.90, $p < 0.001$			
Step 2			0.464	0.418	392.11, $p < 0.001$
Gender	0.09	2.86, $p = 0.004$			
Maternal education	0.06	1.94, $p = 0.053$			
Verbal cognition	0.66	19.80, $p < 0.001$			
Step 3			0.504	0.040	40.35, $p < 0.001$
Gender	0.09	2.0 88, $p = 0.004$			
Maternal education	0.05	1.52, $p = 0.128$			
Verbal cognition	0.60	18.32, $p < 0.001$			
Processing speed and memory	0.21	6.35, $p < 0.001$			
Step 4			0.559	0.054	61.40, $p < 0.001$
Gender	0.10	3.46, $p = 0.001$			
Maternal education	0.04	1.26, $p = 0.207$			
Verbal cognition	0.52	15.77, $p < 0.001$			
Processing speed and memory	0.16	5.06, $p < 0.001$			
Non-verbal cognition	0.26	7.84, $p < 0.001$			

TABLE 6 Parameter estimates contrasting the non-language disorder (LD) versus mild and severe LD groups

Predictor	Non-LD versus ...	B	OR [confidence interval]	p-value
Gender	Mild LD	−0.170	0.84 [0.44 1.62]	0.844
	Severe LD	−0.495	0.61 [0.16 2.32]	0.467
NEPSY Non-Word Repetition	Mild LD	0.731	2.08 [1.47 2.94]	< 0.001
	Severe LD	0.845	2.33 [1.31 4.13]	0.004
CELF Familiar Sequences	Mild LD	0.579	1.79 [1.27 2.52]	0.001
	Severe LD	1.511	4.53 [2.01 10.03]	< 0.001
WASI Vocabulary	Mild LD	0.637	1.89 [1.24 2.89]	0.003
	Severe LD	1.529	4.62 [2.04 10.45]	< 0.001
WASI Similarities	Mild LD	0.473	1.61 [1.09 2.36]	0.017
	Severe LD	1.143	3.14 [1.60 6.15]	0.001
WASI Block Design	Mild LD	0.662	1.94 [1.25 3.01]	0.003
	Severe LD	0.715	2.01 [0.76 5.54]	0.159
WASI Matrix Reasoning	Mild LD	0.376	1.46 [1.01 2.09]	0.043
	Severe LD	0.912	2.49 [1.02 6.07]	0.045

Accordingly, each predictor had two parameters, one for predicting membership in the mild LD rather than non-LD, and one for predicting membership in the severe LD group. The parameter estimates are shown in Table 6.

After controlling for the cognitive variables, gender was not significant for distinguishing LD membership. All other predictors had significant parameters for comparing the non-LD group with the mild LD group. For each one SD decrease in these cognitive skills, the odds of being in the mild LD group rather than the non-LD group increased by 1.46 to 2.08. All the four verbal cognitive predictors were significant parameters for distinguishing between the non-LD group and the severe LD group. The odds of being in the severe LD group rather than the non-LD group were more than doubled for each SD decrease in non-word repetition (OR = 2.33), more than tripled for each SD decrease in WASI Similarities, and more than four times for each SD decrease in WASI Vocabulary (OR = 4.62) and Familiar Sequences (OR = 4.53). WASI Matrix Reasoning was the only non-verbal cognitive measure reliably distinguishing

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TABLE 7 Parameter estimates contrasting the mild versus severe language disorder (LD) group

Predictor	*B*	OR [confidence interval]	*p*-value
Gender	−0.325	0.72[0.21 2.53]	0.611
NEPSY Non-Word Repetition	0.114	1.12 [0.68 1.85]	0.658
CELF Familiar Sequences	0.931	2.54 [1.19 5.41]	0.016
WASI Vocabulary	0.892	2.44 [1.15 5.20]	0.021
WASI Similarities	0.670	1.95 [1.06 3.60]	0.032
WASI Block Design	0.054	1.06 [0.40 2.29]	0.913
WASI Matrix Reasoning	0.536	1.71 [0.72 4.07]	0.225

between the non-LD group and the severe LD group. The odds of being in the severe LD group rather than the non-LD group were more than doubled for each SD decrease in WASI Matrix Reasoning (OR = 2.49). WASI Block Design was not significant for distinguishing between the non-LD group and the severe LD group ($p = 0.159$).

To further examine whether the cognitive factors were significant predictors for distinguishing between mild and severe LD, we performed another multinomial logistic regression, the reference group being children with mild LD. As shown in Table 7, for each one SD decrease in CELF Familiar Sequences, WASI Vocabulary and WASI Similarities, the odds of being in the severe LD group rather than the mild LD group were more than or nearly doubled. Neither NEPSY Non-Word Repetition, WASI Block Design nor WASI Matrix Reasoning reached significance for distinguishing between mild and severe LD. After controlling for the cognitive variables, gender was not significant in distinguishing between mild and severe LD. Using the logistic model to make predictions of group membership resulted in 85.9% correct prediction. Correct predictions were more frequent for the non-LD group (96.3%), than for the severe LD group (54.5%) and the mild LD group (44.2%).

DISCUSSION

The first main aim of the current study was to establish the interrelationship between language, memory, and other cognitive abilities in a sample of 8-year-old Norwegian children. Our second goal was to establish whether non-verbal cognitive skills explain language abilities above and beyond verbal cognitive skills. In addition, we set out to determine which verbal and non-verbal cognitive skills were more reliable in distinguishing severity levels of LD.

The correlation analysis revealed significant associations between all verbal and non-verbal cognitive measures, indicative of the validity of variables selected for the study. An EFA revealed a three-factor structure of the cognitive variables. The EFA also demonstrated that measures of cognitive performance cluster depending on (a) the extent to which they require use of language (e.g., the first verbal factor versus the purely non-verbal fluid intelligence and reasoning factor), and (b) what type of intelligence they tap (the first factor which may be thought to reflect crystallized intelligence and acquired knowledge given the nature of the tasks).

The results from hierarchical multiple regression analyses suggest that both verbal and non-verbal cognitive skills contribute to individual variation in language abilities depending on the extent to which they pose language demands and what aspect of cognition they reflect. These cognitive skills may be concurrently linked to language abilities. For instance, vocabulary size, as assessed by the WASI Vocabulary scale, provides another measure of language ability closely linked to knowledge of word properties and how words combine in language structures beyond the level of the word. Providing word definitions as required by this task not only relies heavily on language ability, but also on already acquired conceptual knowledge and metalinguistic skills. Other abilities, such as those reflected in the WASI Similarities, reveal categorization and conceptual skills, and the ability to detect semantic relations among words, and as such, also reflect crystallized intelligence.

Performance on non-word repetition has an established tradition as a predictor of language deficits (Conti-Ramsden & Botting, 2001; Conti-Ramsden et al., 2015). Since non-word repetition involves both temporary storage and processing of phonological material, it clearly reflects memory for auditory input and, may, as such, reflect the ability to learn language (words and larger chunks). This result is consistent with the idea expressed in Baddeley et al. (1998) of the phonological loop as the main component of the language acquisition device. It also aligns with Bishop's idea that language difficulty is most likely caused by impaired language learning skills (Bishop, 2013). Block Design and Matrix Reasoning are often seen as proxies for fluid intelligence and reflect both visuo-spatial skills and the ability to detect patterns in external input, whether visual or auditory. The skills in the domains tested in these tasks can be implied in the acquisition of regularities in language structure (Archibald, 2013). Previous research has demonstrated that such skills may underlie exceptional language learning skills in highly verbal individuals with autism, as well as heightened sensitivity to morphological structure in first language learning (Vulchanova et al., 2012a, 2012b). The finding that Matrix Reasoning, along with other non-verbal cognitive skills, significantly predicts language competence in the current sample is also consistent with the findings by Saar et al. (2018) who found a significant association between non-verbal reasoning skills and language competence in Finnish children with LD. It is worth noting that non-verbal cognitive ability and the processing speed and memory together explain 9.4% of the variance in language ability above and beyond the verbal cognition measures. This speaks of a modest, albeit significant, contribution to language capacity. The present study documents concurrent relationships, where language ability covaries with non-verbal ability longitudinally and dynamically. Given the results reported in Conti-Ramsden et al. (2012), it can be speculated that the predictive power between the current variables may be subject to change across development, for which future research is needed.

An open question concerning our interpretation of the current results is to what extent the factor we label verbal cognition can be seen as measuring something different or separate from language ability. Indeed, the verbal subtests included in common intelligence batteries all rely heavily on language skills in different domains, and as such, may be thought of as reflecting language ability. In addition, they tap other skills beyond language. For instance, the ability to provide definitions is clearly a metalinguistic skill and requires reasoning about language as structure/system and semantic relations. Language ability is complex and multidimensional, and this multidimensionality emerges in development (LARRC, 2015). In this sense, language is not a single construct, and the measures that we use in research should also reflect and respect this multidimensionality.

The current results also confirm that weaker non-verbal cognitive abilities contribute to LD severity, as outlined in the aims of the study. The multinomial analysis suggests that non-verbal cognitive skills which tap the ability to see patterns, such as those measured by Matrix Reasoning, may be inherently linked to language (development), and specifically, to the acquisition of language structure and grammar. These results are also consistent with findings indicating that the core deficit in LD is manifested in weaker grammar competence (van der Lely, 2005; van der Lely & Marshall, 2011). Since all these cognitive skills are implicated in language learning, these findings suggest that the links are developmental in nature. They are consistent with Botting's (2005) suggestion of a dynamic relationship between language and cognitive mechanisms and skills, which interacts to produce the specific profile observed in children with LD. In keeping with this suggestion, and our results, the relationship between aspects of non-verbal cognition and language may be bidirectional, with impaired language also contributing to a comprise in cognitive capacity, especially given the language demands on a number of cognitive tasks routinely included in intelligence tests.

We further confirm the results of the meta-analyses in Hamrick et al. (2018) of strong systematic associations between generic underlying mechanisms, such as components of the memory system and language learning in both children and adults. Our results also support the definition of LD as a deficit or immature language learning mechanisms (Bishop, 2006; Krishnan et al., 2016). Bishop (2006) further suggests that LD should be regarded as a case in which development is compromised precisely because more than one cognitive process is disrupted, an idea which our findings support.

This study has useful implications for educators and practitioners. Our findings support the importance of measuring both verbal and non-verbal cognitive skills when making an LD diagnosis. Our findings also point to the potential of targeting underlying cognitive skills as one strategy to support language abilities. We suggest that future intervention studies focus on the impact of non-verbal cognitive skills on language development in children with LD.

LIMITATIONS

Our study has several limitations. First, we did not report on a functional measure of LD. Another caveat is that our definition of LD severity was solely based on CELF CLI scores. The severity levels thus do not necessarily align with functional concerns or performance. In future research, the impact of LD should also be considered in terms of functional performance as suggested in Bishop et al. (2017). Further, we excluded children from the Language 8 study when one of their parents spoke another language other than Norwegian. In the MoBa, these children accounted for 9.8% of the whole sample. This limits the representativeness of the LD population in our study. Furthermore, even though maternal education had low predictive value in the analyses of the clinically assessed children, statistical analysis of the clinic sample in comparison with the children participating in the overall research programme (cf. Appendix B) revealed significant differences in maternal education, paternal education, and family income. This suggests that the clinic sample is more highly educated and more affluent than families in the larger MoBa cohort. Study outcomes and their generalizability need to be considered in this context. While we acknowledge this might create a bias, it should be noted that social status and family income are less revealing in Scandinavian welfare states, where social structure is levelled and more egalitarian. In fact, all groups included in Appendix B fell within the average on monthly income, according to Norwegian national census statistics (SSB, 2022).

Our study has yet another potential limitation. Although the size of our study sample is relatively large, the number of children in the severe LD group was small, thus limiting statistical power in detecting differences between this subgroup and others. Last but not least, the low number of girls in the mild and severe LD groups could have resulted in possible bias. Future research should attempt to replicate the present findings with a larger sample in which severe LD and female gender are well represented, to enhance the statistical power and generalizability of the results.

CONCLUSIONS

Using a sample of children participating in the Language-8 Study, the present study contributes to a better understanding of the cognitive underpinnings to language abilities. The current results establish several non-verbal cognitive skills as linked to variation in language abilities and to some extent with degree of severity of LD. Our study attests concurrent links between language and non-verbal cognitive skills above and beyond the contribution of verbal cognitive skills. The findings also confirm that weaker cognitive abilities contribute to LD severity. As the multinomial analysis revealed, performance on certain verbal and non-verbal cognitive tasks successfully distinguished between non-LD and children with LD, as well as between children with mild and severe symptoms. Our findings thus provide further evidence that children with LD tend to experience both language and cognitive problems in mid-childhood.

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ENDNOTE

[1]Throughout, we use language disorder (LD) to refer to conditions where the ability to acquire language is compromised, resulting in poorer language outcomes in language comprehension and/or production. The prevalent term in earlier research, specific language impairment (SLI), was used to refer to cases when problems with language were present, despite typical development in other domains. More recently, the term developmental language disorder (DLD) was adopted to refer to 'a profile of difficulties that causes functional impairment in everyday life and is associated with poor prognosis' in the absence of known biomedical aetiology (Bishop et al., 2017).

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CONFLICTS OF INTEREST STATEMENT

The authors declare no conflicts of interest. The authors alone are responsible for the content and writing of the paper.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the Norwegian Institute of Public Health. Restrictions apply to the availability of these data, which were used under licence for this study. Data are available with the permission of the Norwegian Institute of Public Health at https://www.fhi.no/en/more/access-to-data/.

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APPENDIX A
INCLUSION CRITERIA FOR PROBABLE CASES AND CONTROLS

Criteria for inclusion: Probable cases

Criterion 1: Parent reported in the MoBa 5-year questionnaire (Q5yr), under section 'health problems' 'yes' on 'Delayed or deviant language development'.

Criterion 2: Parent reported in Q5yr 'yes' on the question 'Has your child ever been assessed by a professional due to language difficulties?' and in addition marked off the listed response options under conclusion from the examination 'Only delay in use of language/good language comprehension' or 'Delay both in use of language and delayed language comprehension'.

Criterion 3: The scores on each of the six language scales included in MoBa Q5yr were standardized based on the scores in the total MoBa 5-year sample, and a mean total standardized score across the six scales was constructed for each child. Children who scored one SD or lower below the MoBa 5-year sample mean were considered a possible case.

Criterion 4: Parent reported in the MoBa 8-year questionnaire (Q8yr) under section 'health problems' 'yes' on 'Delayed or deviant language development'.

Criterion 5: The score on each of the two language scales included in MoBa Q8yr was standardized based on the total MoBa 8-year sample, and a mean total standardized score across the two scales were constructed for each child. Children who scored one SD or lower below the MoBa 8-year sample mean were considered a possible case.

Criteria for Inclusion: Controls

Children considered eligible as controls should not meet any of the criteria for CASE definition. In addition, a control should not (1) score lower than −0.5 SD below the MoBa group mean on the two criteria with standardized language scale scores (Criteria 3 and 5); and (2) have any reported family history of late language emergence, difficulties learning to read, or pronunciation difficulties (question in the Q5yr).

Exclusionary Criteria

Children were excluded, if (1) they were registered in the Medical Birth Registry with malformations, intracranial bleeding, multiple birth, birth weight below 1500 g, or gestational age lower than 34 weeks; and (2) children were reported by their parents in any MoBa questionnaire (from 6-month to 8-year questionnaires) to have a syndrome or diagnosis (e.g., cerebral palsy, epilepsy, learning /intellectual disability, hearing loss/deafness, delayed psychomotor development, and chromosomal anomaly) expected to affect language development; and (3) children who had at least one parent with a native language other than Norwegian.

TABLE B1 Demographic data comparing the clinic sample with the children who were (1) consented to participation but were not seen in the clinic, (2) invited but were not consented and (3) were not invited

	Clinic sample (*N* = 507)	Consented, non-assessed (*N* = 295)	Invited, non-consented (*N* = 708)	Non-invited (*N* = 20017)	*p*-value (ANOVA)
Maternal education (on a scale 1–6)[a]	4.95 (1.02)	4.81 (1.17)	4.60 (1.18)	4.66 (1.33)	< 0.001
Paternal education (on a scale 1–6)[a]	4.55 (1.43)	4.49 (1.36)	4.23 (1.46)	4.33 (1.51)	< 0.001
Family income[b]	690.03 (241.90)	679.67 (250.15)	658.88 (241.01)	613.71 (276.00)	< 0.001
Number of siblings at birth	0.75 (0.76)	0.67 (0.80)	0.71 (0.80)	0.72 (0.89)	0.682

Note:
[a]Maternal/paternal education scale: 1 = 9-year elementary, 2 = further education 1–2 years, 3 = further education vocational, 4 = further education, 3 years (general studies), 5 = higher education (university/college) up to and including 4 years, 6 = higher education (university/college) over 4 years
[b]Family income = mean income in 1000 NOK for mother and father combined

TABLE C1 Descriptives and histogram of CELF-4 core language index score

N	Valid	507
	Missing	2
Mean		9725
Standard deviation		1498
Skewness		-278
Standard error of skewness		108
Kurtosis		10
Standard error of kurtosis		217
Minimum		52
Maximum		137

Note: CELF, core language index score.

Table B1
Table C1
Table D1
Table E1

TABLE D1 Descriptive statistics for cognitive measures shown for the whole sample, non-LD, mild LD and Severe LD

Test	Whole sample ($N = 507$) Mean (SD)	Non-LD ($N = 400$) Mean (SD)	Mild LD ($N = 82$) Mean (SD)	Severe LI ($N = 25$) Mean (SD)
WASI Similarities	47.80 (9.38)	49.91 (8.10)	41.88 (9.40)	33.40 (8.01)
WASI Vocabulary	43.71 (8.84)	45.72 (8.05)	37.72 (6.16)	30.84 (6.36)
NEPSY Non-Word Repetition	35.55 (4.41)	36.46 (3.81)	32.52 (4.52)	30.57 (5.58)
CELF Rapid Automatized Naming[a]	96.67 (28.72)	93.92 (28.34)	105.79 (25.66)	114.74 (35.19)
CELF Backward Digit Span	9.75 (2.10)	10.05 (2.06)	8.87 (1.85)	7.92 (1.89)
CELF Familiar Sequences	10.78 (2.94)	11.48 (2.57)	8.71 (2.56)	6.36 (2.52)
WASI Block Design	55.31 (11.21)	57.28 (10.78)	48.51 (8.54)	44.36 (9.75)
WASI Matrix Reasoning	50.84 (10.47)	52.77 (9.93)	44.77 (8.91)	39.08 (8.13)
Knox Cube	7.03 (3.04)	7.42 (3.02)	5.87 (2.64)	4.50 (2.60)

Note:
[a]A longer time indicates a poor score.

TABLE E1 Hierarchical multiple regression predicting language abilities from cognitive factors (with verbal cognition in the last step)

Variable	β	t	R^2	ΔR^2	F for ΔR^2
Step 1			0.046	0.046	12.14, $p < 0.001$
Gender	0.13	2.95, $p = 0.003$			
Maternal education	0.17	3.90, $p < 0.001$			
Step 2			0.281	0.239	167.71, $p < 0.001$
Gender	0.14	3.74, $p < 0.001$			
Maternal education	0.11	2.98, $p = 0.003$			
Non-verbal cognition	0.49	12.95, $p < 0.001$			
Step 3			0.334	0.054	40.84, $p < 0.001$
Gender	0.13	3.65, $p < 0.001$			
Maternal education	0.09	2.52, $p = 0.012$			
Non-verbal cognition	0.43	11.29, $p < 0.001$			
Processing speed and memory	0.24	6.39, $p < 0.001$			
Step 4			0.554	0.220	24883 $p < 0.001$
Gender	0.10	3.46, $p = 0.001$			
Maternal education	0.04	1.26, $p = 0.207$			
Non-verbal cognition	0.26	7.84, $p < 0.001$			
Processing speed and memory	0.16	5.06, $p < 0.001$			
Verbal cognition	0.52	5.77, $p < 0.001$			