Listening Comprehension in profoundly deaf children with cochlear implants: the role of auditory perception and foundational linguistic and cognitive skills

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ABSTRACT

Purpose

The aim of the study was to investigate the listening comprehension (LC) skills in deaf and hard of hearing children (DHH) using cochlear implants (CI). Besides, various factors that could influence the levels of competence reached were analysed.

Methods

Thirty-four children using CI were enrolled. LC skills were assessed through the standardized Italian test "Comprensione Orale-Test e Trattamento" (CO-TT). A univariate analysis was conducted to compare LC with gender, listening mode (unilateral or bilateral), maternal level of education and family income. A bivariate analysis was performed to search possible connections between children performances and their individual characteristics, audiological conditions and language levels. Finally, a multivariate analysis was performed using a stepwise hierarchical linear regression model which included all variables whose p-value resulted $\leq .05$.

Results

Twenty-one children using CI (61.8%) showed adequate performances in terms of chronological age, while 13 (38.2%) showed difficulties in LC. Maternal level of education, age at diagnosis and non-verbal cognitive level accounted for 43% of the observed variance. Auditory attention skills explained an additional 15% of variance. Morphosyntactic comprehension added a further 12% of variance.

Conclusion

CI can really help many DHH children to reach adequate LC skills, but in some cases difficulties remain. Factors influencing LC need to be early investigated and considered when planning an appropriate rehabilitative intervention.

KEYWORDS: cochlear implant, listening comprehension, auditory attention, deaf children

INTRODUCTION

Listening Comprehension (LC) refers to the ability to understand messages that are delivered orally such as conversational language, verbal instructions, lessons explanations and texts read aloud. It represents the principal means through which humans gain competence in oral communication, considering that 45% of one's linguistic competence derives from listening, 30% from speaking, 15% from reading and 10% from writing [1].

LC is also crucial for success in formal education at school, where children are involved in receiving and comprehending orally presented messages by teachers and classmates, for more than 50% of the time [2]. LC abilities significantly impact the academic success and are strictly related to the development of reading comprehension skills [3].

LC is a very complex skill. As explained by Kintsch, the linguistic input of an orally transmitted message is perceived and represented in terms of exact wording and phrases [4]. On this basis, elementary and literal relations between propositions are established. The propositions are thereafter integrated across the discourse, both in accordance with the context and with the listener's background knowledge. The entire process requires adequate processing of the auditory information, adequate foundational linguistic skills (vocabulary and grammatical knowledge) and adequate foundational cognitive skills (working memory and auditory attention) [5].

In details, the auditory perception involves the ability to detect speech sounds, determine their spectral shape and discriminate their modulations in amplitude and frequency with a good temporal resolution and the ability to segregate the signal of interest from background sounds, including other speech sounds, when the message is delivered in noise[6]. Language skills are needed to represent words and phrases in a listened speech, to derive plausible propositions and to grasp the meaning. Children's vocabulary is related to LC [7] and children's grammatical knowledge is related to sentence processing [8]. Phonological working memory is needed to store words temporarily while processing and integrating them with new linguistic information (e.g., phrases). It is also needed to construct elementary local propositions and some initial inferences [9]. Furthermore, phonological working memory is believed to play an important role in integrating propositions and in establishing global consistency between sentences, text and background knowledge [10]. Auditory attention skills, in particular sustained attention and selective attention are necessary to maintain attention for a long time on the desired oral message and to ignore multiple irrelevant stimuli, which occur in a real-life context [11].

All the domains involved in LC are at risk of being compromised in children using Cochlear Implants (CI). In general, CI guarantee an optimal auditory perception in cases where verbal messages are delivered at a normal conversation level and in the absence of competitive noise [12]. Conversely, auditory perception declines significantly when the intensity of the signal decreases or the distance between speakers increases. This happens also when the conversation takes place in presence of background noise or in an environment which has poor acoustic properties, such as reverberant rooms [13]. Challenging listening conditions which reduce speech intelligibility are frequent at school. Children using CI often spend many hours at school and experience listening fatigue that negatively affects their levels of attention, their ability to memorize and the kind of pastimes they pursue [14]. The reduced audibility and listening fatigue interfere with incidental learning. Children with CI often loose opportunities to improve their linguistic competence and they are also at risk of missing important information during oral lessons [15]. Furthermore, they are likely to lag behind in school achievements when compared to their peers who have a better and stable access to oral information [15]. The foundational language skills of children using CI have been improving over the years and nowadays an increasing number of them can gain adequate lexical and grammar skills. However, variability in performances is still reported and children using CI might experience a delay in achieving language competence [16]. Furthermore, children with CI are at risk of presenting diminished working memory abilities if compared to their hearing peers. Studies on pediatric CI users found deficits in some tests: digit span, immediate serial recall of words' list and non-word repetition [17]. Lastly, children using CI seem to have worst performances concerning auditory attention skills. Compared to their hearing peers, they exhibit limited sustained auditory attention skills, making more errors due to inattentive or impulsive responses [18], as well as selective auditory attention skills, showing a reduced ability to ignore a competing stream and to select the stream of interest within the auditory flow, even when they are bilateral CI users [19].

These limitations might impact the development of LC skills in CI users.

LC skills have not been studied as a primary focus of interest in children using CI until now. Only Geers & Sedey [20] and Bell et al [21] considered a partial assessment of LC skills by means of a subtest derived from the Clinical Evaluation of Language Fundamentals- 4th Edition (CELF-4), that is called "Understanding Spoken Paragraphs" and assesses the comprehension and recall of factual details and information from some paragraphs presented orally as connected discourse. Geers & Sedey [20] found that this task was more challenging for CI adolescents, despite they experienced 10 or more years of CI's use, even when oral speaking was supported by sign language. On the contrary, Bell et al [21] reported similar performances between CI users and their hearing peers.

Given the paucity of knowledge in this important domain, the primary outcome of the present study was to investigate the LC levels attained by 8- to 13-year-old deaf and hard of hearing children who were CI users. The secondary outcome was to investigate the factors that could impact the levels of competence these children would reach, considering the CI children's familiar and personal variables, their audiological condition and their foundational linguistic and cognitive skills. It was hypothesized that children with better LC ability would also demonstrate greater listening ability and linguistic competence. Moreover, the best predictive factors of LC were thought to be associated with early intervention, in terms of age at diagnosis and age of cochlear implantation. Higher LC skills were thought to be associated with higher level of foundational cognitive skills like auditory attention and phonological working memory.

METHODS

The present research is an observational cross-sectional study.

Children using CI were recruited in two Italian Cochlear Implant Centers that cooperated for the study's implementation (The Department of xxxxxxxxxx, and the ENT department of xxxxxxxxxxx). Their parents gave written informed consent before any study-related procedure. Ethical approval was obtained by the local IRB (Rif. 5982 Prot. 259/2020).

The study protocol was realized in accordance with the ethical requirements of the Helsinki Declarations, the Epidemiological Good Practice Guidelines of the ICH (International Conference of Harmonization) and the existing legislation in Italy.

Participants

To be eligible to the study, participants should be congenital profound deaf (Pure Tone Average in the better ear ≥90 dB HL for 250–4000 Hz) CI user, aged by 8 to 13 years at the time of enrollment. Additional inclusion criteria were the following: monolingual Italian speakers, normal cognitive level, absence of associated pathologies, normal cochlea anatomy, full insertion of the electrodes' array and absence of central auditory processing disorders (CAPD).

Data related to audiological aspects (age of diagnosis, age of implantation, hearing age, monoaural/binaural condition) were collected for each subject and considered for the analysis of factors influencing LC skills.

Information concerning family income (FI) and maternal level of education (MLE) was also collected. FI was defined referring to the ISEE (Indicatore della Situazione Economica Equivalente) Index as the main expression of household income in Italy. The ISEE index bases the allocation in one FI class computing the annual income, the real estate asset, the number of components in the family and the city of residence (https://www.inps.it/nuovoportaleinps/default.aspx?itemdir=50088#h3heading3). Considering the ISEE index, three FI classes were defined: low, middle and high.

The participants' MLE was classified on the basis of the years of formal education and three levels were considered: low (8 years –junior secondary school diploma), middle (13 years, senior secondary school diploma) and high (18 years, University degree).

General assessment

A general assessment was performed to gain clinical data characterizing the sample that could influence LC skills.

The non-verbal cognitive level was measured through Raven's Coloured Progressive Matrices (CPM) [22]. The test considered normal scores as being equal or over the 25th percentile.

The sound field detection thresholds (SFDT) were obtained for each child both in monaural and binaural conditions. Frequency-modulated tones of the audiometry were used for this purpose and octave frequencies were tested ranging from 250 Hz to 4000 Hz. Speech perception was assessed through open-set tests of spoken word recognition [23]. The tasks consisted of Italian words referred to the pediatric population that were bisyllabic and phonetically balanced. Words were divided in lists of 10 items each. The lists of words were presented at a sound level of 65 dB SPL first in quiet and then in background noise considering a signal-to-noise ratio (SNR) equal to +5 as suggested by Madell et al. [24]. The final score of the tests was considered in terms of the percentage of words correctly repeated by the child. Both SFDT and speech perception were assessed for each child in a sound-treated room, via a loudspeaker placed at a distance of 1 meter in front of the child.

The Categories of Auditory Performance-2 (CAP-2) were also adopted to rate cochlear implants outcomes in an everyday life context [25].

Sustained auditory attention, selective auditory attention (SA) and phonological working memory skills (PWM) were assessed using specific subtests taken from "Batteria per la Valutazione dell'Attenzione Uditiva e della Memoria di Lavoro Fonologica nell'età evolutive - VAUM-ELF" [26]. These subtests, for school-aged children, were performed using recorded lists administered to each child at 65 dB SPL in a double-walled sound-treated room with two loudspeakers placed at ±45°, 1 meter from the subjects' head.

Lexical and morphosyntactic comprehension were respectively investigated through The Peabody Picture Vocabulary Test-PPVT [27] and the Test for Reception of Grammar-TROG-2 [28]. The children were tested individually in a quiet room by two trained speech therapists.

Details on the auditory attention, working memory and linguistic tests are reported in Table 1.

Listening comprehension assessment

The standardized Italian test "Comprensione Orale - Test e Trattamento" (CO-TT) was used to assess the children's LC skills [29-30]. The CO-TT consisted of a series of informative texts. Their complexity was determined on the basis of lexical, syntactic, contextual, inferential and metacognitive processes that each child could master considering their chronological age and the school class they attended. There is a text for each school class attended by the child. The administration followed indication of CO-TT manual [29-30]. The examiner, after selecting the text corresponding to the school class attended by each child, read it aloud in a quiet room at a distance of 1 meter from the listener. The examiner used a conversational level of voice, without any other precautions, to resemble a typical everyday listening condition. The reading test was subdivided in two parts. Each child listened to the first part of the reading and then answered six questions read aloud by the examiner. Each question had four possible answers that the child could choose from. The second part of the reading was followed by another series of six questions structured in the same way.

The number of correct answers were recorded and converted in standardized scores by the examiner. The normal performance indicated by the authors was located equal or beyond the 30th percentile. The CO-TT test was applied and standardized on a sample of 2239 primary school children (8- to 10-years-old) and on 1824 secondary school children (11- to 13- years-old). The Cronbach α and test-retest reliability were .64 and .573 respectively.

Statistical analysis

Continuous variables were expressed through the median and the range, whereas categorical variables were formulated through proportions.

A univariate analysis was conducted using nonparametric tests. Kruskal-Wallis and Mann-Whitney tests were used to compare LC with gender, listening mode (unilateral or bilateral CI users), MLE and FI.

A bivariate analysis was performed using Spearman's rank correlation coefficient. The aim was to assess a possible relationship between LC skills expressed by the CO-TT test and continuous variables characterizing each child. The variables considered were the following: personal variables (CPM, age at diagnosis, age at cochlear implantation, hearing age), audiological variables (SFDT, speech perception both in quiet and in noise, CAP-2), variables related to sustained and selective auditory attention (ACPT, SA1-N, SA1-T, SA2-N, SA2-T), variables related to PWM (DM, NWR, CSNW, NWM) and variables related to language (PPVT and TROG-2).

A multivariate analysis was performed through the use of a stepwise hierarchical linear regression model including all the variables with $p \leq 0.05$ [31]. Each variable's contribution to the prediction of the model was assessed in stages, progressively removing some information and allowing the identification of a statistically significant amount of variance in the outcomes that could be related to specific predictors. Variables progressively entering the subsequent stages of the analysis were tested for their specific contribution to variance after accounting for all other previous variables. The order of the variables entering the analysis was set considering their established importance as predictors, i.e. the well-known effect of age at diagnosis and age at CI for the development of LC skills. Variables of particular interest were added later in the analysis to consider their pure effect on variance. A significant improvement in R^2 was searched for comparing a model to another.

The statistical significance level was set considering p-value < 0.05. Statistical analyses were made using a PC version of Statistical Package for Social Sciences 25.0 (SPSS, Chicago, IL, USA).

RESULTS

Descriptive analysis of the participants

Thirty-four congenital profound deaf CI children met the inclusion criteria stated in method section and were enrolled in the study. Table 2 shows their main demographic and clinical features.

All children participated in aural-oral therapy sessions and used verbal communication, with Italian language as their first and only language. They were all included in normal classes and followed by the support teacher according to the legislative provisions of the Italian Ministry of Education.

Detailed scores for speech perception, auditory attention, PWM and linguistic skills are reported in Table 3.

The majority of children showed good results in terms of speech perception, both in quiet and in SNR +5. Concurrently, they revealed high auditory performances (CAP-2 ≥7) and they were able to converse in difficult contexts such as noisy or reverberant environments or during a phone call.

Sustained attention skills were adequate in most of the children (94%). Only 2 subjects (6% of the sample), who had received CI respectively at the age of 38 and 66 months, made large number of errors, showing performances below what expected for their chronological age. Performances were wholly different regarding dichotic tasks for the assessment of selective auditory attention. Only few children made the number of errors equal or below the cut off value (1 error) and the percentage of those who did not perform adequately was high in all four tasks: SA1-N = 50%; SA1-T = 47.1%; SA2-N = 61.8%; SA2-T = 70.6%. The number of children who perform below the average increased passing from the easiest SA1-N task (fixed target "CANE", presented together with a competitive message with little interference) to the most difficult SA2-T task (a varying target presented together with a very interfering competitive message).

Regarding PWM**,** the most demanding tasks were Non-Words Repetition (NWR) and Comparison of Series of Non-Words (CSNW). The results achieved by 18 children (52.9%) placed them in the Gauss Curve not over 1 standard deviation of the average in both tasks. Conversely, 16 children (47.1%) showed performances below the average of their chronological age. Better performances were observed for Non-Words Memory (NWM) and Digit Memory (DM): 61.8% of children achieved results within the normal range for NWM and up to 70.6% of them reached scores within normality for DM.

Concerning language skills, 64.7% of subjects achieved performances within the normal range for lexical comprehension, while 67.6 % reached normal scores for morpho-syntactic comprehension.

LC skills

CO-TT scores assessing LC did not follow a normal distribution curve. Twenty-one children (61.8%) performed in the range 30th-90th percentile and were positioned in the normal range. A total of 13 children (38.2%) showed difficulties in LC: 7 of them (20.6% of total sample) achieved results that could be comprised between the 10th and 29th percentiles, an alert for a careful and close follow-up; the remaining 6 of them (17.6%) obtained scores lower than the 5th percentile, which represents a clinical cut-off for the need of immediate intervention.

Factors affecting LC

CO-TT results were significantly worst in children whose mothers had a low level of education (H= 10.06, p= .007). Conversely, no statistically significant differences were found considering factors like listening mode (U=98.5, p=.13), gender (U=107, p=.3) and family income (H= 1.3, p= .5).

Variables showing a statistically significant correlation with CO-TT results ($p<0.05$) were the following: CPM, age at diagnosis, bisyllabic word recognition in quiet and in noise, CAP, tasks related to selective auditory attention (SA1-N, SA1-T, SA2-N, SA2-T), PWM subtests (DM, NWR, CSNW, NWM) and language skills tests (PPVT and TROG-2).

Considering the large number of outcome variables and the high correlation between them, a principal component analysis (PCA) was adopted (Johnson, 1998). Three principal components were identified: the audiological component (open set words recognition in quiet and in speech noise equal to 5 S/N, CAP-2), the selective attention component (SAc) (SA1-N/T, SA2-N/T) and the phonological working memory component (PWMc) (DM, NWR, CSNW, NWM). KMO index was equal to 0.69 for the audiological component, while it was equal to 0.743 and 0.85 for the SAc and the PWMc respectively. Bartlett's test was statistically significant with $p < 0.001$ (Table 4).

A new bivariate analysis (Table 5) was then performed to evaluate correlations between variables and the CO-TT results.

The regression analysis was performed stepwise including variables from bivariate correlation and non-parametric analyses with $p \leq 0.05$ (Table 6). Step 1 included MLE, age at diagnosis and CPM: the statistical correlation with CO-TT assessing LC accounted for a 43% of variance. In step 2, the audiological component and the SAc were included, constituting an additional 15% of variance, which represents a significant amount. In this step, the model was explained by the CPM (non-verbal cognitive level) and the SAc. In step 3, the language skills and the PWMc were added. In this last step, the TROG-2 test alone, which describes the morphosyntactic comprehension, added a further

12% of variance. This prediction model indicates the unique contribution of morphosyntactic comprehension and selective attention to the oral comprehension task.

DISCUSSION

The purpose of the present study was to assess the LC skills in a group of educated children using CI. Besides, the scope was to identify not only the personal and audiological variables, but also the foundational aspects of language and the cognitive factors that might contribute to the achievement of proper LC skills. Although the majority of children using CI (61.8%) showed results within the normal range, the remaining 38.2% fell within the range necessitating clinical attention or immediate intervention. This percentage is significantly higher if compared to the population of normal hearing peers, considering that the prevalence of subjects with difficulties in oral comprehension is approximately 11% [32]. So, despite the lowering of age at intervention and the easiest access to the latest technological devices, children using CI have a three times higher risk of showing LC difficulties compared to their peers. Children with CI may experiment daily difficulties in following oral explanations, verbal instructions and informal oral conversations with adults and peers. The variability in children's outcomes and the higher risk to develop deficits in LC are consistent with findings observed in other domains, such as language development, reading and writing skills, mathematical ability and neurodevelopment [16, 33-34].

In contrast with the initial hypothesis of the study, early intervention was not determinant for the development of LC skills in children using CI. The bivariate analysis showed that only the variable "age at diagnosis" correlated significantly with LC. Nevertheless, its role was not confirmed by the stepwise regression analysis, which revealed IQ, MLE, SAc and morpho-syntactic skills as the most significant variables. These factors taken together were responsible for 70% of the observed variance. Early intervention could be considered a protective factor which can improve outcomes for children using CI [16], but it cannot resolve alone the differences with their hearing peers. It surely allows to restore the auditory input within the critical window for optimal spoken language development, that is within a period in which the central neuroplasticity is still evolving [35]. Nevertheless, CI users are likely to experiment challenges in everyday life and individual differences in cognition and learning skills could play a significant role in explaining the long-term achievements in language development and the academic results. It can be assumed that children with higher cognitive levels (in terms of working memory, fluid intelligence, processing speed, sequential processing, reasoning skills) are likely to adopt effective strategies in order to successfully manage the degraded signal delivered by the CI and to overcome the obstacles preventing satisfactory interactions with adults and peers [36-37]. Considering a long-term period, these strategies could help some CI users to gain better LC skills if compared to other children using CI but showing lower cognitive skills. At the moment, nonverbal IQ remains one of the most reliable predictors of outcomes after cochlear implantation in paediatric population. Its role was also underlined in speech perception, speech intelligibility levels, receptive and expressive language, behavioural and social development and academic functioning [33, 37-38].

The second important factor in the development of LC skills was the MLE. The sum of MLE with nonverbal IQ explained 43% of the observed variance. The positive impact of MLE is consistent with some previous studies regarding language outcomes [38] and reading skills [39]. The parental level of education might be associated with environmental influences that establish better opportunities to receive rich and varied language and to positively learn from interactions [40].

The third contributor to LC was the auditory attention skills component which added alone another 15% variance to the observed results. Sustained and selective auditory attention are fundamental to learn through messages that are delivered orally. Sustained attention, defined as the ability to maintain focus and alertness over time, is important to maintain adequate levels of attention if the message is conveyed for an extended period. Conversely, selective attention serves to narrow the focus from a broad range of stimuli, thoughts and answers to a unique element of the context or a selected group of stimulus/response activities. Differently from Sanei et al. [18] findings, in the present study children using CI did not show significant difficulties in auditory sustained attention: apart from 2 subjects, all children showed normal results according to the test normative. The test, which was performed in a silent room, shows that CI users did not have primary difficulties when there is a favourable listening context. Performances for auditory selective attention tasks showed a different scenario: most of the children had difficulties and made errors related to inattention (non-recognition of words) and impulsiveness (misidentification of the target word). The percentage of children who did not achieve adequate performance were equal to 50% for the SA1-N and reached 70.6% for the SA2-T, the more demanding task. Poor selective auditory attention skills in CI children were also found in Misurelli et al [19]: they studied CI contribution in LC development and they considered selective auditory attention as an independent influencing variable, separately from listening skills. Domain-general cognitive abilities to control attention, especially in the presence of internal and external distractors, are critical for higher-order cognitive skills such as language comprehension and fluid reasoning [41]. This is particularly evident for selective auditory attention that is necessary for learning in a classroom where other competing stimuli are constantly present (voices of classmates, environmental noises, visual distractions, etc.). A significant association between results in tests assessing selective auditory attention and school performances was found for normal hearing children [42]. Independently from chronological age, children with poor selective auditory attention skills might be especially vulnerable to the effect of noise despite exhibiting normal hearing and adequate speech perception. Conversely, children with normal hearing and good selective auditory attention skills seem generally protected against the effects of noise, as they were found to perform similarly both in silent and noisy environments [42]. In the present study this observation seems true also for children with CI, despite facing limited hearing perception.The weight of auditory attention component was greater than that of the phonological working memory, whose apparent contribute in the bivariate analysis didn’t survive in the regression model. This finding could be explained by considering the possibility that CI children may store words in a short-term memory buffer using a different code than that of hearing children. Noteworthy, Nittrouer et al (2017), studying verbal working memory in a group of 46 CI children and 47 hearing peers, found that while hearing children used a phonological code for storing words in a short-term memory buffer, CI children used a more global lexical representation [43]. Future studies could be implemented to deepen the analysis and support this hypothesis.

Lastly, syntactic skills contributed alone to 12% of the observed variance and therefore are another factor to consider in the analysis of LC skills in children using CI. Syntax appears to be connected to comprehension ability as it allows to understand relations between words in sentences. Kendeou et al. [3] considered syntax important for both oral and reading comprehension in normal-hearing children. Furthermore, good syntax supports the maintenance of the cohesion and the coherence of sentences and levelled texts and it helps the child to make correct inferences [3]. No study investigated the role of grammar competence on LC in children using CI until now. On the contrary, many studies on this population showed connections between grammatical deficits and difficulties in reading comprehension. Pooresmaeil et al [44] found that readers using CI seem to develop more semantic strategies rather than their hearing peers because their grammatical ability is poorer. These semantic strategies are nevertheless inefficient in reaching good comprehension of a text: an inadequate level of syntax makes it difficult for them to correctly apply their lexical knowledge [44].

Some limitations could be cited in considering the findings of the present study.

The number of children was small and obviously this aspect limits the generalizability of the results. Besides, it was not possible to consider all the foundational processes involved in LC: undoubtedly important elements such as inference, theory of mind, and comprehension monitoring were not analysed [5]. Auditory attention skills were tested for sustained and selective attention and further insights may be disclosed by investigating shifted attention as well. Lastly, a limitation we faced was the lack of data on the relationship between listening and reading comprehension within the peculiar population of cochlear implanted children, considering the significant connections between these skills.

Despite the above-mentioned limitations, the results of the present study have relevant clinical implications. Findings on normal-hearing children show that it is possible to progressively stimulate LC skills using teaching comprehension strategies such as activating prior knowledge, questioning, monitoring comprehension, visualization, drawing inferences and retelling [45]. It is similarly desirable to study the efficacy of these strategies in children using CI with low LC skills and verify their usefulness in supporting their improvements. Further, our findings highlight the importance of routinely assessing auditory attention skills, considering their contributions in achieving LC. Batteries for testing auditory attention skills, such as the VAUM-ELF used in the present study, are available for pre-school and school children and we advocate their use in consecutive referrals in the near future. Timely and early identification of poor auditory attention skills could allow clinicians to include at risk CI children in programs specifically designed to enhance these skills, similarly to what happens for specific language disorders [46] and at the same time to select for them the most appropriate listening assistive devices for supporting listening in noise environments [47].

Finally, the results of the present study underlined the role of syntactic skills in LC and it is undeniable that specific assessments should be potentiated. Focused interventions in preschool and older normal hearing with specific language impairments seem to remediate syntactical weaknesses [48]. These strategies could be adapted to children using CI.

CONCLUSION

More than one third of cochlear implanted children showed delay in LC skills. Best performances were predicted by non-verbal IQ, MLE, selective auditory attention components and morpho-syntactic skills, all together explaining 70% of the observed variance. All these variables should be identified early on and assessed when planning an appropriate rehabilitative intervention. Future research should investigate the role of these factors in predicting LC skills, thus improving the knowledge and the clinical care of children using CI.

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Table 1: Description of the tests used for assessing auditory attention, language and phonological working memory skills

Test name	Test structure	Children task	Scoring
Auditory Continuous Performance Test (ACPT) from VAUM-ELF (Bertelli & Bilancia, 2006)	4 recorded lists of 100 bisyllabic words were presented. The targeted word "CANE" (= dog) was repeated 20 times. 19 distractors (with the same initial syllable of the target) and 61 words (with a different initial syllable) were randomly presented. The 4 lists were continuously conveyed by a unique track though a loudspeaker placed at 0°azimuth at a sound level of 65 dB SPL	To listen the track and raise his or her thumb when hearing the targeted word "CANE", ignoring all the other words.	Final score was equal to the number of total errors (omitted or wrong targeted words). Normal hearing children over 8 years of age can perform the task without errors. Two or more errors suggest the presence of difficulties in sustained attention.
Selective Auditory Attention (SA) Test from VAUM-ELF (Bertelli & Bilancia, 2006)	4 recorded dichotic listening tasks were presented. They differ for the degree of distraction and for the cognitive fatigue required. **SA1-N**: the fixed target "CANE" was presented with the television news as competitive message; **SA1-T**: the fixed target "CANE" with a tale as competitive message; **SA2-N**: the targeted word varied and consisted of a noun denoting animals and it was presented with the television news as the competitive message; **SA2-T:** the targeted word was a noun denoting animals and was presented with a tale as competitive message. The lists and the distractive messages were conveyed at a sound level of 65 dB SPL. The targeted words were presented to the dominant ear: in unilateral CI users it was the cochlear implanted side and in bilateral CI users it was the side with the best listening performances.	To listen the track and raise his or her thumb when hearing the targeted word "CANE" or a noun denoting animals, ignoring all the other words.	Final score was calculated on number of total errors (omitted or wrong targeted words). Normal hearing children from 8 years of age are able to perform 1 error at most. Therefore, after this age a score of 2 or more errors suggests difficulties in selective attention.
Peabody Picture Vocabulary Test-PPVT (Dunn & Dunn, 1981)	The test assesses the level of lexical comprehension. It contains a total of 175 black-and-white drawings and each image plate contains 4 of them. The difficulty increases. The examiner read the word representing one of the 4 pictures in a page.	The child listens to a word uttered by the examiner and then chose one of four pictures that best describes the word's meaning	The raw score was calculated by subtracting the number of errors from the highest number in the examinee's ceiling set and converted in normal standardized scores. Normal performances range between 85 and 115 standardized scores
Test for Reception of Grammar-TROG-2 (Bishop, 2009)	The test assesses morphosyntactic comprehension. 20 blocks, each testing a specific grammatical construction, of increasing difficulty, were presented in a four-picture, multiple-choice format with lexical and grammatical foils. For each item, the examiner read a sentence that referred to one of four drawings.	To point to the one drawing that corresponded to the meaning of the sentence.	The score was calculated as total number of blocks passed, then converted in percentile following the references of TROG-2 manual. Normal scores ≥ 16 percentile.
Phonological Working Memory (PWM) from VAUM-ELF (Bertelli & Bilancia, 2006)	It included 4 subtests: Non-Words Repetition (NWR), Digit Memory (DM), Comparison of Series of Non-Words (CSNW), Non-Words Memory (NWM). NWR subtest included 40 polysyllabic non words with low word-linkness, which were considered the best condition to test the phonologic memory. DM was a classic task of digit span. The number of digits increased in numerosity (from 1 to 9 digit) in each subsequent block. CSNW measures the extent of the phonological buffer, without being influenced by speech competences. The children were presented pairs of non-words series, distributed in seven blocks. The NWM task was constituted by five blocks, each composed by six series of monosyllabic non words, with Consonant-Wovel-Consonant structure (CWC). The number of nonwords increased in each block from one to six.	NWR: to repeat the non-words right after was presented. DM: to repeat in each series the correct numbers in the same order. CSNW: to recognize if the non-words included into the second series had the same order compared to the first series. NWM: to repeat the series of non-words.	NWR: the score was calculated on the number of correctly repeated items. DM: the digit span was determined as the number of digits correctly repeated where four series were correctly repeated. CSNW: the score was determined as the number of non-words contained in the block where four pairs of series were correctly identified. NWM: the non-words span was determined as the number of non-words of the block where four series were repeated correctly. Raw scores for each subtest were converted in Z scores using the normative data reported in the test manual.

Table 2: Demographic and clinical characteristics of the study population (n=34)

Variables		**Median**	**Range**
Age at assessment (years)		10.05	8-13.5
CPM (percentile)		80	37-99
Age at diagnosis (months)		11,50	2-60
Age at CI (months)		18,5	7-66
SFDT (dB HL)		32	15-35
		n (%)	
Gender	Male	13 (38.2)	
	Female	21 (61.8)	
Listening mode	Monoaural CI	19 (55.9)	
	Bilateral CI	15 (44.1)	
FI	Low	11 (32.4)	
	Middle	15 (44.1)	
	High	8 (23.5)	
MLE	Low (8 years)	4 (11.8)	
	Middel (13 years)	14 (41.2)	
	High (18 years)	11 (32.4)	

SFDT: aided sound field detection threshold; CPM: non-verbal cognitive level; FI: family income; MLE: maternal level of education

Table 3: Speech perception, auditory attention, phonological working memory and language skills of the study group (n=34)

	Test	**Median**	**Range**
Speech Perception	Word recognition quiet (%)	100	60-100
	Word recognition SNR +5 (%)	80	10-100
	CAP	7	4-8
Auditory Attention	ACPT (n. errors)	0	0-2
	SA1-N (n. errors)	1	0-7
	SA1-T (n. errors)	1.5	0-8
	SA2-N (n. errors)	2.5	0-8
	SA2-T (n. errors)	3	0-8
Phonological Working Memory	NWR	-.65	-8.5-1.9
	DM	.15	-8-2
	CSNW	-.85	-5.5-1.4
	NWM	-.55	-4.4-1.5
Language Skills	PPVT (normal standardized scores)	90	55-125
	Trog-2 (percentile)	30	1-90

CAP: categories of auditory performance; ACPT: Auditory Continuous Performance Test; SA1-N: Selective Attention fixed target/news; SA1-T: Selective Attention fixed target/tale; SA2-N Selective Attention semantic target/news; SA2-T ; NWR: Non words Repetition; DM: Digit Memory; CSNW: Comparison of Series of Non words; NWM: Non Words Memory; PPVT: lexical comprehension; TROG-2: morphosyntactic comprehension.

Table 4: Principal Components Loadings for Audiological, Phonological Working Memory (PWMc) and Selective Attention (SAc) components.

Components		**Loadings**
Audiological	Word recognition quiet	.84
	Word recognition SNR+5	.92
	CAP	.94
	Total variance explained 81%	
SAc	SA1-N	.93
	SA1-T	.95
	SA2-N	.96
	SA2-T	.94
	Total variance explained 89.9%	
PWMc	NWR	.92
	DM	.91
	CSNW	.91
	NWM	.94
	Total variance explained 84.7%	

CAP: categories of auditory performance; SA1-N: Selective Attention fixed target/news; SA1-T: Selective Attention fixed target/tale; SA2-N Selective Attention semantic target/news; SA2-T; NWR: Non words Repetition; DM: Digit Memory; CSNW: Comparison of Series of Non words; NWM: Non-Word Memory.

Table 5: Spearman bivariate analysis between listening comprehension (CO-TT) and children's demographic, linguistic and audiological variables and the perceptive and attentive components.

	Rho	**P**
CPM	.52	**.002**
Age at Diagnosis	-.41	**.015**
Age at CI	-.28	.101
Hearing age	.14	.41
MLE	.583	**.001**
EI	.21	.22
Audiological component	0.71	**<.001**
PPVT	.76	**<.001**
TROG-2	.76	**<.001**
ACPT	-.3	.078
SAc	-.59	**<.001**
PWMc	.82	**<.001**

CPM: Non-verbal cognitive level; MLE: maternal level of education; EI: economic income; PPVT: lexical comprehension; TROG-2: morphosyntactic comprehension; ACPT: Auditory Continuous Performance Test; SAc: selective attention component; PWMc: Phonological working memory component.

Table 6: Hierarchical regression analysis for listening comprehension at CO-TT test

	STEP 1	**STEP 2**	**STEP 3**
Variables	β (p)	β (p)	β (p)
CPM	**.39 (.02)**	**.38 (.008)**	.18 (.13)
Age at diagnosis	-.14 (.37)	-.14 (.30)	-.043 (.71)
MLE	**.38 (.03)**	.16 (.30)	.17 (.17)
Audiological component		.12 (.50)	.11 (.43)
SAc		**-.55 (<.001)**	**-.34 (.01)**
PWMc			.18 (.38)
PPVT			.02 (.89)
TROG-2			**.6 (<.001)**
ΔR^2		.15	.12
R^2	0.43	.58	.70

CPM: Non-verbal cognitive level; MLE: maternal level of education; SAc: selective attention component; PWMc: Phonological working memory component; PPVT: lexical comprehension; TROG-2: morphosyntactic comprehension.