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Deafness and Specific Learning Disorder: towards a possible comorbidity

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ABSTRACT

Background and aim: Most children and adolescents with deafness receive one or two cochlear implants (CIs). Despite the CI expanding the potential for auditory rehabilitation in deaf children, the improvements in language and literacy skills of some of these children do not align with the expected outcomes. As the main research question, we wondered if the reading and writing deficits reported in some deaf children with CIs may be characterized as a domain-specific learning disorder, rather than only a consequence of deafness. Thus, we analyzed the academic discrepancies, in both reading and writing, between two groups of deaf children with early CI. Method: Three prelingually deaf children with CI and with unexplained disproportionate learning disorders (Deaf+LD group) were compared to control deaf children with similar clinical history, age at CI implantation and auditory experience (Deaf group). The Deaf+LD group was also matched on chronological age to three hearing children with Specific Learning Disorder (SLD group). Results: The results showed that the three cases of the Deaf+LD group demonstrated severe reading and writing deficits, with performances significantly below the age level, similarly to children of the SLD group. By contrast, the three children of the Deaf group demonstrated normal reading and writing abilities. Conclusions: We suggested considering the possibility of comorbidity between deafness and SLD. This hypothesis was supported by the specific features of the language profile that justify such an association; in fact, deaf children with presumed SLD have profiles much more similar to hearing children with SLD than to other deaf children.

1. Introduction

Reading and writing skills are important for a deaf child because they can contribute to improving both linguistic and metalinguistic abilities, and they provide the child with an alternative mode of learning to the auditory-verbal channel. Studies have indicated that early mastery of reading and writing fosters language development in children who are deaf or hard of hearing (DHH) (Wie, 2010). Most deaf children acquire these skills during their preschool years, which helps them broaden their knowledge through written materials. In effect, verbal and written language are very "mixed" in transparent languages such as Italian. In transparent languages, phonology-reading-writing are closely linked and they influence/support each other. Thus, teaching reading and writing to deaf children before entering primary school is a widely implemented clinical practice in Italy, because for a deaf child seeing the written words allows him/her to improve his/her speech discrimination and expressive language (since words are pronounced the same way they are written) (Kobayashi et al., 2003; Wie, 2010).

Providing the cochlear implants (CI) at an early age and early instruction in reading and writing would be expected to minimize the gap between language and literacy development and chronological age. However, the progress of children with CI in their language and literacy skills does not always meet expected outcomes (for a review, see Harris, 2015) and a number of children exhibit important learning deficits (Herman et al., 2014; Sugaya et al., 2019). Sugaya et al. (2019) analyzed data from 546 preschool and elementary school deaf children (with hearing aids and/or cochlear implants) and found a 20.1 % prevalence of reading and writing difficulties, which is relatively high compared to

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hearing children. Herman et al. (2014), investigating reading problems among children with DHH (some with hearing aids and some with CI) in comparison with hearing children with dyslexia, found that >70 % of the school-age deaf students in their study had reading difficulties; moreover, none of the children exhibited a purely dyslexic profile, that is, difficulties with transcoding in the absence of other language-related issues. It should be noted that the studies cited above took together children with hearing aids and children with CI; this methodological choice could explain these high percentages of literacy difficulties among these children.

Certainly, early implantation can greatly enhance the reading and writing skills of these children. There are numerous studies (Colletti et al., 2012; Harris, 2016; Harris et al., 2017; Leybaert et al., 2009; Mayer & Trezek, 2018; Ruben, 2018; Simon et al., 2019; von Mentzer et al., 2013; Wakil et al., 2014; Wang et al., 2021) that, specifically focusing on children implanted early and without associated disabilities, showed good reading and writing skills in these children during their school years. For example, von Mentzer et al. (2013) found similar reading and writing performance in a group of children with CIs matched with a group of hearing peers; moreover, the performance of these deaf children was significantly higher than that of children using only hearing aids on a letter-naming task. A meta-analysis by Wang et al. (2021) found that children with CIs scored significantly lower than their hearing peers on reading tests. However, the group effect indicated that children with CIs performed only one standard deviation (SD) below their hearing peers in emergent and reading skills (decoding and fluency), which means they were within the normal range on reading tests (Archbold et al., 2008; Dillon, 2012). Leybaert et al. (2009), using a dictated words task, compared the writing abilities of a group of children with CI exposed to French Cued Speech (CS) (Cornett, 1967; Dillon, 2012) with both those of a group with CI but not exposed to CS and those of hearing peers (control group). They found that implanted children exposed to CS and those in the control group had similar accuracy, suggesting that the orthographic representations of deaf children are more closely related to the precision of their phonological representations acquired through exposure to CS rather than to the amount of auditory experience with a CI (for similar findings regarding English CS, see Rees & Bladel, 2013). Additionally, Simon et al. (2019) compared word spelling outcomes between deaf children with CIs and hearing children and found comparable spelling accuracy in both groups. These authors proposed that hearing status alone does not significantly affect the percentage of correct answers; auditory processing difficulties may instead influence the types of reading and spelling errors. Therefore, early implanted children show to develop adequate reading and writing abilities.

However, there are other studies which report different results and document a relevant interindividual variability among these children (Çizmeci & Çiprut, 2018; Connor & Zwolan, 2004; Geers & Hayes, 2011; Mayer et al., 2016; Rinaldi et al., 2020). For example, in the study by Connor and Zwolan (2004), deaf children with CI demonstrated significantly worse reading abilities than their hearing peers. Mayer et al. (2016) found that about 24 % and 56 % of the implanted children of their group performed below the normal range on words reading and free writing tasks respectively. Geers and Hayes (2011) documented normal reading abilities only in 47 % and 66 % of them on two reading tests, and many struggles in writing and phonological processing tasks as compared to hearing peers. Another study conducted by Çizmeci and Çiprut (2018) reported significantly lower reading and writing skills in a group of deaf preadolescents with CI compared to hearing TD peers and that age of implantation and duration of CI use had no significant effects on the reading and writing skills of these students.

It is evident that understanding the variability in CI learning outcomes requires a comprehensive approach that goes beyond just auditory recovery. Observing the significant language deficits in some deaf children with CIs, some researchers (Benassi et al., 2021; De Stefano et al., 2019; Hawker et al., 2008) have suggested that these issues are not merely a result of limited exposure to natural and optimal hearing during the critical period for perception. Instead, these deficits might also reflect an underlying impairment in the language system itself. In their studies these authors provided evidence of an association between deafness and Developmental Language Disorder (DLD) in deaf children with CI. In line with this perspective, the possibility of an association between deafness and Specific Learning Disorder (SLD) cannot be ruled out either. To our knowledge, in literature only two studies have investigated this issue further in English-speaking children and adolescents (Herman et al., 2019; Nelson & Crumpton, 2015). The first is the study conducted by Nelson and Crumpton (2015) in which the authors compared three groups of school-age students (aged 6–18 years), i.e. typically developing (TD) students, students with DHH (with CI or hearing aids based on hearing loss) and students with SLD in spoken language, reading and writing abilities; the authors found worse language performances in the students with DHH, relative to the other two groups, and similar difficulties on reading and writing tasks in the students with DHH and SLD, with significantly lower performances than TD students. The authors also found that the phonemic awareness skills of the students with DHH (that were impaired) significantly contributed to their reading decoding. Given these findings, Nelson and Crumpton (2015) ask themselves whether language and literacy delays and difficulties that characterize students with DHH are related directly to altered access to spoken language, to co-occurring language and learning disabilities, or to both. The second study is that by Herman et al. (2019) in which a group of prelingually deaf children aged 10 and 11 years were compared with a group of hearing children with a history of dyslexia; the authors observed striking similarities for word reading, nonword reading, and spelling across groups.

It is well established that impaired phonological processing plays a significant role in the language and literacy difficulties experienced by students with Specific Learning Disabilities (SLD) (Bishop & Snowling, 2004; Catts et al., 2005). Often, these children are initially diagnosed with Developmental Language Disorder (DLD) and later with a language-based learning disorder when hearing problems, neuromotor issues, or cognitive deficits are ruled out. Their phonological processing difficulties are recognized as a critical factor in word-level and subword-level processing challenges, which are central to the difficulties in mapping spoken language to written language seen in both dyslexia and dysorthographia (Bishop & Snowling, 2004; Catts et al., 2005). Thus, these difficulties that tend to also characterize children and adolescents with DHH raise questions about the nature of impaired literacy skills associated with hearing loss.

2. The current study

The current case study analyzed the academic discrepancies, in both reading and writing, between two groups of deaf children with early CI. Specifically, three prelingually deaf children with CI and with important learning deficits (Deaf+LD group), i.e. reading and/or writing performance falling within the diagnostic criteria for SLD in hearing children (International Classification of Diseases - ICD-11, WHO, 2022), were compared to control deaf children with similar clinical history, age at CI implantation and auditory experience but adequate learning abilities (Deaf group). The Deaf+LD group was also matched on chronological age to three hearing children with SLD (SLD group).

Our main research question was whether the reading and writing deficits observed in the three children from the Deaf+LD group could be characterized as a domain-specific learning disorder, rather than solely a consequence of deafness. The early implantation of these three children likely provided them with optimal hearing exposure during the critical perceptual period (Mayberry & Kluender, 2018; Werker & Tees, 2005), which should guarantee a normal literacy development. We therefore hypothesized that the important and unexpected learning difficulties of these three children (Deaf+LD group) were mainly due to a concomitant impairment to the reading and writing system. Thus, in the three children of Deaf+LD group we expected to observe clinical markers equivalent to those of hearing Italian children with SLD (SLD group), such as performances below 2 standard deviations for the speed parameter and below the 5th percentile for the accuracy parameter in reading and writing tasks (APA, 2013; ISS, 2007; PARCC, 2007, 2011).

Focusing on single cases, this work may allow for a more precise delineation of the neuropsychological profile and clinical condition that may characterize some of children with CI (Benassi et al., 2021).

3. Materials and methods

3.1. Participants

The study involved six children with prelingual bilateral profound sensorineural hearing loss (SNHL). These children were selected due to their similar clinical, family, and educational backgrounds, which allowed them to receive identical cochlear implants (CIs) and oral therapy, achieve comparable post-implant auditory thresholds, and possess similar nonverbal intelligence levels (see Table 1 for details). They were recruited from the “XXXXX” Children's Hospital - Audiology and Otosurgery Unit, Cochlear Implant Referral Centre - in XXXX. The inclusion criteria were: (1) prelingual SNHL; (2) no inner ear malformations as confirmed by high-resolution CT and MRI; (3) absence of significant visual, motor, or cognitive issues affecting speech and language development; (4) receipt of oral therapy; and (5) hearing parents with Italian as their native or dominant language.

Details regarding the cause of deafness, age at first amplification, age at intervention enrollment, and age at cochlear implant (CI) surgery are provided in Table 1. The unaided pre-implant auditory threshold was ≤90 dB (PTA) for each of the six children, while the aided hearing threshold ranged between 65 and 70 dB. Deafness was definitively diagnosed between 11 and 22 months in the Deaf+LD group and between 7 and 27 months in the Deaf group. Except for Case 2 in the Deaf group, whose deafness emerged at 16 months, it is assumed that all other children had congenital deafness present at birth. From the time of diagnosis, each child received regular rehabilitation with a speech therapist. All were implanted with a Nucleus multichannel device (Cochlear Ltd., Sydney, Australia). Post-implant auditory thresholds improved significantly, with all six children achieving thresholds between 25 and 35 dB approximately 36 weeks after implantation and at the time of testing. Their speech discrimination thresholds and auditory-verbal skills were assessed using: a) vocal audiometry (Cutugno et al., 2000); b) the Early Speech Perception test (ESP) (Arslan et al., 1997; Moog & Geers, 1991; Pintonello & Ghiselli, 2009a, 2009b); c) the Northwestern University-Children's Perception of Speech(NU-CHIPs) (Elliott & Katz, 1980; Italian version “T.I.P.I. 1 - Test di Identificazione di Parole Infantili” by Pintonello & Ghiselli, 2009b); and d) Word Intelligibility by Picture Identification (WIPI) (Ross & Lerman, 1971; Italian version “T.I.P.I. 2 - Test di Identificazione di Parole Infantili a differenziazione consonantica” by Pintonello & Ghiselli, 2009b). The results demonstrated a high level of accuracy, with speech recognition percentages ranging between 90 % and 100 % for all six children.

All six children had a normal nonverbal intelligence level measured using the Raven Coloured Progressive Matrices (CPM) (Raven, 1984) or the Progressive Raven Standard Matrices (SPM) (Raven, 2000; Raven & Court, 1993) based on the child's age (see Table 1). Table 1 also shows details concerning school and maternal education level for the six cases.

Three of these deaf children demonstrated unexplained disproportionate learning problems, meaning that their reading and/or writing performance fell within the diagnostic criteria for SLD in hearing children (ICD-11, WHO, 2022). Thus, these three deaf children formed the

Table 1
Socio-demographic characteristics and clinical data in the three groups (Deaf+LD group, Deaf group, SLD group).

Groups	Age[a]	Sex	Grade of school	Age at hearing aids	Age at first/second CI activation	Cause of deafness	Unaided pure tone average	Aided hearing threshold level	CI pure tone average	Speech recognition with CI (accuracy)	Type of speech therapy	Familiarity for SLD	Maternal educational level[b]
Deaf + LD group													
Case 1	11 y 11 m	M	Grade 7	23 m	36 m (sx)/–	genetic	106 dB	65–70 dB	25–35 dB	90–100 %	Oral	Yes	High level
Case 2	12 y 6 m	M	Grade 6	14 m	18 m (dx)/18 m (sx)	genetic	106 dB	65–70 dB	25–35 dB	90–100 %	Oral	Yes	High level
Case 3	12 y 8 m	F	Grade 7	12 m	22 m (dx)/57 m (sx)	genetic	106 dB	65–70 dB	25–35 dB	90–100 %	Oral	No	High level
Deaf group													
Case 1	10 y 1 m	F	Grade 4	28 m	30 m (sx)/50 m (dx)	genetic	106 dB	65–70 dB	25–35 dB	90–100 %	Oral	No	High level
Case 2	11 y 6 m	M	Grade 6	–	18 m (dx)/18 m (sx)	meningitis	106 dB	65–70 dB	25–35 dB	90–100 %	Oral	No	High level
Case 3	11 y 7 m	F	Grade 6	8 m	19 m (dx)/41 m (sx)	genetic	106 dB	65–70 dB	25–35 dB	90–100 %	Oral	No	High level
SLD group													
Case 1	11 y 11 m	M	Grade 6	–	–		–	–	–	–	Traditional	Yes	High level
Case 2	12 y 3 m	F	Grade 6	–	–		–	–	–	–	Traditional	No	High level
Case 3	12 y 8 m	M	Grade 7	–	–		–	–	–	–	Traditional	Yes	Low level

[a] Chronological age (years, months).
[b] High level = high-school diploma, Low level = middle-school graduate.

Deaf+LD group while the other three cases formed the Deaf group.

Three additional age-matched hearing children participated in the study, forming the SLD group. These children had a diagnosis of Specific Learning Disabilities (SLD), including dyslexia and dysorthographia. They were recruited from the Anthropos private center for the diagnosis and rehabilitation of learning disabilities. The SLD group children spoke Italian as their primary language and showed no signs of cerebral damage, congenital malformations, or visual and hearing impairments. They received adequate schooling, meaning regular attendance at mainstream schools. Their cognitive levels were within the normal range (for more details, refer to Table 1). All three children in the SLD group receive traditional speech therapy. Traditional speech therapy works on the decoding process, lexical and sublexical aspects (Ripamonti et al., 2010); with regard to dyslexia, it focuses mainly on correctness - reading errors - and speed -using the tachistoscope; it also works to strengthen areas underlying learning (e.g., executive functions).

3.2. Procedure

Both parents of each child were informed about the study's purpose, the voluntary nature of participation, and the right to withdraw at any time. After this phase, both parents provided their informed consent to participate voluntarily.

The six children with CI were evaluated at the Audiology and Otosurgery Unit, Cochlear Implant Referral Center of the "XXXX" Children's Hospital and Research Institute of XXXX, while the three hearing cases with SLD at the Anthropos private centre by a speech therapist.

Testing consisted of a nonverbal intelligence test and a set of standardized tests that examined a variety of language and related domains and reading and writing abilities.

All tests were conducted in a quiet room, following test recommendations, and were administered orally in live voice during two 45-min sessions. The study followed ethical guidelines for the protection of human participants, ensuring compliance with the legal regulations of the country (Declaration of Helsinki), and was granted formal approval by the Research Ethics Committee of Roma Tre University (the approval document was issued on April 8, 2022).

3.3. Measures

Test for Reception of Grammar – version 2 (TROG-2) (Bishop, 1983; Laws & Bishop, 2003; Italian version by Suraniti et al., 2009). The TROG-2 assesses grammatical comprehension in children and adolescents. It includes 80 items divided into 20 blocks, each containing four items that focus on different grammatical constructions. For each item, a sentence is read aloud, and the child is shown four pictures, with one accurately representing the sentence's content. The other three pictures act as lexical or grammatical distractors. Results are reported as raw scores (the number of correctly answered blocks out of a maximum of 20) and percentile values based on Italian norms.

Phonological Processing Test (Test di Programmazione Fonologica). It is a clinical tool designed for Italian children from first to eighth school grade. It consists of 31 three-syllable, four-syllable, five-syllable, six-syllable words (e.g., "diverbio", "chiedibile", "termosifone", "insostenibile"). All words are of medium-low frequency, cover all Italian consonants and vowels and vary across Italian typical phonemic contrasts. The child is asked to repeat the word after the examiner who pronounces the word at normal pitch and loudness. The phonological errors were recorded and converted into standardized scores.

Boston Naming Test (Kaplan et al., 2001; Riva et al., 2000). It's a test designed to assess the subject's word retrieval or word finding abilities. The 60-item stimuli consist of line drawings representing a broad range of tools, animals, foods, and other objects, organized by increasing difficulty. The examined subject is required to pronounce the name of each image. The examiner records the number of correct responses provided by the subject with no semantic or phonemic cues. Standardized scores were calculated for the results.

Battery for the Assessment of Developmental Dyslexia and Spelling Disorders (DDE-2) (Sartori et al., 2007). This tool is a standardized diagnostic test widely used in Italy, consisting of five subtests for assessing oral reading (single grapheme identification, lexical decision task, word reading, nonword reading, and homophone identification) and three subtests for evaluating writing (word dictation, nonword dictation, and sentence dictation with homophones). For the current study, the subtests selected were word reading, nonword reading, word dictation, and nonword dictation. In the reading subtests, the child reads aloud a list of words in the first subtest and a list of nonwords in the second subtest, with the goal of reading as quickly and accurately as possible. The examiner times the performance and records mistakes without interrupting the child. Each subtest is scored based on the number of incorrect pronunciations (errors) and the time (in seconds) taken to read the list. In the dictation subtests, the child writes down a list of words or nonwords as dictated.

MT *reading text – Clinic* (Cornoldi & Carretta, 2018). The MT test is an Italian assessment tool designed to gauge speed and accuracy in oral text reading tasks. It includes a set of texts tailored to different school grades. Participants are instructed to read aloud, aiming for both speed and accuracy, within a 4-min time frame. The examiner records the time taken for reading and notes any mistakes made. The scoring involves the number of misread words (errors) and the calculation of syllables per second (speed). These metrics are then converted into percentile values for interpretation.

Text dictation - Battery for the Assessment of Writing Skills (BVSCO-2) (Tressoldi et al., 2013). This test involves writing a text read aloud by the examiner. It includes a series of texts tailored for different school grades. Five categories of errors are recorded: phonological errors, orthographic errors, accents and doubles, word omissions, semantic errors. The number of errors per category and the total number of errors are calculated and converted to standardized scores.

3.4. Statistical analysis

All statistical analyses were carried out using SPSS 23.0 for Windows. For cognitive (CPM/SPM) investigation we calculated the Intelligence Quotient (IQ); for language (TROG-2, Phonological Processing Test, Boston Naming Test) and learning (DDE-2, MT reading text, BVSCO-2) investigations, we calculated for each participant z-score or percentile value (compared to normative data) and the alpha was set at 0.05.

TROG-2, MT reading text and BVSCO-2 gave us percentile value that represents the percentage of values that fall below a given value.

Regarding Phonological Processing Test, Boston Naming Test and DDE-2 we calculated z-score that consists in the raw score obtained by each participant minus the population mean, divided by the population standard deviation; these values (mean and SD) are shown in tests' manuals with the statistical analysis of psychometrical properties of each validated instrument.

According to tests' manuals and guidelines, scores under 5 percentile or − 2 sd were considered below normal range.

4. Results

Table 2 shows the results of cognitive and language tests in the three experimental groups: Deaf+LD group, Deaf group and SLD group. As can be seen from Table 2, the six implanted deaf children demonstrated adequate cognitive skills. Instead, their reading and writing performances showed a remarkable intersubjective discrepancy, with the children in the Deaf+LD group showing important deficits in both domains.

Table 2
Results from the cognitive and language tests (raw scores and standardized scores) in the three groups (Deaf+LD group, Deaf group, SLD group).

Groups	CPM/SPM		TROG-2		Phonological Processing Test		Boston Naming Test	
	Raw score	IQ	Blocks passed	Percentile value	Raw score	Z score	Raw score	Z score
Deaf + LD group								
Case 1	42	107	9	1°[b]	25	<−10.00[b]	30	−7.72[b]
Case 2	45	112	18	81°	5	−4.27[b]	43	−3.82[b]
Case 3	42	107	15	42°	5	−5.59[b]	38	−5.32[b]
Deaf group								
Case 1	25	90	11	5°[b]	4	−3.83[b]	36	−1.23
Case 2	28	101	16	55°	1	−0.30	48	−1.75[a]
Case 3	41	108	14	27°	4	−3.28[b]	47	−1.98[a]
SLD group								
Case 1	49	121	19	90°	0	0.69	45	−2.43[b]
Case 2	31	88	18	81°	0	0.69	48	−2.32[b]
Case 3	48	117	16	55°	2	−1.95[a]	41	−4.42[b]

[a] Just within normal range.
[b] Below normal range.

As shown in Table 1, post-implant audiometry demonstrated that all six implanted children reached a comparable and effective hearing threshold, with their hearing levels remaining stable at 25–35 dB across frequencies from 250 to 4000 Hz. Additionally, speech perception assessments revealed a high percentage of correctly recognized words among the six implanted children (see Table 1). Nonetheless, clear discrepancies emerged in the language and learning variables that we examined.

Grammar comprehension (TROG-2) was good for two out of three children in both groups (Deaf+LD group and Deaf group), whereas one child per group fell in clinical range; the grammatical comprehension was plainly efficient in the three hearing children with SLD (see Table 2). In the Phonological Processing Test, all three children of the Deaf+LD group and two children of the Deaf group showed phonological competencies clearly below the normal boundaries, with more marked difficulties in the children of Deaf+LD group (Table 2).

The results indicated that the lexical production (Boston Naming Test) was unevenly distributed across the six deaf cases, as well. The children of the Deaf+LD group displayed a marked impairment, similarly to children of the SLD group, whereas the three children of the Deaf Group showed a performance not impaired: within normality (on average) in one case and just within normal range in the other two cases (see Table 2).

When we moved to learning skills, the discrepancies between the two groups of implanted deaf children became even more marked (see Table 3).

Table 3 shows the results from the reading tests: from Table 3, we can observe that both words reading and nonwords reading were clearly below the normal range in the Deaf+LD group, with performance deficits in both accuracy and reading speed. Similarly, the reading performance on the MT reading text was significantly impaired in both accuracy and reading speed (Table 3). In general, the performances of these three children appeared similar to those of the three hearing peers with SLD (SLD group) (Table 3). Instead, the performances showed by the implanted children of the Deaf group in all of these reading tasks were within normal range (see Table 3).

Table 4 shows the results from the writing tests: the assessment of the writing skills (by means of the DDE-2 and BVSCO-2) brought to light a marked intersubjective discrepancy between the learning “efficient” and the learning “inefficient” implanted children (see Table 4). As evident from Table 4, words dictation and text dictation were significantly impaired in the three children of the Deaf+LD group. One case also showed poor performance in nonwords dictation (Table 4). Instead, the three children of the Deaf group performed within the norm in all the tasks, with the exception of one child who showed difficulty writing words (Table 4). The qualitative analysis of writing errors showed the

Table 3
Results from the reading tests (raw scores and standardized scores) in the three groups (Deaf+LD group, Deaf group, SLD group).

Groups	DDE-2 Words reading		DDE-2 Nonwords reading		MT reading text - Clinic	
	Errors/Z score	Time/Z score	Errors/Z score	Time/Z score	Errors/percentile	Speed/percentile
Deaf + LD group						
Case 1	10/−3.00[b]	134 s/−4.19[b]	7/−1.00	97 s/−3.29[b]	6/15–20°[a]	2.18 sill/s/<5°[b]
Case 2	10/−4.00[b]	125 s/−2.38[b]	22/−6.00[b]	92 s/−1.60[a]	12/5°[a]	2.37 sill/s/<5°[b]
Case 3	10/−3.00[b]	102 s/−2.19[b]	16/−4.00[b]	90s/−2.79[b]	22/<5°[b]	2.37 sill/s/<5°[b]
Deaf group						
Case 1	3/0.00	107 s/0.13	6/−0.25	71 s/0.41	3/50–60°	3.02 sill/s/30–40°
Case 2	0/1.00	65 s/0.48	3/0.33	30s/1.50	2/60°	4.63 sill/s/70–80°
Case 3	2/0.00	103 s/−1.33	4/0.00	73 s/−0.65	1/80°	3.34 sill/s/20–30°
SLD group						
Case 1	7/−2.50[b]	111 s/1.71[a]	6/−0.67	94 s/−1.70[a]	14.5/<5°[b]	3.21 sill/s/15–20°
Case 2	18/−4.50[b]	131 s/−2.67[b]	26/−7.33[b]	100 s/−2.00[b]	30/<5°[b]	2.38 sill/s/<5°[b]
Case 3	2/−0.33	141 s/−4.63[b]	3/−0.33	87 s/−2.57[b]	12/<5°[b]	2.32 sill/s/<5°[b]

[a] Just within normal range.
[b] Below normal range.

Table 4
Results from the writing tests (raw scores and standardized scores) in the three groups (Deaf+LD group, Deaf group, SLD group).

Groups	DDE-2 Words dictation		DDE-2 Nonwords dictation		BVSCO-2 Text dictation		BVSCO-2 Type of error		
	Errors	Z score	Errors	Z score	Errors	Percentile value	Phonological errors/Z score	Orthographic errors/Z score	Accents and double letters/Z score
Deaf + LD group									
Case 1	5	−4.00[b]	13	−5.50[b]	23	<5°[b]	19/−15.66[b]	0/–	4/−9.82[b]
Case 2	9	−8.00[b]	5	−1.00	18	<5°[b]	8/−5.01[b]	1/0.00	9/−8.08[b]
Case 3	8	−7.00[b]	5	−1.50[a]	17	<5°[b]	9/−7.04[b]	0/–	8/<−10.00[b]
Deaf group									
Case 1	6	−2.50[b]	6	−1.50[a]	3	40–50°	3/−0.93[a]	0/–	0/–
Case 2	0	1.00	4	−0.50	3	30–50°	2/−0.60	1/0.00	0/–
Case 3	0	1.00	5	−1.00	5	10–20°[a]	1/0.14	0/–	4/−2.64[b]
SLD group									
Case 1	2	−1.00	0	1.50	6	5–10°[a]	1/0.14	2/−0.89[a]	3/−1.55[a]
Case 2	9	−8.00[b]	8	−2.50[b]	27	<5°[b]	18/−12.36[b]	3/−1.79[a]	6/−4.82[b]
Case 3	1	0.00	2	0.00	9	<5°[b]	6/−4.46[b]	2/−1.23[a]	1/−2.13[a]

[a] Just within normal range.
[b] Below normal range.

children of the Deaf+LD group make a high number of phonological errors and omissions of accents and double letters, similarly to children of the SLD group (see Table 4). In the Deaf group, only one case showed a number of omissions of accents and double letters below the normal range (Table 4).

5. Discussion

In this case study, we examined two groups of prelingually deaf children with CI who showed strongly discrepant reading and writing outcomes. Specifically, the three cases of the Deaf+LD group showed severe reading and writing deficits, with performances significantly below the age level. By contrast, the three children of the Deaf group demonstrated normal reading and writing abilities.

The aim of this work is to study the possible comorbidity between deafness and learning disabilities. There are not many studies that investigate the intersection of deafness and learning disorders. The most relevant ones (see the paragraph “Introduction”) show that in students with specific learning disabilities, an altered phonological processing plays a significant role in the language and literacy difficulties found (Bishop & Snowling, 2004; Catts et al., 2005). Another relevant study on single cases (see the paragraph “Current study”), outlines the neuropsychological profile and clinical conditions that can characterize some children with CI (Benassi et al., 2021).

Auditory and speech perception are thought to contribute significantly to individual differences in phonological development, which in turn plays a crucial role in reading and writing skills (Bailey & Snowling, 2002; Boets et al., 2007; Goswami et al., 2021; Ramus et al., 2010). Neurobiologically, auditory stimuli processing, speech perception, and higher-level phonological and linguistic information are mediated by two parallel pathways (Hickok & Poeppel, 2000; Scott & Johnsrude, 2003). The first pathway connects the posterior temporal cortex to inferior parietal regions, as well as to inferior frontal regions (Hickok & Poeppel, 2000). This parietal-frontal network functions as an interface between auditory and articulatory representations of language (Démonet et al., 2005). It is also implicated in lexical retrieval (e.g., Misra et al., 2004), grapheme-to-phoneme conversion (e.g., Jobard et al., 2003; Simos et al., 2002), and processes related to phonological memory (e.g., Becker et al., 1999; Scott & Wise, 2003). The second pathway is the antero-ventral route, which links the bilateral dorsal superior temporal gyrus (STG), responsible for analyzing the physical characteristics of speech, to the superior temporal sulcus (STS) and middle temporal gyrus (MTG), which are involved in lexical-semantic processing and higher-level linguistic functions (Liebenthal et al., 2005; Scott et al., 2000; Scott & Wise, 2003). This pathway processes acoustic features which are crucial for speech perception, such as temporal variations in amplitude and spectral shape (Liebenthal et al., 2005; Scott & Wise, 2003). As some authors observed (Sharma et al., 2004), the early stages of the speech processing in early implanted children “may be positively influenced by the rate of plastic changes in central auditory pathways” (p. 511). In the literature, several studies (e.g., Cuda et al., 2014; Kral & Sharma, 2012; Nakahara et al., 2004; Robbins et al., 2004) have highlighted that the enhanced auditory perception resulting from early cochlear implantation significantly influences the language acquisition of children with hearing loss. To put it differently, early cochlear implantation seems to be ideal for fostering neural pathways related to auditory perception, as it enables children to take advantage of the brain's neuronal connection development. As a result, many children who receive the CI at early age develop adequate language skills and good reading and writing abilities (e.g., Colletti et al., 2012; Simon et al., 2019; Wang et al., 2021).

However, the phonological processing skills and the reading and writing abilities of some of these early implanted children appear significantly impaired, as some studies found (Herman et al., 2019; Nelson & Crumpton, 2015) and as we observed in the three children of the Deaf+LD group. Some authors observed striking similarities between the literacy profiles of English-speaking students with CI and hearing students with SLD (Herman et al., 2019; Nelson & Crumpton, 2015). We believe that our results provide new evidence of a possible comorbidity between deafness and SLD in implanted Italian children in whom reading and writing development should also be facilitated by the transparency of the Italian language. The phonological deficit theory, the prevailing etiological perspective on developmental dyslexia (DD) and dysorthography, posits that literacy challenges stem from a cognitive deficit specifically related to the representation and processing of speech sounds (Snowling, 2000). Investigations into the neurological basis of DD and dysorthography suggest that phonological difficulties may arise from a more fundamental deficit in the basic perceptual mechanisms responsible for auditory temporal information processing. A basic impairment in perceiving auditory temporal cues can lead to difficulties in accurately detecting the rapid acoustical changes in speech (Boets et al., 2007; McArthur & Bishop, 2001). For example, the temporal sampling framework (Goswami, 2011) suggests that difficulties in auditory discrimination, especially concerning amplitude rise times, play a significant role in the phonological challenges observed in children with developmental dyslexia (DD) across various languages. Essentially, problems with speech perception trigger a cascade of effects, beginning with disruptions in the normal development of the phonological system and leading to subsequent difficulties in learning to read and spell (Ramus, 2003; Talcott et al., 2002). The three cases of the Deaf+LD group may fall into this scenario. By contrast, the three children of the Deaf group, although showing similar clinical features and language difficulties (especially of phonological processing) to the Deaf+LD group, demonstrated normal reading and writing skills. Specifically, two of them demonstrated literacy abilities within normal range; one of them showed some writing difficulties but not severe enough to meet the criteria for dysorthography. It should also be noted that this last case received hearing aids later than the other cases (of both groups) and the CI later than the other two children of the Deaf group; the writing difficulties of this case may therefore be attributed to deafness.

In explaining the possible causes of these literacy outcomes, it is also necessary to consider that the unique sensory and linguistic experience of the deaf children may influence the basic processes that guide their reading and writing acquisition (Emmorey & Lee, 2021). For instance, research suggests that, during visual word processing, deaf adults rely less on phonological processing and exhibit greater activation of the right brain. Skilled deaf readers, when reading, process visual word forms more efficiently and rely more on semantic information compared to hearing peers (Emmorey & Lee, 2021). While activation of the right brain is considered dysfunctional for hearing readers—since the right brain tends to treat words more like images, which can result in less precise orthographic representations (Laszlo & Sacchi, 2015)—it appears to be an effective strategy for deaf adults. This is because their reduced auditory input and the absence of phonological tuning for orthographic representations make right brain engagement advantageous for processing visual word forms (Emmorey et al., 2017; Sehyr et al., 2020). Although these studies primarily focus on English-speaking adults, this evidence suggests that there may be additional neurofunctional processes affecting reading and writing difficulties in Italian deaf children with cochlear implants.

It is widely recognized that reading and writing circuits are inherently complex, and a single-deficit perspective, while significant on its own, does not align with the current multi-componential understanding of reading disabilities (Norton & Wolf, 2012). Wolf and Bowers (1999), in their research with large samples of children with developmental dyslexia (DD) in the United States and Canada, found that phonological skills and Rapid Automatized Naming (RAN) each independently contributed to reading ability. They proposed the double deficit hypothesis (DDH), which suggests that children can be classified into different sub-groups based on their performance in these areas. According to DDH, a deficit in either phonological skills or RAN can lead to reading difficulties, and when both deficits are present, they are associated with more severe reading disabilities. Further studies (Katzir et al., 2008; Waber et al., 2004; Wolf et al., 2002) reported that 60 % to 75 % of individuals with specific learning disabilities (SLD) exhibit RAN deficits, which may serve as a significant marker of developmental dyslexia (Brizzolara et al., 2006; Georgiou et al., 2012;Swan & Goswami, 1997; Wolf, 1991), particularly in transparent languages (Becker et al., 2017). Additionally, some findings (Swan & Goswami, 1997; Wolf, 1991) indicated that children with DD tend to make more lexical errors compared to typical readers in picture naming tasks. Although a RAN task was not administered to our children, the three cases of the Deaf+LD group showed naming skills (at the Boston naming test) well below the normal range, similarly to the group of hearing children with SLD. Instead, the children of the Deaf group showed performances within normal limits. Thus, the literacy profiles of the three children of the Deaf+LD group, compared with those of the Deaf group, seem to reinforce our hypothesis of a comorbidity between deafness and SLD in these children. The familiarity for SLD that we observed in two out of three cases of the Deaf+LD group appears to strengthen our hypothesis as well. Family history for SLD is evident in the Deaf+LD group (as well as in the SLD group). Indeed, SLD is a condition that also exhibits strong familial and genetic predisposition, as several studies have demonstrated (e.g., Becker et al., 2017; Grigorenko, 2021; van Bergen et al., 2014; for a wide review on the relation between dyslexia and genetics, see Peterson & Pennington, 2015).

According to the two main international diagnostic manuals, the Diagnostic and Statistical Manual of Mental Disorders (DSM-5) (APA, 2013) and ICD-11 (WHO, 2022), a child receives the diagnosis of SLD when he/she shows impaired reading, writing and/or math abilities in the absence of intellectual disorder, sensory impairment (vision or hearing), neurological disorder, psychosocial adversity, and despite the presence of adequate education and proficiency in the language of academic instruction. In Italian context, a more detailed definition of the clinical criteria for the diagnosis of dyslexia and dysorthography (ISS, 2007; PARCC, 2007, 2011; SNLG-ISS, n.d.) establishes that the literacy performances of the child, assessed using standardized tasks, should be significantly lower than those of peers of the same school grade, namely below 2 standard deviations (SD) for the speed parameter and below the 5th percentile for the accuracy parameter in at least two reading tasks (for diagnosis of dyslexia) and two writing tasks (for diagnosis of dysorthography). This is exactly what we observed in the three children of the Deaf+LD group, who showed performances below normal levels ($<$ 2 SD or $< 5^{\circ}$ percentile) in almost all the reading and writing tests that were administered. The number of errors and the executive slowness demonstrated by these children in reading and writing tasks could therefore be attributed not only to deafness but to a concomitant impairment of those brain structures involved in reading and writing computation. In the Italian context and in many other countries, the diagnosis of SLD in a deaf child cannot be made, as deafness is one of the exclusion criteria for this disorder. But, are the sensory problems that we observed in early implanted children high enough to justify their learning difficulties? Or can we talk about comorbidity? In the past, when there were no state-of-the-art hearing aids and cochlear implants, it was more difficult to discriminate between learning problems resulting from deafness or SLD. But now, the hearing experience of these children has greatly improved and studies from the last 10 years show good literacy abilities in early implanted children (Colletti et al., 2012; Harris, 2016; Harris et al., 2017; Simon et al., 2019; Wakil et al., 2014; Wang et al., 2021). In some cases, however, this does not happen; despite very good speech perception skills, some of these children show disproportionate difficulties in reading and writing tasks.

In light of the above, it is possible that certain neurobiological and neurofunctional processes occurring in the brain of a child with SLD may sometimes also occur in the brain of a deaf child with CI. According to some authors (Kral et al., 2016), CI certainly restores the functionality of the auditory cortex; however, the bottom-up and top-down connections that emanate from it and that constitute the connectome may react very differently from brain to brain. In some cases, deafness may lead to what the authors refer to as a "connectome disease" (Kral et al., 2016). Perhaps this is not very different from what occurs in the brain of a hearing child with SLD. Starting from deficits in the underlying basic perceptual processes, there are cascading negative effects on the connections for the phonological development, for example, and consequently on the acquisition of reading and writing (Goswami, 2011; McArthur & Bishop, 2001). Increasing evidence suggests that the issue in dyslexia may lie in the type of connections and the speed at which information is transmitted through them (Lou et al., 2019; Paulesu et al., 2014); some authors provide evidence that the problem may reside within the "reading connectome" (Sihvonen et al., 2021). Similar neurobiological and neurofunctional processes therefore seem to occur in the brains of some deaf children with CI, and this may account for the wide interindividual variability observed among them. In children like those described in the Deaf+LD group, we cannot determine whether their reading and writing deficits stem from deafness, genetic factors, or another neurobiological cause. However, what is evident is that in some cases, we are facing atypical neurodevelopment of reading and/or writing functions. The clinical profile that characterizes some of these children is the same of hearing children with SLD.

Thus, if SLD is a neurodevelopmental disorder that affects the general population, why should it not affect deaf children as well? We believe that it is necessary to start thinking about the possibility of making a diagnosis of SLD even in deaf children with early CI. The possibility of making early diagnoses of a learning disorder would allow immediate intervention with specific reinforcements. By specific intervention, we mean intervention that is not aimed only at deafness but, as with children with SLD, supports the skills in difficulty, namely reading, writing, and computation.

Limitations of this study should be acknowledged. Firstly, due to its nature as a case study, caution is needed in generalizing the findings. Replication of these results with larger sample sizes is essential for future research. Secondly, the current study did not incorporate the evaluation of RAN and did not consider the influence of domain-general neurocognitive processes, such as verbal working memory, procedural memory, and executive functions. Several authors showed the relevance of these processes to language development in children with DLD (e.g., Pettenati et al., 2015), as well as to reading and writing skills in both students with SLD (e.g., Altemeier et al., 2008; Varvara et al., 2014) and deaf children with CI (e.g., Arfé et al., 2015; Fastelli et al., 2021). Third, the lack of longitudinal data may influence the generalizability of the results since it does not provide us with an evolutionary trajectory but only a snapshot of a specific time point. Fourth, we did not measure the psychological wellbeing of these children. Several studies have found psychological difficulties in Italian students with SLD (Benassi, Camia, et al., 2022; Benassi et al., 2022; Scorza et al., 2018) and close relationships between the levels of reported learning difficulties and externalizing problems (Benassi et al., 2022). Deaf students as those of the Deaf+LD group could greatly suffer from the dual condition of disability. Future research should consider all these factors to better understand their contribution on the academic outcomes of these children. Finally, another limitation of this study is the lack of neurofunctional correlates, which are essential for explaining the link between deafness and functional deficits in reading and writing systems. Future research should follow these directions. Despite these shortcomings, we think that this work may prompt the scientific and clinical communities to consider the possibility that diagnosing SLD in certain children with CI could be appropriate.

6. Conclusions

In the present work, we suggest the potential presence of comorbidity between deafness and SLD, especially in cases where factors promoting good linguistic development, which serve as the foundation for reading and writing skills, are present (e.g., early age of first amplification and rehabilitation, early age at implantation, good auditory recovery, normal cognitive abilities, high maternal education level).

This possibility could have important clinical implications for both assessment and intervention with these children. During the assessment, tests valid for identifying impaired reading and writing skills and precursors of SLD among deaf children must be used. Although the reading and writing tasks used in this work and widely used in the Italian clinical practice appeared effective in this sense, deeper investigations of the validity of these and other assessments when used with implanted children are warranted. The early identification of reading and writing impairments in these children may allow for planning and implementation of more adequate interventions in both clinical and school contexts. In children like those of the Deaf+LD group, interventions are necessary that specifically target the affected literacy areas, in a manner similar to those provided for children and adolescents with SLD. In school context, the Italian guidelines for the teaching and inclusion of students with SLD (Law 170/2010) are structured around a comprehensive and systemic action plan, designed to support and safeguard students throughout their academic journey. This includes ensuring the implementation of compensatory tools and dispensatory measures, such as alternative learning methods and the use of technologies. If the hypothesis of a comorbidity between deaf and SLD is true, then these same actions should also be implemented with children like those of the Deaf+LD group, to support their learning and prevent psychological consequences. Furthermore, as stated by Holzinger et al. (2022), since these children have to deal with a double difficulty, early interventions should also include a focus on emotional health, psychosocial skills, family coping and quality of life (Gragnaniello et al., 2024).

In conclusion, it is essential to remain aware that the cause of an atypical developmental trajectory in deaf children with CI could be either primary (as in hearing children) or secondary to deafness. We also believe that, regardless of the cause behind the atypical trajectory, the focus should be on the developmental outcomes, namely the child's current clinical condition. The child's clinical condition may appear as atypical neurodevelopment in literacy (and math) abilities, which it is important to classify as SLD to ensure appropriate interventions both in clinical and school settings.

CRediT authorship contribution statement

Elena Tomasuolo: Writing – review & editing, Writing – original draft, Supervision, Methodology, Conceptualization. **Arianna Bello:** Supervision, Funding acquisition, Conceptualization. **Manuela Gragnaniello:** Methodology, Data curation, Conceptualization. **Alessandra Resca:** Methodology, Data curation, Conceptualization. **Maddalena Bassoli:** Data curation. **Erika Benassi:** Writing – original draft, Supervision, Formal analysis, Conceptualization.

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Declaration of competing interest

The authors of this article have not reported any financial or non-financial conflict of interest.

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Data availability

Data will be made available on request.

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