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Differential language markers of pathology in Autism, Pervasive Developmental Disorder Not Otherwise Specified and Specific Language Impairment

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ABSTRACT

Language impairment is a common core feature in Pervasive Developmental Disorders (PDD) and Specific Language Impairment (SLI). Many studies have tried to define the specific language profiles of these disorders, some claiming the existence of overlaps, and others conceiving of them as separate categories. Fewer have sought to determine whether and how PDD-NOS language profile, including prosody, differs from those of Autistic Disorder (AD) and SLI. Here, 12 children with AD (mean age 9.75; sd 3.5), 10 with PDD-NOS (mean age 9.83; sd 2.17), and 13 children with SLI (mean age 9.17; sd 3.9) matched for age, sex and academic skills were explored for both receptive and expressive language skills. Prosody was also assessed with an intonation imitation task analyzed through automatic speech processing and compared to 70 typical developing controls matched for age and sex. A similar delay in phonology and vocabulary was observed in the three groups as were significant but variable differences between the groups in syntax, pragmatics and prosody. SLI showed correlations between chronological age and raw scores in all language tasks, while AD and PDD-NOS did not. Furthermore, SLI showed correlation within all raw scores in language tasks. Most of those correlations were also found in PDD-NOS but not in AD. In conclusion, these findings support the hypothesis that language skills in AD and SLI rely on different mechanisms, while PDD-NOS show an intermediate profile sharing some characteristics of both AD and SLI. They also suggest that expressive syntax, pragmatic skills and some intonation features could be considered as language differential markers of pathology, challenging the DSM-V proposal of broad criteria.

1. Introduction

Pervasive Developmental Disorder (PDD) is characterized by a triad of severe deficits and pervasive impairments in developmental areas such as reciprocal interactions, communication skills and stereotyped behavior. PDD is mostly seen as a "spectrum disorder" with several variants and gradients. DSM IV (APA, 2000) distinguishes three main disorders: Autistic

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Disorder (AD) with early onset, possible mental retardation, language impairment and symptoms in all areas characterizing PDD; Asperger Syndrome (AS) without language delay or mental retardation; and Pervasive Developmental Disorder Not Otherwise Specified (PDD-NOS) in which social, communicative and/or stereotypic impairments either do not coexist, or to a lesser degree resulting in that they do not fit other subtypes of PDD. Thus, diagnostic criteria for PDD-NOS are quite vague and mostly lead to a diagnosis by default (Volkmar, 2005) while being statistically the largest category (Fombonne, 2003).

1.1. Language in PDD

Language and communication impairment in PDD, especially in AD, has led to numerous studies over the last decades trying to specify profiles. Language in autism, when present, may show several varying subtypes within the spectrum (Kjelgaard & Tager-Flusberg, 2001; Rapin & Dunn, 1997; Tager-Flusberg, 2006). Some individuals may have *structural language disturbances:* (i) delayed phonology, especially in non-word repetition tasks (Bartolucci, Pierce, Streiner, & Tolkin Eppel, 1976; Kjelgaard & Tager-Flusberg, 2001; Tager-Flusberg, 1981; Whitehouse, Barry, & Bishop, 2007); (ii) poor comprehension skills, sometimes more impaired than the expressive ones (Bartak, Rutter, & Cox, 1977; Boucher, 2003; Tager-Flusberg, 1981), (iii) immature syntax and prevalence of syntactic errors (Kjelgaard & Tager-Flusberg, 2001). Functional deficits are characterized by: (i) a core pragmatics disorder (defined as the ability to use and understand the rules governing language as a communicative tool including tone of voice, facial expressions, communicative gesture and affect), accepted as universal in the whole spectrum and long-lasting, even in adult life (Lord & Paul, 1997; Rapin & Dunn, 1997, 2003); (ii) impairment regarding semantics, i.e. the linguistic meaning of utterances and bounds established between words/utterances and what they do/may represent (Boucher, 2003; Rapin & Dunn, 1997, 2003).

1.2. Overlapping with SLI?

Language was compared persons with autism and SLI participants. SLI, which excludes PDD, is defined as a "pure" impairment despite adequate hearing, intelligence or physical condition, encompassing a broad range of deficits regarding phonology, vocabulary, syntax, semantics and pragmatics. Rapin and Allen (1983) distinguished: (i) mixed receptive/expressive disorders, with comprehension and expression impairment, including verbal-auditory agnosia (word deafness) and phonologic-syntactic syndrome; (ii) expressive disorders, with spared comprehension, including verbal apraxia and phonologic disorder; (iii) higher order disorders, with spared articulation and phonology but disordered pragmatics and lexical-syntactic organization. This last category is controversial. Some authors consider it as a part of the ASD continuum while others refuse the systematic equation between pragmatic difficulties and ASD and identify intermediate characteristics (Bishop & Frazier-Norbury, 2002). Some studies conclude that the *structural disorders* observed in some AD children are similar to those of SLI (especially regarding phonology and syntax) and suggest overlaps between the disorders, hypothesizing a common phenotype (Bartak, Rutter, & Cox, 1975; Bartak et al., 1977). Conversely, studies focusing on non-word repetition, considered to be a psycholinguistic marker of SLI (Bishop, North, & Donlan, 1996; Conti-Ramsden, Botting, & Faragher, 2001), found similarities in AD and SLI regarding syntactic reception and expression, but differences in speech motor skills, verbal short-term memory, and error types in non-word repetition (Whitehouse, Barry, & Bishop, 2008). They thus rejected the hypothesis of an SLI subtype in Autism.

Some genetic studies suggest that the two conditions may be related (Folstein & Mankoski, 2000; Vernes et al., 2008) although others discuss an overlapping etiology and "phenomimicry" (Bishop, 2003, 2010). Moreover, although studies regarding ASD and SLI language and communication in first-relatives are consistent with the hypothesis that both disorders are highly inheritable, they do not support the hypothesis of one shared phenotype but rather suggest that language deficits in ASD and SLI have different origins (Lindgren, Folstein, Tomblin, & Tager-Flusberg, 2009; Whitehouse et al., 2007). A recent fMRI study found that SLI and Autistic children with Language Impairment (ALI) compared to normal controls showed abnormalities in the circuits that manage motor control and processing of language, cognition, working memory and attention. They also observed that cerebellar white matter was significantly larger in ALI than in SLI as well as regional volume differences between ALI and SLI groups in right hemisphere VIIA Crus I, suggesting similarities but also important language related developmental differences (Hodge et al., 2010).

1.3. Prosody in PDD

Prosody concerns the supra-segmental properties of the speech signal that modulate and enhance its meaning. It supports expressive language at several communication levels (McCann & Peppé, 2003). Abnormal prosody is identified as a core feature of individuals with autism (Kanner, 1943). The observed prosodic differences include monotonic or machine-like intonation, aberrant stress patterns, deficits in pitch and intensity control and a "concerned" voice quality. These inappropriate patterns related to communication/sociability ratings tend to persist over time even while other language skills improve (Paul, Augustyn, Klin, & Volkmar, 2005; Paul et al., 2005). Many studies have tried to define the prosodic features in patients with Autism Spectrum Disorder (ASD) (for a review see McCann & Peppé, 2003). With regards to intonation contours production and intonation contours imitation tasks, results are contradictory. In a reading-aloud task, Fosnot and Jun (1999) found that AD children did not differentiate questions and statements; all utterances sounded like statements. In an imitation condition task AD children performed better. AD participants could produce intonation contours but did not understand their communicative value. Paul, Augustyn, et al. (2005) found no difference between AD and TD children in the use of intonation to distinguish questions and statements. McCann, Peppé, Gibbon, O'Hare, & Rutherford (2007) observed a tendency in AD participants to utter a sentence sounding like a question when a statement was appropriate. Le Normand, Boushaba, & Lacheret-Dujour (2008) found that children with AD produced more words with flat contours than did typically developing children. Paul, Bianchi, Augustyn, Klin, & Volkmar (2008) documented the abilities to reproduce stress in a nonsense syllable imitation task of an ASD group that included patients with high-functioning autism, Asperger's syndrome and PDD-NOS. Perceptual ratings and instrumental measures revealed small but significant differences between ASD and typical speakers.

1.4. Prosody in SLI

Intonation has been poorly studied in children with SLI (Wells & Peppé, 2003). Some researchers hypothesized that intonation provides reliable cues to grammatical structure by referring to the theory of phonological bootstrapping (Morgan & Demuth, 1996) which claims that prosodic processing of spoken language allows children to identify and then acquire grammatical structures as inputs. Consequently, difficulties in the processing of prosodic features such as intonation and rhythm may generate language difficulties (Weinert, 2000). While some studies have concluded that SLI patients do not have significant intonation deficits and that intonation is independent of both morphosyntactic and segmental phonological impairments (Marshall, Harcourt Brown, Ramus, & Van Der Lely, 2009; Snow, 1998a, 1998b), some others have shown small but significant deficits (Hargrove & Sheran, 1989; Samuelsson, Scocco, & Nettelbadt, 2003; Wells & Peppé, 2003). With regards to intonation contours production, Wells and Peppé (2003) found that SLI children produced less congruent contours than typically developing children. The authors hypothesized that SLI children understand the pragmatic context but fail to select the corresponding contour. Concerning intonation imitation tasks, the results seem contradictory. Van der Meulen and Janssen (1997) and Wells and Peppé (2003) found that SLI children were less able to imitate prosodic features. Several interpretations were proposed: (i) the weakness was due to the task itself rather than to a true prosodic impairment (Van der Meulen & Janssen, 1997); (ii) a failure in working memory was more involved than prosodic skills (Van der Meulen & Janssen, 1997) and (iii) deficits in intonation production at the phonetic level were sufficient to explain the failure to imitate prosodic features (Wells & Peppé, 2003). Conversely, Snow (1998b) reported that children with SLI showed a typical use of falling tones, and Marshall et al. (2009) did not find any difference in the ability to imitate intonation contours between SLI and typically developing children.

1.5. Aims of the study

Most studies have aimed at determine whether AD or SLI children's language skills differed from or shared an equivalent phenotype, but really few have compared AD, PDD-NOS and SLI. Mayes, Volkmar, Hooks, & Cicchetti (1993) tried to define clinical features that differentiate PDD-NOS from both AD and SLI and were able to do so on items related to the degree of socialization and relatedness. Conversely, PDD-NOS exhibited difficulties with relatedness and needed routines more than SLI. Ramberg, Ehlers, Nyden, Johansson, & Gillberg (1996) compared language and pragmatic functions in AS, High Functioning Autism (HFA), Deficits in Attention, Motor control and Perception (DAMP) and Speech and Language Disordered (SLD) groups. The present study clearly discriminated DAMP and SLD from AS and HFA. Finally, Allen et al. (2001) compared verbal and adaptive skills in PDD-NOS, AD and SLI. Their findings indicated that PDD-NOS, obtaining intermediate scores, did not differ from either SLI or AD children in verbal or adaptive skills. Nor did they differ from AD regarding maladaptive behaviors, although the two groups had significantly more behaviors of this type than the SLI group. Regarding prosodic skills, studies sought to determine if AD or SLI differed from those of typically developing children, but they rarely focused on differences between diagnostic categories.

The aim of the present study was (i) to document language profiles in AD, PDD-NOS and SLI (phonology, vocabulary, syntax, pragmatics, prosody) and (ii) to determine language differential markers of pathology. To avoid previous methodological bias we first carefully matched our three groups of patients for age, sex and academic skills; and second, we used an automatic intonation recognition algorithm, computed for the current study (Ringeval et al., in press), to assess prosody during a prosodic imitation task.

2. Methods

2.1. Participants (Table 1)

Thirty-five monolingual participants with communicative verbal skills were recruited in two university departments of child and adolescent psychiatry located in Paris, France. They consulted for pervasive developmental disorders (PDD) and specific learning impairments which were diagnosed as Autistic Disorder (AD), Pervasive Developmental Disorder Not Otherwise Specified (PDD-NOS) or Specific Language Impairment (SLI) according to DSM IV criteria (APA, 2002). Patients were matched for age, sex and academic skills. Socio-demographic and clinical characteristics of the participants are summarized in Table 1.

Table 1
Socio-demographic, clinical and language characteristics of the participants.

	AD (N = 12)	PDD-NOS (N = 10)	SLI (N = 12)
Age, mean (±SD), year	9.75 (±3.5)	9.83 (±2.17)	9.17 (±3.9)
Male–female	10–2	9–1	9–3
ADI-R, current, mean (±SD)			
Social impairment score	21.1 (±5.8)	12.7 (±7.8)	Not relevant
Communication score	19.3 (±5.2)	8.5 (±6.4)	Not relevant
Repetitive interest score	6.4 (±2.4)	2.0 (±1.6)	Not relevant
Total score	50.7 (±12.8)	25.7 (±15.4)	Not relevant
CARS score	33.2 (±15.4)	22.3 (±5.4)	Not relevant
ADI-R, 5 year-old			
Autism	N = 12	N = 3	Not relevant
PDD-NOS	N = 0	N = 7	Not relevant
Cognitive level			
WISC3/WPPSI			
VIQ	50 (±8.3)	85 (±14.4)	71.3 (±11.7)
PIQ	77 (±16.3)	76.8 (±10.5)	95.4 (±14.5)
WISC 4			
ICV		79.8 (±26.2)	96 (±19.8)
IRP		83 (±25.1)	95 (±22.6)
IMT		75 (±20.1)	77.5 (±6.4)
IVT		83.5 (±22.6)	99 (±18.4)
ELO tasks: mean (±SD)			
Receptive vocabulary	2.4 (±1.6)	1.9 (±1.5)	1.9 (±1.0)
Expressive vocabulary	2.0 (±1.8)	1.2 (±1.8)	1.4 (±1.1)
Word repetition	2.9 (±1.5)	2.7 (±1.4)	3.5 (±0.7)
Immediate understanding	3.4 (±1.2)	1.8 (±1.5)	0.8 (±0.9)
Global understanding	3.3 (±1.1)	1.4 (±1.6)	0.6 (±0.9)
Correct sentences	3.2 (±1.3)	2.3 (±1.3)	1.7 (±1.5)
Linguistic errors	2.7 (±1.4)	2.1 (±1.5)	1.8 (±1.8)
Pragmatic errors	3.5 (±1.0)	2.3 (±2.0)	0.3 (±0.9)

AD = Autistic Disorder; PDD-NOS = Pervasive Developmental Disorder-Not Otherwise Specified; SLI = Specific Language Impairment; SD = Standard Deviation; ADI-R = Autism Diagnostic Interview-Revised; CARS = Children Autism Rating Scale.

AD and PDD-NOS groups were assigned from patients' scores on Autism Diagnostic Interview-Revised (ADI-R, Lord, Rutter, & Le Couteur, 1994) and Children Autism Rating Scale (CARS, Schopler, Reichler, Devellis, & Dally, 1980). The psychiatric assessments and parental interviews were conducted by four child-psychiatrists specialized in autism (JX, DP, DC, LR). To give a developmental view of the older patients with autism and PDD-NOS, the ADI-R diagnosis at age 5 was reported. In three participants diagnosis had evolved from age 5 from AD to PDD-NOS (Leroy et al., 2010). Of note, all PDD-NOS also fulfilled diagnostic criteria for Multiple Complex Developmental Disorder (Buitelaar & Van Der Gaag, 1998; Van Der Gaag et al., 1995), a research diagnosis used to limit PDD-NOS heterogeneity and improve its stability overtime (Rondeau et al., 2011). As expected, current ADI-R and CARS scores were significantly higher in participants with AD than with PDD-NOS (*Mann–Whitney test*: $U = 80.50$, $p = 0.002$; $U = 112.00$, $p \leq 0.0001$, respectively). SLI participants received a formal diagnosis of SLI by Speech Pathologists and Child Psychiatrists specialized in language impairments (DC, LR) according to the DSM IV criteria for expressive language disorder. Additionally, all of them fulfilled criteria for Mixed Phonologic-Syntactic Deficit Disorder (Rapin & Allen, 1983).

2.2. Language assessment

Oral language was assessed using five tasks of the ELO Battery (*Evaluation du Langage Oral*: Assessment of Oral Language; Khomsi, 2001), i.e., Receptive Vocabulary, Expressive Vocabulary, Word Repetition, Sentence Understanding, Sentence Completion. ELO is dedicated to children aged 3–11 years. Although many participants of our study were older than 11, their oral language difficulties did not allow using other tests because of important floor-effect. Consequently, we adjusted the scoring system and determined severity levels (see below). For most participants, all tasks were administered in one 30–45 min session. For some autistic participants, two, three or four sessions were necessary to complete all tasks.

2.3. Receptive vocabulary

This task containing 20 items requires word comprehension. The examiner gives the patient a picture booklet saying: "*Show me the picture in which there is a...*" The subject has to select from 4 pictures the one corresponding to the uttered word. Each correct pointing gives one point and maximal score is 20.

2.4. Expressive vocabulary

This task containing 50 items requires picture naming. The examiner gives the patient a booklet comprising object pictures and asks him "*What is this?*", then "*What is he/she doing*?" for the 10 last pictures, showing actions. Each correct answer gives one point, maximal mark for objects is 20 for children from 3 to 6, 32 from 6 to 8, and 50 for children above 9.

2.5. Word repetition

This task comprising two series of 16 words requires verbal encoding and decoding. The first series contains disyllabic words, with few consonants groups. The second contains longer words with many consonants groups which allows observing any phonological disorder. The examiner says "*Now, you are going to repeat exactly what I say. Listen carefully, I won't repeat*". Then patient repeats the 32 words, maximal score is 32.

2.6. Sentence understanding

Oral sentence understanding is assessed with picture designation. There are 32 sentences, 16 simple and 16 more complex requiring accurate grammatical skills. The examiner gives the patient a 34 page booklet in which each page contains four pictures. There are two demonstration items, and instruction is as follows: "*Show me the picture that means...*" In case of error, a second choice is offered "*Listen carefully, and show me the picture exactly corresponding to what I say*". Each correct answer gives one point, and 2 sub-scores may then be calculated: (i) *Immediate understanding*, corresponding to addition of items, simple and complex, and succeeded on first trial. Maximal score is 32. (ii) *Global understanding*, corresponding to addition of immediate understanding score and items succeeded on the second trial. Maximal score is 32.

2.7. Sentence completion

In this task, the subject is asked to complete sentences whose beginning is uttered by the examiner. The patient is given a 28 page booklet, and each page contains two pictures. The examiner comments the first picture, and the patient has to complete the second one that implicates a grammatical variation (plural, negation, passive voice, conjugation...) "*Here, the boy is running, there the boy.. (is not running)*". There are three demonstration items followed by 25 items; each correct answer gives one point and maximal score is 25. Errors may be categorized as (i) *Linguistic errors*, corresponding to grammatical or syntactic errors, reflecting delayed language skills; and (ii) *Pragmatic errors*, when linguistic or pragmatic context is not taken into account.

2.8. Scoring system procedure

We first referred to the means and standard deviations of each task. But due to our population particularities, oral language abilities differed widely from those expected at chronological age. Standard deviations were extremely high and reached floor effect. To adjust the scoring system to all participants including those older than 11 years (the maximum age limit of the test), we determined for each subject the corresponding age for each score then calculated the discrepancy between this "verbal age" and the chronological age. The difference was converted into severity levels using a 5 level Likert-scale, i.e., 0 standing for expected level at chronological age, 1 standing for 1 year deviation from expected level at chronological age, 2 for 2 years deviation, 3 for 3 years deviation, and 4 standing for more than 3 years deviation. As the ELO Battery test is not standardized for participants older than 11 years, we expected for them the 11-year level. In order to validate the procedure, we calculated Pearson's correlations between raw scores and severity levels. All r^2 coefficients ranged from 0.47 to 1 ($p < 0.0001$), except for word repetition ($r^2 = 0.27$, $p = 0.001$).

2.9. Prosodic assessment

Our main goal was to compare children's abilities to reproduce different kinds of intonation sentences. In order to facilitate the reproduction and to avoid undue cognitive demand, the sentences were phonetically easy and relatively short. Children were asked to repeat sentences that were randomly presented. Four intonation groups (or prosodic contours) were used in this study: descending (e.g. "David ate a croissant."); falling (e.g. "Can you go to my office?"); floating (e.g. "Anna will come with you."); and rising (e.g. "A croissant?"). Each intonation group included seven sentences to ensure different phonetic contexts and thus diversity in prosodic contours (detailed list is given in Ringeval et al., in press). Children were recorded in their usual environment. During recordings they were asked to repeat exactly the sentences they heard, even if they did not catch one or several words. If the children reproduced the prosodic contours of the sentences in an exaggerated way, or if they showed difficulties, sentences were replayed several times.

As many sources of perturbation appeared during the recordings (e.g. false-starts, repetitions or noise from the environment), manual based speech segmentation was preferred. As an automatic detector could hardly handle all perturbations found in the recordings, the sentences reproduced by the children were manually segmented and post-processed to keep only those that had complete prosodic contour (i.e. whatever the pronounced words). Nearly 900 sentences were collected from the recordings.

To assess prosodic performance of the children by group, an automatic classifier developed to recognize prosodic contour of short sentences taken from the same list was used. The classifier used both static and dynamic approaches that were fused to provide best recognition scores (see scheme in Fig. 1A). Computational characteristics of the classifier are given in detail in Ringeval et al. (in press). Performance of the best fusion configuration on a group of 70 typical developing children matched for age and sex (1 patient for 2 controls) recruited in elementary schools was as follow: descending 0.64, falling 0.55, floating 0.72, rising 0.95. Given that performance of the classifier was below 0.6 for falling sentences, the method was not considered valid for classifying falling sentences in pathological groups.

2.10. Statistical analysis

Statistics were done with R statistical software. To compare groups' severity levels in each ELO task, one-way analysis of variance followed by *post hoc* analysis was used. The Spearman non-parametric method was then used within each group to test the correlation between raw scores in language tasks and chronological age. To compare group sentence duration and prosodic performance in the intonation imitation task, a one-way analysis of variance was also used followed by *post hoc* analysis.

3. Results

3.1. Receptive vocabulary, expressive vocabulary and word repetition

Regarding vocabulary tasks (Table 1) no significant differences were found between groups' mean severity levels: $K(2, 34) = 1.41$, $p = 0.5$ for Receptive task, $K(2,34) = 1.77$, $p = 0.41$ for Expressive task. The three groups were similarly delayed (1–2 years). Word repetition task showed impaired phonological encoding skills in all three groups with an average delay of three years: $K(2,34) = 0.41$, $p = 0.81$.

3.2. Sentence understanding

All groups were delayed in immediate understanding (Table 1), and strong significant group differences were observed: $K(2,34) = 14.88$, $p = 0.0006$. *Post hoc* analyses showed significant differences between AD and SLI groups ($p = 0.001$), and between AD and PDD-NOS ($p = 0.005$). However, no differences were found between PDD-NOS and SLI groups ($p = 0.08$).

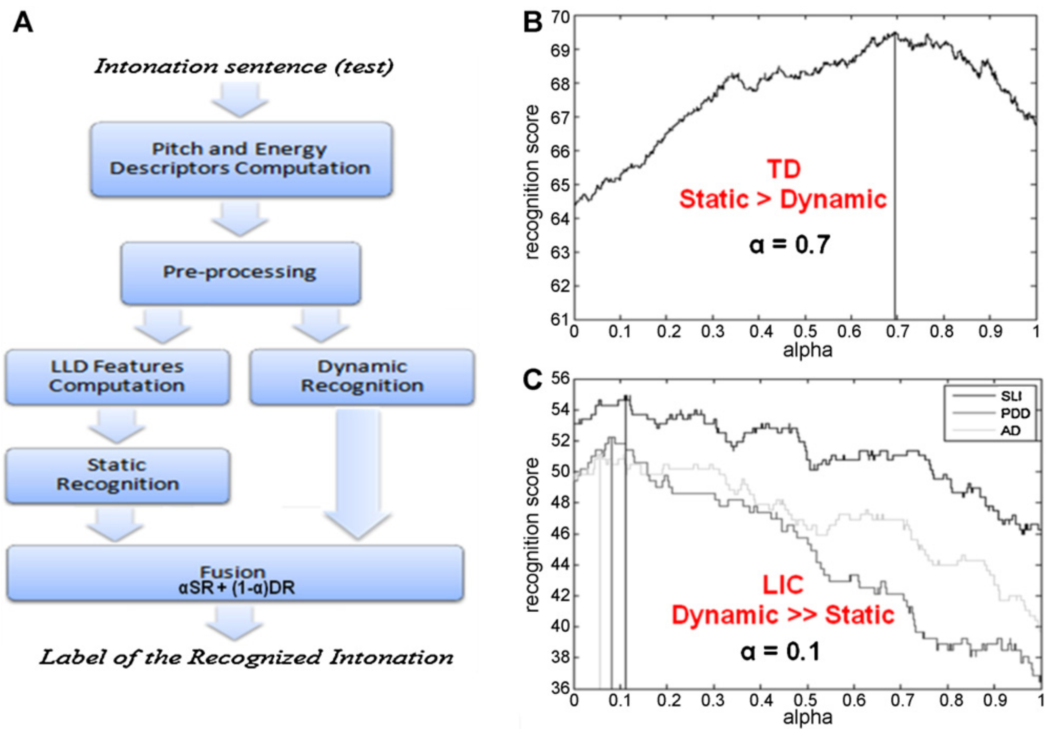

Fig. 1. Relative contribution of static classifier and dynamic classifier of prosody for best recognition of intonation sentence according to typical development or language impairment. A. Scheme of the automatized intonation recognition system. B. Fusion recognition scores as function of weight alpha attributed to both static and dynamic classifiers in typical developing children (TD). C. Fusion recognition scores as function of weight alpha attributed to both static and dynamic classifiers in language impairment children (LIC). SLI = Specific Language Impairment; PDD = Pervasive Developmental Disorder-NOS; AD = Autism Disorder; LLD = Low-Level Descriptors; SR = Static Recognition; DR = Dynamic Recognition.Source: Adapted from Ringeval et al., in press, IEEE SALP.

Table 2
Spearman rank correlations table, between raw scores in language tasks and chronological age within each group (AD, PDD-NOS and SLI patients).

ELO tasks	AD age Spearman's ρ	PDD-NOS age Spearman's ρ	SLI age Spearman's ρ (p)
Receptive vocabulary	−0.05	−0.21	0.84***
Expressive vocabulary	−0.03	−0.08	0.90***
Word repetition	0.25	−0.07	0.88***
Immediate understanding	−0.17	0.24	0.95***
Global understanding	0.38	0.25	0.87***
Correct sentences	−0.35	0.08	0.94***
Linguistic errors	0.22	−0.11	−0.90***
Pragmatic errors	0.14	0.72*	−0.61*

AD = Autistic Disorder; PDD-NOS = Pervasive Developmental Disorder Not Otherwise Specified; SLI = Specific Language Impairment.
* $p < 0.05$.
*** $p < 0.001$.

As observed in immediate understanding, all groups were delayed in global understanding and did not benefit from a second trial (Table 1). Again, strong significant differences appeared between groups: $K(2,34) = 16.58$, $p = 0.0003$. *Post hoc* analysis showed significant differences between AD and SLI groups ($p = 0.0001$), AD and PDD-NOS groups ($p = 0.001$), but no differences between SLI and PDD-NOS groups ($p = 0.127$).

3.3. Sentence completion

All groups had delayed expressive skills as evidenced by correct sentence scores. Mean severity levels ranged from 1.5 for SLI group, to 2.3 for PDD-NOS and 3.2 for AD, with an average delay of two years. A significant difference appeared between groups: $K(2,34) = 6.48$, $p = 0.039$. *Post hoc* analyses showed significant difference between AD and SLI groups but not between AD and PDD-NOS groups, nor between PDD-NOS and SLI groups. In all groups, the number of linguistic errors was above the expected range according to chronological age with an average delay of two years. No significant differences appeared between groups: $K(2,34) = 1.78$, $p = 0.41$. In contrast, regarding pragmatic errors significant differences were found between groups: $K(2,34) = 18.75$, $p = 0.0001$. SLI participants obtained scores in the average of normal children of the same age, whereas AD participants and PDD-NOS committed numerous pragmatic errors. *Post hoc* analyses showed significant differences between AD and SLI groups ($p < 0.0001$), PDD-NOS and SLI groups ($p = 0.001$), and also between PDD-NOS and Autistic groups ($p = 0.044$).

3.4. Correlations study

3.4.1. Correlations between raw scores in language tasks and chronological age, within each group

In the AD group no correlations were found between raw scores in language tasks and chronological age, nor in the PDD-NOS group, except for pragmatic errors: $r_s(10) = 0.72$, $p = 0.02$. Unlike the two previous groups, all language tasks raw scores were strongly and positively correlated to chronological age in the SLI group (Table 2), except for Linguistic Errors: $r_s(12) = -0.90$, $p < 0.0001$ and Pragmatic errors: $r_s(12) = -0.61$, $p = 0.04$, where correlations were negative.

3.4.2. Correlations within raw scores in language tasks, within each group

In the AD group few correlations appeared within tasks (Table 3, top). Receptive Vocabulary raw scores were correlated to Expressive Vocabulary: $r_s(12) = 0.74$, $p = 0.03$, Word Repetition: $r_s(12) = 0.76$, $p = 0.02$ and Correct Sentences: $r_s(12) = 0.85$, $p = 0.006$. Expressive Vocabulary was also correlated to Word Repetition: $r_s(12) = 0.74$, $p = 0.03$. More correlations were observed in the PDD-NOS group, as most of the tasks' scores were correlated within them, p values ranging from 0.04 to <0.0001. However, Receptive Vocabulary, Linguistic Errors and Pragmatic Errors were not correlated to any other component (Table 3, middle). In the SLI group, all raw scores were strongly and positively correlated within them, p values ranging from <0.0001 to 0.013. Unlike previous groups, even Linguistic Errors were correlated, though negatively, to all the other language components (Table 3, bottom). Pragmatic Errors were here negatively correlated to Immediate Understanding: $r_s(12) = -0.61$, $p = 0.04$ and to Global Understanding $r_s(12) = -0.60$, $p = 0.045$.

3.5. Performances in the intonation imitation task

Compared to the reference sentences, sentence duration was conserved for all intonation groups when reproduced by TD children. In contrast, durations of pathological group intonation sentences were strongly different from those of TD children (Table 4, top). Values were lengthened by 30% for the three first groups of intonation sentences and by more than 60% for the "Rising" contour. Moreover, the duration of SLI children's sentences intonation was significantly longer than those of AD and PDD-NOS groups, except for "Rising" intonation.

Characteristics of the automatized classifier are shown in Fig. 1. For TD children, best recognition scores were obtained with a major contribution of the static classifier ($\alpha = 0.7$), that is based on global statistics of features of prosody (Fig. 1B). In

Table 3
Spearman rank correlations table within raw scores in language tasks for AD, PDD-NOS and SLI patients.

	Rec.Voc	Exp.Voc	W.Rep	Imm.Und	Glo.Und	Corr.Sen	Ling.Err	Prag.Err
Autism disorder: r_s								
Rec.Voc	1	0.74*	0.76*	0.24	0.48	0.85**	−0.04	−0.51
Exp.Voc	0.74*	1	0.74*	0.50	0.36	0.62	0.01	0.0
W.Rep	0.76*	0.74*	1	−0.15	0.13	0.50	−0.09	−0.10
Imm.Und	0.24	0.50	−0.15	1	0.59	0.39	0.03	0.01
Glo.Und	0.48	0.36	0.13	0.59	1	0.28	0.15	−0.37
Corr.Sen	0.85**	0.62	0.50	0.39	0.28	1	−0.13	−0.43
Ling.Err	−0.04	0.01	−0.09	0.03	0.15	−0.13	1	−0.34
Prag.Err	−0.51	0.004	−0.10	0.01	−0.37	−0.43	−0.34	1
Pervasive Developmental Disorder-NOS: r_s (p)								
Rec.Voc	1	0.26	−0.11	0.20	0.20	0.25	−0.33	−0.31
Exp.Voc	0.26	1	0.71*	0.82**	0.81**	0.67*	−0.36	−0.29
W.Rep	−0.11	0.71*	1	0.83**	0.78**	0.86**	−0.33	−0.30
Imm.Und	0.20	0.82**	0.83**	1	0.96***	0.90***	−0.57	−0.20
Glo.Und	0.20	0.81**	0.78**	0.96***	1	0.90***	−0.53	−0.24
Corr.Sen	0.25	0.67*	0.86**	0.90***	0.90***	1	−0.61	−0.34
Ling.Err	−0.33	−0.36	−0.33	−0.57	−0.53	−0.61	1	0.15
Prag.Err	−0.31	−0.29	−0.30	−0.20	−0.24	−0.34	0.15	1
Specific Language Impairment: r_s (p)								
Rec.Voc	1	0.85***	0.71*	0.78**	0.73**	0.78**	−0.78**	−0.54
Exp.Voc	0.85***	1	0.88***	0.86***	0.91***	0.93***	−0.89***	−0.39
W.Rep	0.71*	0.88***	1	0.81**	0.78**	0.82**	−0.79**	−0.26
Imm.Und	0.78**	0.86***	0.81**	1	0.90***	0.93***	−0.93***	−0.61*
Glo.Und	0.73*	0.91***	0.78**	0.90***	1	0.94***	−0.90***	−0.60*
Corr.Sen	0.78**	0.93***	0.82**	0.93***	0.94***	1	−0.95***	−0.57
Ling.Err	−0.78**	−0.89***	−0.79**	−0.93***	−0.90***	−0.95***	1	0.47
Prag.Err	−0.54	−0.39	−0.26	−0.61*	−0.60*	−0.57	0.47	1

AD = Autistic Disorder; PDD-NOS = Pervasive Developmental Disorder Not Otherwise Specified; SLI = Specific Language Impairment; r_s = Spearman's rho; p = p value; Rec.Voc = Receptive Vocabulary; Exp.Voc = Expressive Vocabulary; W.Rep = Word Repetition; Imm.Und = Immediate Understanding; Glo. Und = Global Understanding; Corr.Sen = Correct Sentences; Ling.Err = Linguistic Errors; Prag.Err = Pragmatic Errors.
[*] $p < 0.05$.
[**] $p < 0.01$.
[***] $p < 0.001$.

contrast, in children with language impairments (LIC), best recognition scores were obtained with a major contribution of the dynamic classifier ($1 - \alpha = 0.9$) allowing modelling the temporal structure of the features (Fig. 1C). Abilities in reproducing prosodic contours as assessed by the automated classifiers with the best fusion for each group are presented in Table 4 (bottom). All pathological groups' recognition scores were close to those of TD children and similar between LIC's groups for "Descending" intonation. In contrast, all other intonations were significantly different between TD and all pathological groups. However, SLI and TD children had very high recognition rate for the "Rising" intonation while both AD and PDD-NOS performed significantly much lower.

Table 4
Sentence duration and prosodic performances of typical developing children and children with AD, PDD-NOS and SLI during the intonation task.

Intonation	TD	AD	PDD-NOS	SLI
Sentences duration (in seconds)				
Descending	1.7 *(0.6)*	2.2[*T,S] *(0.9)*	2.2[*T,S] *(0.8)*	2.4[*T,A,P] *(0.9)*
Falling	1.3 *(1.4)*	1.6[*T] *(0.6)*	1.7[*T] *(0.8)*	1.8[*T,A,P] *(0.8)*
Floating	1.6 *(0.4)*	2.1[*T,S] *(0.7)*	2.1[*T] *(0.5)*	2.4[*T,A,P] *(1.0)*
Rising	0.5 *(0.2)*	0.9[*T] *(0.3)*	0.9[*T] *(0.3)*	0.8[*T] *(0.2)*
Intonation recognition performances				
Descending	64	64	70	63
Floating	72	48[*T]	40[*T]	31[*T]
Rising	95	57[*T,S]	48[*T,S]	81[*T,A,P]
All including falling	77	56[*T]	53[*T]	58[*T]

Statistics of sentences duration are given for both mean (normal style) and standard-deviation (italic style and between parenthesis) values; Performances are given in percentage of recognition performed by the automatic system intonation recognition where a stratified 10-cross-fold validation based approach crossed with the one employed for TD children was used. Intonation's performances do not include those of "Falling" intonation as recognition score in TD was below 0.6 (see method).
[*] Kruskal–Wallis' significativity level below 5% compared to children's groups, i.e., T, A, P and S; TD (T): typically developing; AD (A): autism disorder; PDD (P): pervasive developmental disorders not-otherwise specified; SLI (S): specific language impairment.

4. Discussion

4.1. Summary of the current results

The aim of the study was to document language profiles in French-speaking SLI, PDD-NOS, AD patients and to determine differential markers of pathology. At the lexical and phonological levels we observed a similarity between the three groups in vocabulary and word repetition tasks, with a respective average delay of 1–2 years and 3 years. *Vocabulary and phonology thus do not appear to be differential but rather general markers of developmental pathology. Lexical and phonological skills are vulnerable, whatever the child's impairment.* Regarding syntactic skills, at the receptive level the groups were delayed in sentence understanding; significant differences were observed between AD and SLI groups, AD and PDD-NOS, but not between PDD-NOS and SLI groups. At the expressive level, the three groups were similarly delayed, producing few correct sentences. Significant differences were observed between AD and SLI groups but not between AD and PDD-NOS, nor between PDD-NOS and SLI groups. Regarding expressive errors patterns, the three groups produced similar linguistic errors above the expected range. Our findings confirm other studies which observed poor comprehension (Bartak et al., 1977; Boucher, 2003; Rapin & Allen, 1997; Tager-Flusberg, 1981), immature syntax and prevalence of syntactic errors in PDD (Kjelgaard & Tager-Flusberg, 2001). In our study, AD performed lower than PDD-NOS at the receptive level. *Expressive syntax thus appears to be a differential marker between AD and the two other groups*. Regarding pragmatic errors, significant differences were found between the groups. SLI participants obtained expected scores, and while AD participants and PDD-NOS were deficient, PDD-NOS performed significantly better than AD. This finding is of interest as PDD-NOS is often included in PDD rather than being considered a separate category. Inasmuch as AD appeared pragmatically more deficient than PDD-NOS, pragmatic skills could be considered as a differential marker between AD and the other groups, notably PDD-NOS.

At the prosodic level, fusion parameters of the classifier for best recognition scores were very different between TD children and LIC, meaning that the way to achieve a certain quality of prosody was not similar in TD and LIC, whatever the pathological subgroup. In terms of intonation imitation, the pathological groups and the TD children performed similarly for the "Descending" intonation pattern. In contrast, for the "Rising" intonation pattern, SLI and TD children had very high recognition rates, whereas both AD and PDD-NOS performed significantly much lower. *This suggests that one feature of prosody, the "rising intonation", is a differential marker of psychopathology allowing the separation of the SLI and PDD groups.* Such a finding is in accordance with studies showing that SLI patients do not have significant intonation deficits and that intonation is independent of both morphosyntactic and segmental phonological impairments (Marshall et al., 2009; Snow, 1998a, 1998b).

4.2. PDD-NOS: developmental delay or pervasive development?

In children matched for age, sex and academic level, language skills appear to be differently spared and affected in SLI, PDD-NOS and AD groups. The AD group is the most deficient, presenting difficulties at the lexical, syntactic, pragmatic and prosodic levels. The SLI group is comparable to normal children at the pragmatic level and some aspects of the prosodic level. PDD-NOS and SLI groups perform similarly at the lexical and syntactic levels, but not at the pragmatic and prosodic ones. The PDD-NOS group appears as intermediate, close to SLI in lexical and syntactic skills, poorer than SLI but better than AD in pragmatic and prosodic skills. The correlation study also supported an intermediate position for PDD-NOS. Indeed, in SLI high correlation rates were found both between language scores and chronological age and between scores in the different language tasks. This profile confirms the view that SLI is a developmental language disorder and supports a delayed profile as intellectual disability for general cognitive skills. In contrast, we found no correlations in AD, either between language scores and chronological age or between language scores in the different language task, suggesting a deviant or pervasive development of language skills in autism. The correlation between language skills with age for SLI and the lack of correlation with age for AD was also found in an automated vocal analysis of naturalistic recordings from children with autism, language delay, and typical development (Oller et al., 2010). In our study, PDD-NOS shared with SLI some correlations between the scores in the different language tasks, showing that development of language followed some kind of hierarchy. However, like AD, PDD-NOS showed no correlation between language scores and chronological age. Therefore, with regard to the language dimension PDD-NOS showed some form of developmental delay but also some form of pervasive development. The language deficit of the AD group appears to be more global than those of the two other groups suggesting large cognitive abnormalities involving language disturbances, as shown by a recent fMRI study (Hodge et al., 2010).

4.3. Implication for DSM-5

Theoretically our study does not support the hypothesis of an overlapping and common phenotype between AD and SLI (Bartak et al., 1975, 1977; Bishop, 2003; Kjelgaard & Tager-Flusberg, 2001; Tager-Flusberg, 2006) and tends to reject, as did other authors (Bishop et al., 1996; Conti-Ramsden et al., 2001), the hypothesis that SLI could be a subtype of PDD. Taken together, our findings evidence the clinical necessity to assess every language domain in all pathological groups in order to refine diagnosis criteria and specify language remediation axis. Focusing on syntactic, pragmatic and prosodic markers could be of strong differential interest. The possibility to use an engineering approach to automatically assess prosodic skills is of high interest as it has been shown to be able to distinguish pathological participants with language impairment in a naturalistic setting (Oller et al., 2010; Warren et al., 2010) as well as in an experimental imitation task (Ringeval et al., in press).

With respect to the current proposed revision of DSM-IV-R criteria for ASD including merging the three subtypes, AD, AS and PDD-NOS, into one category, namely Autism Spectrum Disorder (ASD), Rondeau et al. (2011) studied stability over time and showed the lack of support for reliably distinguishing PDD-NOS as a diagnostic entity. They clearly demonstrated the heterogeneity of the PDD-NOS group which would impact the predictive validity of the proposed DSM-V entity. PDD-NOS would be conceived as corresponding to a group of heterogeneous pathological conditions including prodromic forms of later AD, remitted or less severe forms of AD, and developmental delays in interaction and communication. The international clinical and research consensus on the robustness of AD as defined by currently more stringent DSM criteria would be lost. International communication and comparison between interventions will be jeopardized.

The DSM-V expert Committee does not consider language to be a differential marker (http://www.dsm5.org/ProposedRevisions/Pages/proposedrevision.aspx?rid=94#). Our study strongly suggests the pertinence of distinguishing SLI, AD and PDD-NOS inasmuch as the language developmental pattern, when finely assessed, appears specifically altered and spared in the three groups. To limit PDD-NOS heterogeneity (Towbin, 2005) and stability (Rondeau et al., 2011), another view would be to develop appropriate clinical algorithm to individuate PDD-NOS subtypes as proposed earlier with the concept of Multiplex Developmental Disorder (Van Der Gaag et al., 1995). However, if the enlarged "ASD" diagnosis is adopted in DSM-V, it could be important to recommend a dimensional clinical approach of the patients including language as it may have major implications regarding treatment and remediation.

5. Conclusions

Our findings support the hypothesis that language skills and development in AD and SLI rely on different mechanisms, while PDD-NOS shows an intermediate profile sharing some characteristics of both AD and SLI. They also suggest that expressive syntax, pragmatic skills and some intonation features could be considered as language differential markers of pathology.

Conflict of interest

The authors have no conflict of interest.

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