

# Language and Reading Abilities of Children With Autism Spectrum Disorders and Specific Language Impairment and Their First-Degree Relatives

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Autism spectrum disorder (ASD) and specific language impairment (SLI) are developmental disorders exhibiting language deficits, but it is unclear whether they arise from similar etiologies. Language impairments have been described in family members of children with ASD and SLI, but few studies have quantified them. In this study, we examined IQ, language, and reading abilities of ASD and SLI children and their first-degree relatives to address whether the language difficulties observed in some children with ASD are familial and to better understand the degree of overlap between these disorders and their broader phenotypes. Participants were 52 autistic children, 36 children with SLI, their siblings, and their parents. The ASD group was divided into those with (ALI,  $n = 32$ ) and without (ALN,  $n = 20$ ) language impairment. Relationships between ASD severity and language performance were also examined in the ASD probands. ALI and SLI probands performed similarly on most measures while ALN probands scored higher. ALN and ALI probands' language scores were not related to Autism Diagnostic Interview—Revised and Autism Diagnostic Observation Schedule algorithm scores. SLI relatives scored lowest on all measures, and while scores were not in the impaired range, relatives of ALI children scored lower than relatives of ALN children on some measures, though not those showing highest heritability in SLI. Given that ALI relatives performed better than SLI relatives across the language measures, the hypothesis that ALI and SLI families share similar genetic loading for language is not strongly supported.

**Keywords:** autism spectrum disorder; specific language impairment; parents; siblings; broader phenotype; genetics; language; reading

## Introduction

There is a long-standing debate in the literature about the extent of overlap between the language phenotypes of autism spectrum disorder (ASD) and specific language impairment (SLI) and whether these deficits arise from similar genetic bases [for a review, see Williams, Botting, & Boucher, 2008]. Studies have attempted to address this issue by investigating language abilities in first-degree relatives. Atypical language, or a broader language phenotype, has been described in family members of individuals with ASD and SLI, but few studies have quantified these deficits using standardized language measures, particularly those assessing structural aspects of language. Such studies are necessary to test the specificity of the language phenotypes in ASD and SLI as well as identify which aspects may be genetically mediated.

## *Overlap Between ASD and SLI*

Autism and SLI are two developmental disorders that share language as a deficit. In both disorders, concerns are typically raised during the toddler years [Dahlgren & Gillberg, 1989; Tager-Flusberg & Cooper, 1999]. Autism and SLI are both considered as spectrum disorders [Bishop, 1989; Gillberg & Coleman, 2000; Resnick & Rapin, 1991], and this is supported by the considerable heterogeneity in language abilities observed in affected individuals [Tager-Flusberg, Paul, & Lord, 2005; Tomblin & Zhang, 1999]. There is also evidence that genes play a significant role in these disorders. Several studies have supported this hypothesis in autism [for reviews, see Beshalova & Buxbaum, 2003; Folstein & Rosen-Sheidley, 2001], and a strong genetic basis of SLI is supported by significant differences in the concordance rates for monozygotic vs. dizygotic twins [Bishop, North, &

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Donlan, 1995; Lewis & Thompson, 1992; Tomblin & Buckwalter, 1998]. Segregation analyses provide strong evidence of familial transmission of SLI [Lewis, Cox, & Byard, 1993; Tomblin & Zhang, 1999], and several studies have described an increased prevalence of language delay and language-based learning deficits in the parents and siblings of autistic individuals [Bailey, Palferman, Heavey, & Le Couteur, 1998; Bolton et al., 1994; Fombonne, Bolton, Prior, Jordan, & Rutter, 1997; Piven, Palmer, Jacobi, Childress, & Arndt, 1997]. This relationship may be bi-directional, and siblings of children with SLI may also be at a higher risk of developing autism. A study by Tomblin, Hafeman, and O'Brien [2003] found that although there were no significant group differences in autism risk to siblings when SLI and control groups were defined categorically, when language was treated as a continuous variable, siblings of children who had poor spoken language skills in kindergarten were at higher risk for autism. Similarly, although Rapin [1996a] described higher rates of autism in siblings of high- and low-functioning children with autism, the rate of autism in siblings of SLI children was higher than that in siblings of non-autistic children with low IQs. Finally, some genetic studies have described overlap in genetic loci implicated in autism and SLI [for an ASD review, see Abrahams & Geschwind, 2008; Alarcon et al., 2008; Arking et al., 2008; Bakkaloglu et al., 2008; O'Brien, Zhang, Nishimura, Tomblin, & Murray, 2003; Vernes et al., 2008; Warburton et al., 2000]. Of particular interest is the recent study by Vernes et al. [2008] that identified a candidate gene for SLI showing significant associations with non-word repetition performance. This gene, CNTNAP2, has also been implicated in ASD [Alarcon et al., 2008; Arking et al., 2008; Bakkaloglu et al., 2008], especially in individuals who experienced language delay [Alarcon et al., 2008]. These findings support the view that there is at least one gene contributing to the common language phenotype observed in these disorders.

Despite these similarities, there are differences between autism and SLI. Autism is defined by qualitative impairments in three realms by the age of three: social interaction, communication, and a restricted repertoire of activities and interests [American Psychiatric Association, 1994]. SLI is characterized by delayed onset and slowed acquisition of language as compared to other areas of development [Tager-Flusberg & Cooper, 1999], but according to *Diagnostic and Statistical Manual of Mental Disorders—Fourth Edition* [American Psychiatric Association, 1994], individuals cannot meet criteria for autism and receive a diagnosis of SLI. There are also differences in the types of language difficulties observed in these disorders. In autism, some individuals express a developmental regression, especially in language, with one study citing rates as high as 33% [Goldberg et al., 2003], while this trajectory is absent in individuals with

SLI [Rapin, 1996b]. Furthermore, individuals with autism may exhibit other language characteristics, such as echolalia and pronoun reversal, that are not often described in SLI [e.g., Bartak, Rutter, & Cox, 1975, 1977].

There have been several studies investigating overlap between language phenotypes in autism and SLI. Bartak et al. [1975, 1977] completed the first studies to directly investigate this relationship. The authors found that although autistic children scored significantly lower on measures of language comprehension, the groups exhibited similar deficits in expressive language and language production. In another study by Kjelgaard and Tager-Flusberg [2001], a large group of children with autism was tested on a variety of standardized language measures, including the Clinical Evaluation of Language Fundamentals—Third Edition (CELF-III) and a non-word repetition test. The authors found that, as a group, children with autism performed one standard deviation or more below the mean in total language ability as measured by the CELF-III and on non-word repetition. However, when the group was subdivided based on total language ability on the CELF-III into normal, borderline, or impaired language ability, only the borderline and impaired groups (about 75% of the total sample) scored significantly below the mean on non-word repetition. These children exhibited language profiles of grammar, vocabulary, and phonological processing similar to children with SLI. A follow-up study found that children with autism and language impairment made grammatical tense marking errors that were similar to those of children with SLI [Roberts, Rice, & Tager-Flusberg, 2004], further supporting the hypothesis of overlap between these groups. Finally, a recent study by Whitehouse, Barry, and Bishop [2008] was the first to directly compare children with autism and SLI on non-word repetition performance. The authors found that those children with autism and normal structural language (ALN) scored higher than both the SLI group and the group of autistic children with poor structural language (ALI). Further analyses of group differences in non-word repetition performance and its relation to syllable length in those children who performed poorly on this test (SLI,  $n = 18$ ; ALI,  $n = 8$ ) found similar rates of error on words two or three syllables in length but significantly poorer performance on five-syllable words in the SLI group; however, given the small sample size and number of observations for each syllable length (three trials each for two to four syllables and four trials for five syllables), the latter analyses require further investigation.

The diagnostic boundaries between autism and SLI have also been questioned. In the early studies by Bartak et al. [1975, 1977], about 10% of the original SLI sample displayed some autistic characteristics. When the children from these studies were then followed into middle childhood [Cantwell, Baker, Rutter, & Mawhood, 1989]

and later into adulthood [Howlin, Mawhood, & Rutter, 2000; Mawhood, Howlin, & Rutter, 2000], the authors noted that some of the SLI individuals had developed social and behavioral impairments similar to those observed in the autism group. A recent study also noted poorer quality of friendships in adolescents with SLI [Durkin & Conti-Ramsden, 2007]. Bishop and Norbury [2002] found that some children with either SLI or pragmatic language impairment, as defined by the Children's Communication Checklist [Bishop, 1998], scored above cutoff on two of the three domains of the Autism Diagnostic Interview—Revised (ADI-R) or met criteria for autistic disorder on this measure. There was, however, also a group of children that failed to exhibit clear autistic symptoms outside of the communication domain. In a similar study by Conti-Ramsden, Simkin, and Botting [2006], 14-year-old children with a history of SLI were evaluated on a variety of diagnostic measures, including the ADI-R, the Autism Diagnostic Observation Schedule (ADOS), and the Family History Interview. The prevalence of ASD in this group was higher than that of the general population, and a number of children exhibited milder autistic behaviors on these measures. More recently, a study by Bishop, Whitehouse, Watt, and Line [2008] investigating the hypothesis of diagnostic substitution in autism found that in their sample of 38 individuals who had previously been diagnosed with language disorder in childhood, 13 met criteria for ASD on both the ADI-R and ADOS in adulthood. This study raises the question of whether SLI individuals in previous studies truly developed autistic symptoms later in life or whether they were misdiagnosed in childhood. These results highlight the possible continuity between autism and SLI and the lack of clear boundaries between these heterogeneous disorders.

#### *Language Characteristics of Relatives of Individuals With Autism and Individuals With SLI*

Family studies have noted language impairments in first-degree relatives of children with SLI and children with ASD, supporting a genetic basis for these deficits. Using family history questionnaires, several studies have described higher rates of language impairments in parents and siblings of SLI children when compared to relatives of typically developing children [Lahey & Edwards, 1995; Neils & Aram, 1986; Rice, Haney, & Wexler, 1998; Tallal, Ross, & Curtiss, 1989; Tomblin, 1989; van der Lely & Stollwerck, 1996]. As many as 60% of children with SLI have at least one additional family member with language impairments [Lahey & Edwards, 1995], although it is unclear whether the occurrence rates vary depending on the relationship of the family member to the proband [Rice, Wexler, & Cleave, 1995; Tomblin, 1989]. Family studies of children with autism have also

noted similar features, or a “broader phenotype,” in first-degree relatives, including impairments in language functioning. Studies of twins discordant for autism have reported language difficulties in the non-affected twins [Folstein & Rutter, 1977; Le Couteur et al., 1996]. Using family history data, higher rates of communication deficits have been identified in relatives of children with autism when compared to relatives of children with Down syndrome [Bolton et al., 1994; Piven, Palmer, Jacobi et al., 1997]. These deficits were also greater in biological vs. non-biological relatives of children with autism [Szatmari et al., 2000], further supporting the hypothesis that the communication impairments observed in autism and in the broader phenotype have a shared genetic basis.

Studies in family members of children with ASD and SLI have mainly focused on two types of language deficits: those in pragmatic language, or the social use of language, and those in structural language, such as phonology, grammar, and vocabulary difficulties. Pragmatic language deficits are consistently described as part of the ASD broader phenotype. Studies using questionnaires, such as the Autism Spectrum Quotient [Bishop, Maybery, Maley et al., 2004] or the Children's Communication Checklist [Bishop, Maybery, Wong, Maley, & Hallmayer, 2006], have demonstrated clear communication deficits in some parents and siblings of children with ASD when compared to family members of typically developing children. Higher rates of poor narrative performance [Landa, Folstein, & Isaacs, 1991] and pragmatic language impairments [Landa et al., 1992; Piven, Palmer, Landa et al., 1997] have also been identified in parents of children with ASD when compared to parents of typically developing children or children with Down syndrome. More recently, Ruser et al. [2007] noted these communication deficits on a modified version of the Pragmatic Rating Scale in both parents of children with autism and parents of children with SLI when compared to parents of children with Down syndrome. Together, these findings suggest that pragmatic deficits are evident in a subset of first-degree relatives of both children with autism and children with SLI and that they may contribute to the broader phenotypes associated with these disorders. Of note, however, one study using the Autism Spectrum Quotient failed to identify impairments in social communication in parents of children with SLI [Whitehouse, Barry, & Bishop, 2007].

Studies assessing structural language abilities in parents and siblings of individuals with SLI have described clinically impaired performance in some relatives on standardized measures with rates ranging from 21 to 63% [Conti-Ramsden, Simkin, & Pickles, 2006; Plante, Shenkman, & Clark, 1996; Tomblin & Buckwalter, 1998]. Similar deficits have also been found in phonological

processing, including poor performance on a non-word repetition task [Barry, Yasin, & Bishop, 2007; Bishop et al., 1999; Bishop, North, & Donlan, 1996]. Studies evaluating structural language in relatives of autistic individuals, however, have produced mixed results. Folstein et al. [1999] found higher rates of early language difficulties and poorer performance on a nonsense word reading task in parents, but not siblings, of children with autism vs. relatives of children with Down syndrome. Among the relatives of children with autism, parents and siblings with a history of language impairment performed more poorly than family members without a positive history on tests of verbal intelligence, reading, spelling, and nonsense word reading. Similarly, Bishop et al. [2006] described abnormalities in structural language in some siblings of children with autism, suggesting that the broader phenotype of autism may overlap with SLI. Another study described poorer phonological processing, reading, writing, and vocabulary abilities in brothers, but not mothers, fathers, or sisters, of autistic females when compared to relatives of individuals with Down Syndrome [Plumet, Goldblum, & Leboyer, 1995]. Other studies, though, have suggested that structural language deficits may not be part of the broader autism phenotype. Pilowsky, Yirmiya, Shalev, and Gross-Tsur [2003] investigated language abilities of siblings of children with autism, children with SLI, and children with mental retardation and found no differences between the groups on a variety of language abilities, including verbal intelligence, receptive and expressive language, and reading, writing, and spelling performance. Another study failed to identify phonological processing deficits in first-degree relatives of children with autism on non-word repetition and nonsense word reading tests [Bishop, Maybery, Wong et al., 2004]. Similarly, a recent comparison of parents of children with autism, children with SLI, and typically developing children on various language measures found no evidence of overlap between the broader phenotypes of the autism and SLI groups [Whitehouse et al., 2007]. This absence of overlap remained even after the parents of children with autism were divided based on the proband's performance on a non-word repetition task, although the sample of parents of children with autism and language impairments was small ( $n = 9$ ). To explain the existence of linguistic deficits in autism but not in the first-degree relatives, the authors hypothesized that these deficits are not heritable but rather a consequence of the ASD phenotype and its effect on language development.

Given that only a subset of children with ASD exhibits language profiles that overlap with those of children with SLI [Kjelgaard & Tager-Flusberg, 2001; Tager-Flusberg & Joseph, 2003], these studies [Bishop, Maybery, Wong et al., 2004; Pilowsky et al., 2003; Whitehouse et al., 2007] may have found no overlap between the broader

phenotypes of these disorders because they combined samples of relatives of autistic children with and without language impairment. One of these studies attempted to investigate this in parents of autistic children but had small sample sizes, characterized language impairment in the proband using only one measure, and only included relatives of higher-functioning children [Whitehouse et al., 2007]. In addition, the majority of studies on the broader phenotype in autism investigated either parents or siblings. Only one study included probands, siblings, and parents, but it was limited to comparisons of families with children with autism to those with typically developing children and only focused on deficits in phonological processing [Bishop, Maybery, Wong et al., 2004].

In the current study, we included families of autistic children without language impairment (ALN), families of autistic children with language impairment (ALI), and families of children with SLI. We studied the proband, both parents, and the sibling closest in age to the proband in each family. All probands were thoroughly assessed to confirm diagnoses, and SLI probands who exhibited autistic symptoms (i.e., met diagnostic cutoffs for social impairments or the presence of stereotyped or repetitive behaviors) were excluded from the sample. Language impairment was defined with tests that detect clinically significant language impairments in older children [Bishop et al., 1996; Conti-Ramsden, 2003; Conti-Ramsden, Botting, & Faragher, 2001; for a review, see Coady & Evans, 2008], demonstrate heritability in SLI [Barry et al., 2007; Bishop et al., 1996, 1999], and are highly sensitive in identifying language impairment in children with autism [Kjelgaard & Tager-Flusberg, 2001]. To address whether the linguistic deficits observed in ASD are secondary to the ASD phenotype, as suggested by Whitehouse et al. [2007], we investigated the relationship between performance on language and non-word repetition tests and scores on the algorithm domains of the ADI-R and ADOS. Group comparisons were also made on a wide variety of measures, including assessments of intelligence, receptive and expressive language, phonological processing, lexical comprehension, and reading ability, in probands, siblings, mothers, and fathers from these families. We hypothesized that ALN probands and family members would perform better than ALI and SLI families on these measures and that ALI and SLI probands and family members would perform similarly. Such findings would provide strong support for the view that the language impairments in ALI and SLI are based on the same etiology. Impaired performance in relatives of ALI children vs. relatives of ALN children would suggest that the language difficulties observed in these children are familial, whereas comparable performance would suggest that these language difficulties are not part of the broader ASD phenotype.

## Methods

### Participants

Two groups of families were recruited for this study: families with children with ASD ( $N = 52$ ) and families with a child with SLI ( $N = 36$ ). The ASD families were then divided into two groups: families with a child with ASD without language impairment (ALN;  $n = 20$ ) and families with a child with ASD and language impairment (ALI;  $n = 32$ ). We studied the probands, the sibling closest in age to the proband, and both parents (Table I). All probands had verbal IQ scores higher than 50 as measured by the Wechsler Intelligence Scale for Children—Third Edition (WISC-III) [Wechsler, 1991], and probands and siblings were between the ages of 6 and 16 years. All first-degree relatives were screened using a structured family and personal history interview to exclude individuals meeting criteria for ASD. Participants in the study were required to speak standard English as their first language.

Two sites participated in this study: Tufts-New England Medical Center and the University of Iowa. SLI families from the Iowa site were recruited from a longitudinal cohort [see Tomblin, Zhang, Buckwalter, & Catts, 2000] that had been sampled from a cross-sectional population sample of kindergarten children [Tomblin et al., 1997]. To avoid bias toward ascertaining SLI families who were concerned that their child may have symptoms of autism, SLI families at the Boston site were recruited through classes and services specifically for children with language impairment or language-based learning disorders. Recruitment of the ASD families was carried out through services for children with autism and Asperger syndrome at both the Iowa and Boston sites. After recruitment, as part of the consent process, the families were notified that the purpose of the study was to investigate inherited contributions to both autism and SLI, and they understood that once enrolled in the study the children would be assessed both for autism and SLI.

Table I summarizes the characteristics and group differences for all groups. Group comparisons for age were

**Table I. Participant Characteristics**

	Proband diagnosis			Results	F or $\chi^2$	P
	ALN	ALI	SLI			
Probands (ALN = 20, ALI = 32, SLI = 36)						
Chronological age (yr)	10.3 ± 2.6	10.4 ± 2.6	11.6 ± 1.6	No differences	$F_{2, 85} = 3.13$	0.05
Parental education sum <sup>a</sup>	12.5 ± 1.0	10.5 ± 1.2	9.4 ± 1.4	ALN > ALI > SLI	Overall: $\chi^2 = 59.78$	< 0.0001
					ALN vs. ALI: $\chi^2 = 25.22$	0.0003
					ALN vs. SLI: $\chi^2 = 34.32$	< 0.0001
					ALI vs. SLI: $\chi^2 = 16.14$	0.0065
Gender	18M/2F	28M/4F	17M/19F	SLI > ALI = ALN (proportion of females)	Overall: $\chi^2 = 17.83$	0.0001
					ALN vs. ALI: $\chi^2 = 0.08$	0.78
					ALN vs. SLI: $\chi^2 = 10.04$	0.0015
					ALI vs. SLI: $\chi^2 = 12.28$	0.0005
Siblings (ALN = 19, ALI = 31, SLI = 36)						
Chronological age (yr)	10.7 ± 3.3	9.6 ± 2.2	11.8 ± 2.3	SLI > ALI, ALN = ALI, ALN = SLI	$F_{2, 83} = 6.92$	0.0017
Gender	10M/9F	16M/15F	15M/21F	No differences	$\chi^2 = 0.90$	0.64
Mothers (ALN = 20, ALI = 31, SLI = 35)						
Chronological age (yr)	42.4 ± 4.1	40.1 ± 3.8	38.8 ± 5.3	ALN > SLI, ALN = ALI, ALI = SLI	$F_{2, 83} = 3.96$	0.023
Education <sup>a</sup>	6.0 ± 0.8	5.4 ± 0.8	4.8 ± 0.8	ALN = ALI > SLI	Overall: $\chi^2 = 29.13$	0.0001
					ALN vs. ALI: $\chi^2 = 7.58$	0.11
					ALN vs. SLI: $\chi^2 = 20.28$	0.0004
					ALI vs. SLI: $\chi^2 = 9.89$	0.042
Fathers (ALN = 19, ALI = 31, SLI = 35)						
Chronological age (yr)	43.7 ± 5.1	42.0 ± 4.2	39.7 ± 5.4	ALN > SLI, ALN = ALI, ALI = SLI	$F_{2, 82} = 4.22$	0.018
Education <sup>a</sup>	6.5 ± 0.5	5.2 ± 1.0	4.6 ± 1.0	ALN > ALI = SLI	Overall: $\chi^2 = 45.15$	< 0.0001
					ALN vs. ALI: $\chi^2 = 22.23$	0.0002
					ALN vs. SLI: $\chi^2 = 35.92$	< 0.0001
					ALI vs. SLI: $\chi^2 = 6.99$	0.14

SLI, specific language impairment.

<sup>a</sup>Education based on the seven-point Hollingshead scale. Higher values indicate higher education levels.

tested using one-way analyses of variance (ANOVAs), and post hoc comparisons were made using Tukey–Kramer honestly significant difference (HST) tests. Comparisons for gender distribution and parental education, as measured using the Hollingshead scale [Hollingshead, 1965], were tested using Pearson  $\chi^2$  tests.

### *Diagnosis of Autism in the Proband*

All the ASD probands met criteria for ASD on the basis of clinical impression, and diagnoses were confirmed using the ADI-R [Lord, Rutter, & Le Couteur, 1994] and the Autistic Diagnostic Observation Schedule—Generic (ADOS-G) [Lord et al., 2000]. Thirty-seven probands met criteria for autism on both the ADI-R and the ADOS-G. Seven probands met criteria for autism on the ADI-R and criteria for ASD on the ADOS-G. Four probands met criteria for autism on the ADI-R but did not meet criteria for ASD on the ADOS-G. Four probands met criteria for ASD on the ADOS-G and met criteria for autism on either social or communication on the ADI-R and scored within two points on the other domain. Based on these scores, all of the probands met criteria for either autism or ASD as defined by the Collaborative Programs of Excellence in Autism (<http://www.autismresearchnetwork.org>) [Lainhart et al., 2006].

Proband screening for the following exclusionary criteria: known genetic disorders (e.g., fragile X, Rett's syndrome, tuberous sclerosis, neurofibromatosis, cerebral palsy, and phenylketonuria), deafness, frank neurological damage, and major physical abnormalities.

SLI probands were screened for autistic symptoms using the ADI-R and ADOS-G. None of the SLI probands included in the study met criteria for autism or ASD on the social or repetitive behavior domains of either measure. Ranges (and medians) for these domains in the included SLI sample were 0–9 (and 2) for ADI reciprocal social interaction, 0–2 (and 0) for ADI repetitive behaviors and stereotyped patterns, and 0–3 (and 0) for ADOS social interaction. Fourteen children with SLI that were originally recruited for this study were excluded from the SLI group. Six met criteria for either ASD or autism on the ADOS but did not meet criteria for autism on the ADI-R. Three met criteria for autism or ASD on the social domain of both the ADI-R and the ADOS, four only met criteria for autism on the social domain of the ADI-R, and seven only met criteria for ASD on the social domain of the ADOS. These diagnostic findings are further addressed in another article [Leyfer, Tager-Flusberg, Dowd, Tomblin, & Folstein, 2008]. SLI probands were not excluded for meeting criteria for autism or ASD on the communication domain of the ADI-R or ADOS.

### *Diagnosis of Language Impairment*

Diagnosis of language impairment (ALI and SLI groups) was made if the proband had a positive history of

language delay and/or deficits and met at least one of the following criteria: (1) a standard score lower than one standard deviation below the mean (standard score <85) for total language ability on the CELF-III [Semel, Wiig, & Secord, 1995] or (2) a standard score lower than one standard deviation below the mean (standard score <7) on the non-word repetition subtest of the Comprehensive Test of Phonological Processing [CTOPP; Wagner, Torgesen, & Rashotte, 1999]. Deficits on these tests contribute to the defining phenotype of SLI [Tager-Flusberg & Cooper, 1999] and have been identified as good clinical markers for this disorder [Conti-Ramsden, 2003; Conti-Ramsden et al., 2001; for a review, see Coady & Evans, 2008]. In the ALI proband group, 8 met criteria for language impairment on both tests, 5 met criteria only on non-word repetition, and 16 met criteria only on total language ability. Three ALI probands met criteria on non-word repetition but did not have total language ability scores. In the SLI proband group, 16 met criteria on both tests, 3 met criteria only on non-word repetition, and 17 met criteria only on total language ability. Of note, 6/19 ALN probands and 25/32 ALI probands exhibited delays in language acquisition as defined by the late onset of first words or phrases on the ADI-R (data were not available for one ALN proband).

### *Procedures*

**IQ tests.** Four subtests of the Wechsler Intelligence Scales were administered to participants to assess the intellectual ability [Wechsler, 1991, 1997]. The *WISC-III* was administered to probands and siblings, and the *Wechsler Adult Intelligence Scale—Third Edition* was administered to parents. Z-scores for verbal IQ were calculated using an algorithm based on Vocabulary and Similarities standard scores ((Similarities+Vocabulary–20)/5.564), and z-scores for performance IQ were calculated using an algorithm based on Picture Arrangement and Block Design standard scores ((Picture Arrangement+Block Design–20)/5.144). Z-scores for full-scale IQ were calculated using an algorithm based on the standard scores from the four subtests mentioned above ((Similarities+Vocabulary+Picture Arrangement+Block Design–40)/9.469). The three z-scores (verbal, performance, and full-scale IQ) were converted to standard scores using the following formula:  $100+15(z\text{-score})$  [Ruser et al., 2007].

**Language assessment.** The CELF-III [Semel et al., 1995] was administered to probands and siblings. The CELF-III is a measure designed to evaluate semantics, morphology, syntax, and memory for language. Z-scores for receptive language were calculated using an algorithm based on standard scores from Concepts and Directions (CD, all ages), Sentence Structure (SS, ages 6–8), and Word Classes (WC, ages 9–16). Receptive language z-scores were  $(SS+CD-20)/5.109$  for children aged 6–8 and  $(WC+CD-20)/5.265$  for children aged 9–16. Z-scores for

expressive language were calculated using an algorithm based on standard scores from Recalling Sentences (RS, all ages), Word Structure (WS, ages 6–8), and Formulated Sentences (FS, ages 9–16). Expressive language z-scores were  $(RS+WS-20)/5.213$  for children aged 6–8 and  $(RS+FS-20)/5.126$  for children aged 9–16. Z-scores for total language ability were calculated using an algorithm based on standard scores from the four age-appropriate subtests described above. Total language z-scores were  $(SS+CD+RS+WS-40)/9.468$  for children aged 6–8 and  $(WC+CD+RS+FS-40)/9.353$  for children aged 9–16. The three z-scores (receptive, expressive, and total language) were converted to standard scores using the following formula:  $100+15(z\text{-score})$ . Norms are available for the subtests and composite scores for individuals aged 6–21 years.

The CTOPP [Wagner et al., 1999] was administered to all participants. The CTOPP assesses phonological processing in three realms: phonological awareness, phonological memory, and rapid naming. Phonological awareness is a measure of one's ability to recognize and use the sound structure of oral language. Phonological memory is an assessment of one's ability to code information and store it in working memory. Rapid naming examines one's ability to efficiently retrieve phonological information from long-term memory. There are two versions of the test, one for children aged 5–6 and the other for individuals aged 7 to adulthood. The former contains seven core subtests, while the latter contains only six. All of the core subtests were administered, and the composites were calculated as documented in the examiner's manual. Norms are available for the subtests and composite scores.

In addition to the composite scores, the non-word repetition subtest of the CTOPP was used as a language measure. This subtest is designed to evaluate one's ability to repeat non-words ranging in length from 3 to 15 sounds and is a good measure of phonological memory. Non-words are composed of random phonemes and follow rules of standard English phonology and stress patterns; however, these non-words are intentionally designed to be dissimilar to existing English words to discourage the use of other strategies besides phonological memory.

The *Peabody Picture Vocabulary Test—Third Edition* [PPVT-III; Dunn & Dunn, 1997] was administered to all participants. The PPVT-III measures lexical comprehension by asking subjects to select one of four pictures based on the word stated by the examiner. Norms are available for ages 2;6 through adulthood.

The *Woodcock–Johnson Psycho-Educational Battery—Revised* [WJ-R; Woodcock & Johnson, 1990] was administered to all participants. The WJ-R is a comprehensive battery used to measure a wide range of reading abilities. Participants were administered three standard subtests (letter–word identification, passage comprehension, and dictation) and one supplemental subtest (word attack).

Two composite scores were also calculated as documented in the examiner's manual: basic reading, which is based on the performance on letter–word identification and word attack, and broad reading, which is based on letter–word identification and passage comprehension. Norms are available for ages 2;0 through adulthood for the subtests and composite scores.

Testing was usually conducted in 1 day with ample opportunity for breaks but if necessary was conducted over two sessions. All data were analyzed with JMP 7.0 [SAS Institute Inc., 2007].

#### *Data Analysis*

Between-group differences in the proband groups were assessed using one-way ANOVAs for all measures. Between-group differences in siblings for CELF-III receptive, expressive, and total language ability scores were also assessed using one-way ANOVAs. Between-group differences in family members for IQ, PPVT, CTOPP, and WJ-R were assessed using a mixed effects model with score as the dependent variable, group as the between-subjects factor (family identifier nested within it as a random effect), and relationship to proband and relationship to proband-by-group as fixed effects. Post hoc comparisons for all analyses were made using Tukey–Kramer HSD with adjustments for multiple comparisons within the model.

#### *Proportion of First-Degree Relatives Performing in the Normal and Language-Impaired Range*

Family members were categorized into language-normal and language-impaired based on the same criteria described above for an ALN or ALI diagnosis on the CELF-III (mothers, fathers, and siblings) and non-word repetition (siblings only). Between-group differences in the number of first-degree relatives performing in the language-impaired and language-normal ranges were examined using Pearson  $\chi^2$  analyses. To examine whether the rate of impaired performance on these measures differed between brothers and sisters of children with ASD or SLI, we used a Pearson  $\chi^2$  analysis comparing the number of brothers and sisters categorized as language-normal and language-impaired for each diagnostic group.

#### *Relationship of Language Abilities to ASD Severity*

Relationships between total language ability (CELF-III) and non-word repetition (CTOPP) with algorithm scores on the ADI-R and ADOS were examined using pairwise correlations across the ALN and ALI groups. The algorithm domains included verbal communication, reciprocal social interaction, repetitive behaviors and stereotyped patterns, and a total sum (verbal communication+social interaction+repetitive behaviors and stereotyped patterns) on the ADI-R and communication, reciprocal social interaction, and a total sum

(communication+social interaction+imagination/creativity+stereotyped behaviors and repetitive interests) on the ADOS. Between-group differences on the total sums for both the ADI-R and ADOS were also examined using two-tailed Student's *t*-tests. Only those children who were administered a module 3 ADOS (ALN 16/20, ALI 25/32) were included in the ADOS analyses to control for differences in the number of algorithm items.

## Results

Group comparison data are summarized in Table II (IQ), Table III (CELF-III and PPVT), Table IV (CTOPP), and Table V (WJ-R).

### Group Comparisons—Probands

As expected based on our definition of the proband groups, ALI and SLI probands had comparable receptive, expressive, and total language scores on the CELF-III and non-word repetition scores, and both groups scored lower than ALN probands. ALI and SLI probands also performed similarly on verbal, performance, and full-scale IQ, lexical comprehension, phonological awareness and memory, broad reading, reading skill, dictation, and passage comprehension with scores in both groups lower than that of the ALN group. ALN probands scored similarly to ALI probands on rapid naming but better than SLI probands. There was no difference in rapid naming performance between ALI and SLI probands. Word attack scores were highest in the ALN probands and lowest in the SLI probands.

### Group Comparisons—Family Members

Performance was highest in ALN relatives and lowest in SLI relatives (i.e., ALN>ALI>SLI) on the following measures: verbal and full-scale IQ, receptive and total language ability, and all measures of reading ability. ALN and ALI relatives performed similarly but significantly higher than SLI relatives (i.e., ALN = ALI>SLI) on the following measures: performance IQ, expressive language, lexical comprehension, and all measures of phonological processing. For performance IQ, a significant group by relationship interaction was obtained. Scores for ALN and ALI siblings were similar to one another but significantly higher than the scores of the SLI siblings. ALN fathers scored higher than SLI fathers but there were no significant group differences between ALN and ALI fathers or ALI and SLI fathers, and no group differences for mothers of all three groups. There were significant main effects of relationship for non-word repetition, phonological awareness, dictation, and passage comprehension. For non-word repetition, mothers and fathers scored similarly but poorer than siblings across groups. For phonological awareness and dictation, siblings and mothers scored similarly but higher than fathers across groups. For passage comprehension, siblings scored higher than fathers, while there were no differences between siblings and mothers or mothers and fathers on this measure across groups.

### Proportion of First-Degree Relatives Performing in the Normal and Language-Impaired Range

Table VI displays the number and percentage of first-degree relatives that performed in the normal or

**Table II. Performance on WISC-III (Probands and Siblings) and WAIS-III (Parents)**

	Proband diagnosis			Results (proband and family)	<i>F</i>	<i>P</i>	$\eta_p^2$
	ALN	ALI	SLI				
<i>Full-scale IQ</i>							
Probands	113.0 ± 16.5	86.5 ± 19.2	85.4 ± 12.8	ALN > ALI = SLI	$F_{2, 84} = 20.71$	<0.0001	0.33
Siblings	120.7 ± 13.9	114.5 ± 12.5	93.4 ± 15.5*	ALN > ALI > SLI	Group: $F_{2, 85} = 36.51$	<0.0001	0.61
Mothers	117.6 ± 11.4	109.3 ± 12.9	96.7 ± 13.5*		Relation: $F_{2, 164} = 0.67$	0.51	0.01
Fathers	119.8 ± 11.0	109.5 ± 13.3	96.7 ± 12.7*		Group × Relation: $F_{4, 164} = 2.10$	0.08	0.05
<i>Verbal IQ</i>							
Probands	113.5 ± 15.5	85.1 ± 20.4	84.6 ± 12.2	ALN > ALI = SLI	$F_{2, 84} = 22.86$	<0.001	0.35
Siblings	117.4 ± 11.5	112.8 ± 12.0	93.8 ± 16.2*	ALN > ALI > SLI	Group: $F_{2, 85} = 42.22$	<0.0001	0.64
Mothers	119.8 ± 10.3	110.4 ± 12.3	93.9 ± 13.1*		Relation: $F_{2, 164} = 0.02$	0.98	0.0004
Fathers	120.3 ± 9.9	108.3 ± 13.7	96.0 ± 12.1*		Group × Relation: $F_{4, 164} = 1.28$	0.28	0.03
<i>Performance IQ</i>							
Probands	109.4 ± 20.4	91.3 ± 20.9	89.9 ± 14.6	ALN > ALI = SLI	$F_{2, 84} = 7.78$	0.0008	0.16
Siblings	119.3 ± 15.8	112.8 ± 16.8	94.7 ± 16.2*	ALN = ALI > SLI	Group: $F_{2, 85} = 17.98$	<0.0001	0.35
Mothers	110.9 ± 14.0	105.8 ± 13.3	100.5 ± 13.0*		Relation: $F_{2, 164} = 1.45$	0.24	0.02
Fathers	114.4 ± 13.1	108.4 ± 13.7	98.3 ± 14.0*		Group × Relation: $F_{4, 164} = 3.17$	0.015	0.07

The values with \* indicate analyses using a mixed effects model with score as the dependent variable, group as the between-subjects factor (family identifier nested within it as a random effect), and relationship to proband and relationship to proband-by-group as fixed effects. WISC-III, Wechsler Intelligence Scale for Children—Third Edition; WAIS-III, Wechsler Adult Intelligence Scale—Third Edition; SLI, specific language impairment.

**Table III. Performance on CELF-III and PPVT**

	Proband diagnosis			Results (probands and family)	<i>F</i>	<i>P</i>	$\eta_p^2$
	ALN	ALI	SLI				
<b>CELF-III</b>							
Total language <sup>a</sup>							
Probands	107.2 ± 15.0	72.0 ± 16.2	73.3 ± 9.5	ALN > ALI = SLI	$F_{2, 81} = 48.79$	< 0.0001	0.55
Siblings	115.6 ± 10.8	103.9 ± 13.5	89.3 ± 16.6	ALN > ALI > SLI	$F_{2, 81} = 21.86$	< 0.0001	0.35
Receptive language							
Probands	106.9 ± 15.1	76.6 ± 18.0	76.9 ± 9.0	ALN > ALI = SLI	$F_{2, 82} = 35.06$	< 0.0001	0.46
Siblings	116.4 ± 10.5	104.3 ± 13.3	92.0 ± 15.9	ALN > ALI > SLI	$F_{2, 81} = 19.69$	< 0.0001	0.33
Expressive language							
Probands	105.0 ± 16.0	72.5 ± 12.8	74.9 ± 10.0	ALN > ALI = SLI	$F_{2, 83} = 46.25$	< 0.0001	0.53
Siblings	111.8 ± 13.1	102.8 ± 13.7	88.8 ± 15.8	ALN = ALI > SLI	$F_{2, 81} = 17.13$	< 0.0001	0.30
<b>PPVT</b>							
Probands	111.1 ± 11.9	87.5 ± 17.4	91.5 ± 9.9	ALN > ALI = SLI	$F_{2, 84} = 20.30$	< 0.0001	0.33
Siblings	118.1 ± 12.0	113.5 ± 12.2	99.7 ± 12.0*	ALN = ALI > SLI	Group: $F_{2, 84} = 26.01$	< 0.0001	0.46
Mothers	111.1 ± 13.6	105.6 ± 12.5	95.7 ± 10.0*		Relation: $F_{2, 164} = 11.04$	< 0.0001	0.12
Fathers	112.4 ± 8.7	105.0 ± 9.8	97.8 ± 9.3*		Group × Relation: $F_{4, 164} = 1.11$	0.35	0.03

The values with \* indicate analyses using a mixed effects model with score as the dependent variable, group as the between-subjects factor (family identifier nested within it as a random effect), and relationship to proband and relationship to proband-by-group as fixed effects. CELF-III, Clinical Evaluation of Language Fundamentals—Third Edition; PPVT, Peabody Picture Vocabulary Test—Third Edition; SLI, specific language impairment.

<sup>a</sup>This measure was used for diagnosis of language impairment in ALI and SLI probands.

**Table IV. Performance on CTOPP**

	Proband diagnosis			Results (probands and family)	<i>F</i>	<i>P</i>	$\eta_p^2$
	ALN	ALI	SLI				
<i>Phonological awareness</i>							
Probands	107.4 ± 10.1	87.9 ± 17.6	82.3 ± 11.0	ALN > ALI = SLI	$F_{2, 84} = 21.59$	< 0.0001	0.34
Siblings	109.7 ± 12.1	101.3 ± 9.1	93.0 ± 15.5*	ALN = ALI > SLI	Group: $F_{2, 82} = 11.57$	< 0.0001	0.22
Mothers	105.5 ± 13.6	100.5 ± 12.4	93.4 ± 16.2*		Relation: $F_{2, 162} = 10.39$	< 0.0001	0.11
Fathers	99.5 ± 14.4	92.7 ± 16.8	86.5 ± 15.2*		Group × Relation: $F_{4, 162} = 0.28$	0.89	0.01
<i>Phonological memory</i>							
Probands	103.0 ± 8.7	82.1 ± 14.5	81.2 ± 10.3	ALN > ALI = SLI	$F_{2, 84} = 24.72$	< 0.0001	0.37
Siblings	106.2 ± 15.0	97.9 ± 10.4	90.9 ± 12.1*	ALN = ALI > SLI	Group: $F_{2, 81} = 18.13$	< 0.0001	0.31
Mothers	105.1 ± 7.3	97.5 ± 11.6	88.6 ± 13.3*		Relation: $F_{2, 160} = 0.61$	0.54	0.004
Fathers	100.6 ± 12.3	99.5 ± 12.8	88.4 ± 12.7*		Group × Relation: $F_{4, 160} = 1.00$	0.41	0.03
<i>Rapid naming</i>							
Probands	96.8 ± 19.0	81.8 ± 18.8	87.1 ± 19.7	ALN > SLI, ALN = ALI, ALI = SLI	$F_{2, 79} = 3.44$	0.04	0.08
Siblings	104.3 ± 14.2	102.9 ± 11.7	92.3 ± 15.4*	ALN = ALI > SLI	Group: $F_{2, 80} = 5.74$	0.0047	0.09
Mothers	100.6 ± 18.0	99.1 ± 14.5	93.4 ± 13.2*		Relation: $F_{2, 160} = 0.34$	0.71	0.002
Fathers	100.5 ± 17.7	100.8 ± 17.4	94.5 ± 16.8*		Group × Relation: $F_{4, 160} = 0.47$	0.76	0.01
<i>Non-word repetition<sup>a</sup></i>							
Probands	9.9 ± 1.6	7.0 ± 2.4	6.3 ± 1.6	ALN > ALI = SLI	$F_{2, 84} = 22.46$	< 0.0001	0.35
Siblings	10.1 ± 2.5	9.4 ± 2.0	7.4 ± 2.0*	ALN = ALI > SLI	Group: $F_{2, 80} = 20.00$	< 0.0001	0.30
Mothers	8.7 ± 1.6	7.8 ± 1.8	6.1 ± 2.2*		Relation: $F_{2, 160} = 17.09$	< 0.0001	0.16
Fathers	8.3 ± 2.2	7.6 ± 2.6	6.3 ± 1.7*		Group × Relation: $F_{4, 160} = 0.39$	0.82	0.01

The values with \* indicate analyses using a mixed effects model with score as the dependent variable, group as the between-subjects factor (family identifier nested within it as a random effect), and relationship to proband and relationship to proband-by-group as fixed effects. CTOPP, Comprehensive Test of Phonological Processing; SLI, specific language impairment.

<sup>a</sup>This measure was used for the diagnosis of language impairment in ALI and SLI probands.

language-impaired range on total language ability or non-word repetition.

There were significant group differences in the proportion of siblings, mothers, and fathers performing in the

language-impaired range on non-word repetition (mothers, fathers, and siblings) and CELF-III total language ability (siblings only). For siblings, this proportion was highest in the SLI group but was similar between

**Table V. Performance on WJ-R**

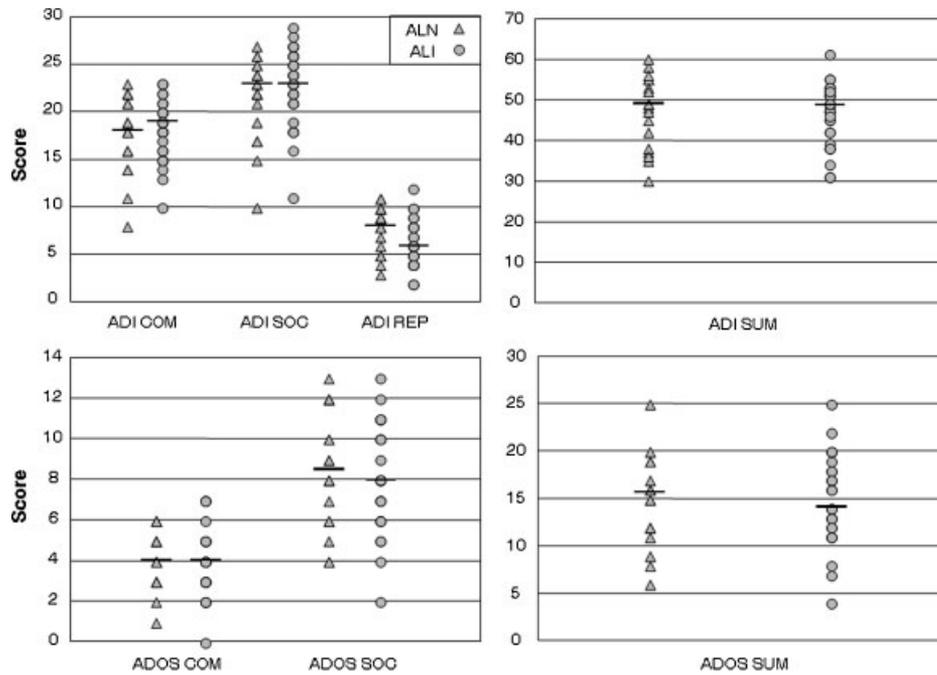
	Proband diagnosis			Results (probands and family)	F	P	$\eta_p^2$
	ALN	ALI	SLI				
<i>Broad reading composite</i>							
Probands	106.6 ± 15.0	91.6 ± 21.7	87.1 ± 9.9	ALN > ALI = SLI	$F_{2, 84} = 9.20$	0.0002	0.18
Siblings	122.5 ± 15.1	112.2 ± 13.9	98.8 ± 16.6*	ALN > ALI > SLI	Group: $F_{2, 83} = 37.71$	<0.0001	0.52
Mothers	120.5 ± 16.2	113.2 ± 14.3	95.1 ± 14.0*		Relation: $F_{2, 161} = 1.31$	0.27	0.01
Fathers	120.8 ± 11.1	109.1 ± 16.7	93.1 ± 13.8*		Group × Relation: $F_{4, 161} = 0.49$	0.74	0.01
<i>Reading skill composite</i>							
Probands	110.0 ± 17.3	93.8 ± 21.5	85.5 ± 12.3	ALN > ALI = SLI	$F_{2, 84} = 12.57$	<0.0001	0.23
Siblings	119.9 ± 15.0	110.1 ± 14.1	95.6 ± 17.6*	ALN > ALI > SLI	Group: $F_{2, 83} = 34.55$	<0.0001	0.51
Mothers	121.1 ± 15.9	114.6 ± 15.7	95.6 ± 14.6*		Relation: $F_{2, 162} = 0.88$	0.42	0.01
Fathers	119.9 ± 11.6	109.5 ± 16.5	93.3 ± 15.5*		Group × Relation: $F_{4, 162} = 0.43$	0.84	0.01
<i>Dictation</i>							
Probands	97.3 ± 13.0	84.8 ± 25.1	81.4 ± 7.5	ALN > ALI = SLI	$F_{2, 84} = 5.57$	0.005	0.12
Siblings	107.1 ± 13.0	99.1 ± 10.1	88.6 ± 13.1*	ALN > ALI > SLI	Group: $F_{2, 83} = 28.35$	<0.0001	0.45
Mothers	103.3 ± 11.7	99.4 ± 10.0	88.5 ± 11.5*		Relation: $F_{2, 162} = 7.06$	0.001	0.08
Fathers	101.5 ± 10.0	93.6 ± 12.8	82.8 ± 11.7*		Group × Relation: $F_{4, 162} = 0.43$	0.78	0.01
<i>Passage comprehension</i>							
Probands	107.1 ± 16.3	92.3 ± 21.2	90.3 ± 9.0	ALN > ALI = SLI	$F_{2, 84} = 7.38$	0.001	0.15
Siblings	122.7 ± 13.1	110.5 ± 14.6	101.1 ± 14.7*	ALN > ALI > SLI	Group: $F_{2, 83} = 28.37$	<0.0001	0.42
Mothers	118.8 ± 16.1	111.0 ± 14.9	95.3 ± 15.7*		Relation: $F_{2, 162} = 3.22$	0.04	0.04
Fathers	116.8 ± 12.3	107.3 ± 17.8	93.7 ± 16.1*		Group × Relation: $F_{4, 162} = 0.55$	0.70	0.02
<i>Word attack</i>							
Probands	112.8 ± 21.3	95.6 ± 19.9	84.4 ± 16.2	ALN > ALI > SLI	$F_{2, 84} = 14.31$	<0.0001	0.25
Siblings	117.8 ± 14.5	105.2 ± 13.1	92.9 ± 18.3*	ALN > ALI > SLI	Group: $F_{2, 83} = 24.13$	<0.0001	0.43
Mothers	119.3 ± 17.7	114.0 ± 16.5	96.4 ± 16.2*		Relation: $F_{2, 162} = 2.90$	0.06	0.03
Fathers	114.6 ± 11.4	107.3 ± 16.6	94.5 ± 16.9*		Group × Relation: $F_{4, 162} = 0.86$	0.49	0.02

The values with \* indicate analyses using a mixed effects model with score as the dependent variable, group as the between-subjects factor (family identifier nested within it as a random effect), and relationship to proband and relationship to proband-by-group as fixed effects. WJ-R, Woodcock–Johnson Psycho-Educational Battery—Revised; SLI, specific language impairment. Broad reading = letter–word identification and passage comprehension, basic reading = letter–word identification and word attack.

**Table VI. Proportion of First-Degree Relatives Performing in the Normal and Language-Impaired Range on CELF-III or Non-Word Repetition**

	Proband diagnosis			Results	$\chi^2$	P
	ALN	ALI	SLI			
<i>Siblings</i>						
LN	17 (8M/9F) (89%)	26 (12M/14F) (84%)	21 (8M/13F) (58%)	SLI > ALI = ALN	Overall: $\chi^2 = 8.61$	0.014
LI	2 (2M/0F) (11%)	5 (4M/1F) (16%)	15 (7M/8F) (42%)		ALN vs. ALI: $\chi^2 = 0.31$	0.58
					ALN vs. SLI: $\chi^2 = 5.65$	0.018
					ALI vs. SLI: $\chi^2 = 5.19$	0.022
					By gender (SLI): $\chi^2 = 0.26$	0.61
					By gender (ASD): $\chi^2 = 3.71$	0.054
<i>Mothers</i>						
LN	19 (95%)	22 (71%)	14 (40%)	SLI > ALI > ALN	Overall: $\chi^2 = 17.74$	0.0001
LI	1 (5%)	9 (29%)	21 (60%)		ALN vs. ALI: $\chi^2 = 4.45$	0.035
					ALN vs. SLI: $\chi^2 = 16.04$	<0.0001
					ALI vs. SLI: $\chi^2 = 6.36$	0.011
<i>Fathers</i>						
LN	15 (79%)	20 (65%)	16 (46%)	SLI > ALN, ALN = ALI, ALI = SLI	Overall: $\chi^2 = 6.08$	0.048
LI	4 (21%)	11 (35%)	19 (54%)		ALN vs. ALI: $\chi^2 = 1.17$	0.28
					ALN vs. SLI: $\chi^2 = 5.56$	0.018
					ALI vs. SLI: $\chi^2 = 2.34$	0.13

Number (and percentage) of first-degree relatives that performed in the language-impaired (LI) and normal (LN) range on non-word repetition (mothers, fathers, and siblings) and total language ability (siblings only). CELF-III, Clinical Evaluation of Language Fundamentals—Third Edition; SLI, specific language impairment; ASD, autism spectrum disorder.



**Figure 1.** Scatterplots of algorithm scores for verbal communication (ADI COM), reciprocal social interaction (ADI SOC), repetitive behaviors and stereotyped patterns (ADI REP), and total sum (ADI SUM) on the ADI-R and communication (ADOS COM), reciprocal social interaction (ADOS SOC), and total sum (ADOS SUM) on the ADOS in ALN and ALI probands. Horizontal lines indicate medians for each group on each algorithm score. ADI-R, Autism Diagnostic Interview—Revised; ADOS, Autism Diagnostic Observation Schedule.

ALN and ALI siblings. For mothers, this proportion was highest in the SLI group and lowest in the ALN group. For fathers, this proportion was significantly higher in the SLI group vs. the ALN group; however, there was no group difference between ALN and ALI fathers or between ALI and SLI fathers.

#### *Relationship of Language Abilities to ASD Severity*

Figure 1 displays scatterplots of ADOS and ADI-R algorithm scores in the ALN and ALI probands. There were no group differences between ALN and ALI probands for the sum scores for the ADI-R (ALN mean = 47.37, SD = 8.80; ALI mean = 46.72, SD = 7.25;  $t(49) = 0.29$ ,  $P = 0.78$ ) or the ADOS (ALN mean = 14.75, SD = 4.92; ALI mean = 14.84, SD = 4.92;  $t(39) = 0.06$ ,  $P = 0.95$ ). There were also no significant correlations between total language ability on the CELF-III and the algorithm domain scores of the ADI-R or the ADOS across the ALN and ALI groups. There were no significant correlations between non-word repetition and the algorithm domains of the ADI-R. Only the social domain score on the ADOS was correlated with non-word repetition ( $r = 0.36$ ,  $P = 0.02$ ); however, this relationship did not maintain significance after a Bonferroni correction for multiple comparisons.

## **Discussion**

### *Probands*

ALN children scored significantly higher than both ALI and SLI children on the majority of the assessments, while no differences were observed between ALI and SLI probands except for higher performance by ALI probands on word attack on the WJ-R. Group differences were expected on the CELF-III and non-word repetition given how our samples were defined, but these differences extended beyond basic language abilities. ALI and SLI children also had significantly lower non-verbal IQ, phonological processing, lexical comprehension, and reading abilities than ALN children. Poor reading ability has been documented in children with SLI [Catts, Bridges, Little, & Tomblin, 2008; Catts, Fey, Tomblin, & Zhang, 2002; Flax et al., 2003; McArthur, Hogben, Edwards, Heath, & Mengler, 2000], but it is interesting that ALI children also demonstrated these deficits. A study by Nation, Clarke, Wright, and Williams [2006] described significant heterogeneity in reading abilities in children with autism with scores ranging from floor to ceiling so that perhaps those children performing in the lower range in their study fit the ALI profile. Our findings are also consistent with previous studies that have noted

overlap in language phenotypes of children with autism and children with SLI [Bartak et al., 1975, 1977; Kjelgaard & Tager-Flusberg, 2001; Roberts et al., 2004; Whitehouse et al., 2008]. Importantly, there were similarities between the ALI and SLI groups in our sample despite excluding SLI children who met criteria for ASD on any domain of the ADI-R or ADOS besides communication, thus minimizing the likelihood of misdiagnosis in the SLI group.

It has been hypothesized that the language deficits observed in ALI are a consequence of the ASD phenotype [Whitehouse et al., 2007]. In our study, however, there were no group differences between the sum scores of ALN and ALI probands on either the ADI-R or ADOS, and there were no significant correlations between any language measures and ASD severity. These findings indicate that the language difficulties observed in the ALI group are not secondary to the severity of the ASD phenotype. Primary etiological candidates for the language impairments in ASD have been suggested based on genetic and neuroimaging research. Several genetic loci have been implicated in genetic studies that have subset their ASD samples on the basis of language delay or impairment [Abrahams & Geschwind, 2008; Alarcon et al., 2008; Arking et al., 2008; Bakkaloglu et al., 2008; O'Brien et al., 2003; Vernes et al., 2008; Warburton et al., 2000]. Neuroimaging studies have described structural abnormalities in perisylvian cortices, especially in children with autism and language impairment [De Fossé et al., 2004; Herbert et al., 2002]. Similar abnormalities have also been reported in children with SLI [De Fossé et al., 2004; Gauger, Lombardino, & Leonard, 1997; Herbert et al., 2005; Leonard et al., 2002; Plante, Swisher, Vance, & Rapcsak, 1991] and their first-degree relatives [Jackson & Plante, 1996; Plante, 1991], suggesting that these anomalies are heritable neurobiological markers for language impairment.

Neuroanatomical studies comparing ASD and SLI in regions beyond the perisylvian cortices have yielded less consistent findings. Herbert et al. [2005] described asymmetry patterns in other cortical regions that were present in both autistic and SLI children but not typically developing children; however, these findings have not been replicated in other studies of SLI children. While some studies found increased total brain volume, perhaps due to disproportionately greater white matter volumes, in both ASD [Aylward, Minshew, Field, Sparks, & Singh, 2002; Carper, Moses, Tigue, & Courchesne, 2002; Courchesne et al., 2001; Filipek et al., 1992; Hardan, Minshew, Mallikarjunn, & Keshavan, 2001; Piven, Arndt, Bailey, & Andreasen, 1996; Piven et al., 1995; Sparks et al., 2002] and SLI [Filipek et al., 1992; Herbert et al., 2003; Woodhouse et al., 1996], other studies have found decreased total brain volume in SLI [Jernigan, Hesselink, Sowell, & Tallal, 1991; Leonard, Eckert, Given, Virginia, & Eden, 2006; Leonard et al., 2002]. These findings suggest

that there may be more limited shared etiology between ASD and SLI than has been argued by some researchers.

#### *First-Degree Relatives*

SLI family members performed the worst of the three groups on all measures, and over half scored in the language-impaired range on the CELF-III or non-word repetition, supporting other studies that have shown high heritability of language deficits in SLI. When compared to the proportion of ALN and ALI family members performing in the language-impaired range on these measures, this difference was most pronounced among siblings and mothers. There was no difference, however, in the proportion of brothers vs. sisters from SLI families performing in the language-impaired range. Poor performance on non-word repetition tasks has previously been described in parents of children with SLI in comparison to parents of both typically developing [Barry et al., 2007] and autistic children [Whitehouse et al., 2007]. In our study, on average, non-word repetition performance was borderline or impaired in the relatives of SLI children, and as a group SLI relatives scored lower than the relatives of the ALI and ALN children. In contrast to Pilowsky et al. [2003], we found that siblings of SLI children performed significantly lower on the CELF-III compared to both ALN and ALI siblings. These conflicting results may be attributable to differences in the inclusion criteria for the SLI probands between studies. SLI children in Pilowsky and colleagues' study only had to have normal intelligence and score more than one standard deviation below the mean on the CELF-III, while the SLI children in our study also had to have a documented positive history of language delay or deficits. Furthermore, all of the children in Pilowsky and colleagues' study were native Hebrew speakers, and there is some evidence that the characteristic SLI phenotype varies depending on the language [Dromi, Leonard, Adam, & Zadunaisky-Ehrlich, 1999; Leonard, Dromi, Adam, & Zadunaisky-Ehrlich, 2000; Owen, Dromi, & Leonard, 2001; Stokes, Wong, Fletcher, & Leonard, 2006; Thordardottir & Namazi, 2007].

In addition to poor performance on primary language measures, SLI family members also scored lower than ALN and ALI family members on measures of verbal IQ, phonological processing, and reading ability. Whitehouse et al. [2007] also found relatively poor performance on language measures in parents of SLI children when compared to parents of autistic children. Similarly, Flax et al. [2003] described elevated rates of reading impairments in first-degree relatives of SLI children as well as a high co-occurrence of reading impairment with language impairment. Overall, these findings suggest that the heritable SLI phenotype is not restricted to basic language ability but also encompasses reading deficits.

The pattern of language and reading performance of the relatives of ALN and ALI probands was not consistent. On some measures, there were no significant differences between the ALN and ALI relatives. These included expressive language, lexical comprehension, and all measures of phonological processing, including non-word repetition. On other measures, including verbal IQ, total and receptive language, and all reading measures, the siblings or parents of the ALI probands scored lower than the relatives of the ALN probands. However, it is unclear whether these group differences indicate familial aggregation of susceptibility to those language and reading impairments or whether these group differences are attributable to above normal performance in the ALN relatives and their higher education levels (ALN parents on average completed college, whereas ALI parents on average only partially completed college).

It is important to note that overall, there were no differences between the ALN and ALI relatives on either expressive language or phonological processing, two measures exhibiting high heritability in SLI. This is consistent with previous studies concluding that phonological deficits are not clearly part of the heritable language phenotype in ASD [Bishop, Maybery, Wong et al., 2004; Whitehouse et al., 2007]. While at the group level there were no differences in non-word repetition, the proportion of mothers of ALI probands who scored in the impaired range on this measure was significantly higher compared to the mothers of ALN probands. Based on our definition of language impairment for this analysis, one would expect approximately 16% of mothers to be categorized as language-impaired, but 29% of ALI mothers in our sample scored within this range. There was also a trend toward a greater proportion of brothers vs. sisters of ASD children scoring in the language-impaired range on the CELF-III or non-word repetition, which is consistent with the findings of higher rates of learning and speech issues in brothers vs. sisters of individuals with ASD [Interactive Autism Network, 2007; Plumet et al., 1995]. These findings suggest that there may be some genetic component to the language impairments in ASD that is transmitted through the maternal line to their male children [cf. Ruser et al., 2007]; however, replications of these findings on independent samples are needed before such conclusions are warranted.

Contrary to our predictions, relatives of ALI probands scored higher than relatives of SLI probands on all the language and reading measures. Moreover, language impairments are more prevalent in SLI families than ALI families. As many as 60% of children with SLI have at least one additional family member with language impairments [Lahey & Edwards, 1995], whereas the rate of speech and language deficits is approximately 20–25% in ASD families [Bartak et al., 1975; Piven, Palmer, Jacobi

et al., 1997]. These percentages are consistent with those of first-degree relatives performing in the impaired range on non-word repetition or total language ability in our study. Given these differences between ASD and SLI, the language deficits in these populations cannot be linked to the identical genetic etiology [Williams et al., 2008]. It remains to be seen, however, whether there is some limited partial overlap between these populations as suggested by the association of the CNTNAP2 gene, a component of the FOXP2 pathway, with both ASD and SLI [Alarcon et al., 2008; Vernes et al., 2008]. Further analyses of this pathway and its relationship to language abilities in ASD and SLI families are warranted to better understand its role in the ALI and SLI language phenotype.

It may also be that, in comparison to relatives of SLI probands, ALI relatives are more likely to outgrow early language impairments or be better able to compensate for them. Because our sample only included siblings aged 6 and older, we were unable to see if at a younger age siblings of ALI children exhibit greater evidence of language impairment. This hypothesis is supported by a longitudinal study by Gamliel, Yirmiya, and Sigman [2007] reporting that a number of siblings of ASD children who scored poorly on language measures at age 14 months had improved functioning at age 54 months. It has also been suggested that the language impairments observed in ALI children diminish with age [Williams et al., 2008]; however, our data do not support this hypothesis as there were no differences on any of our language measures between the ALI and SLI groups of children. Further investigations of the developmental trajectories of language and reading abilities in ALI and SLI probands as well as identification of the strengths and weaknesses of affected individuals and their relatives are necessary to better understand the relationship between autism and SLI. Moreover, longitudinal studies of language development in siblings of ALI and SLI children would provide insight into whether there is greater overlap in the broader phenotypes of these disorders at an early age and what risk factors predict language performance later in life. Finally, neuroimaging studies of first-degree relatives of children with ASD and SLI are also needed to examine whether the similarities in abnormal brain structure between these disorders are heritable and are related to language impairment. Understanding the overlap of and differences between these complex disorders has important implications for diagnosis and treatment in clinical practice.

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