The Influence of Auditory Selective Attention on Linguistic Outcomes in Deaf and Hard of Hearing Children with Cochlear Implants

Maria Nicastri; Ilaria Giallini; Bianca Maria Serena Inguscio; Rosaria Turchetta; Letizia Guerzoni; Domenico Cuda; Ginevra Portanova; Giovanni Ruoppolo; Hilal Dincer D'Alessandro; Patrizia Mancini

European Archives of Oto-Rhino-Laryngology

Prof. Giovanni Ruoppolo

Department of Sense Organs

University Sapienza of Rome

Giovanni.ruoppolo@uniroma1.it

ABSTRACT

Purpose Auditory Selective Attention (ASA) is crucial to focus on significant auditory stimuli without being distracted by irrelevant auditory signals and has an important role on language development. The present study aimed to investigate the unique contribution of ASA on the linguistic levels reached by a group of cochlear implanted (CI) children.

Methods Thirty-four CI children with a median age of 10.05 years were tested using both the "Batteria per la Valutazione dell'Attenzione Uditiva e della Memoria di Lavoro Fonologica nell'età evolutiva-VAUM-ELF", to assess their ASA skills, and two Italian standardized tests, to measure lexical and morphosyntactic skills. A regression analysis, including also demographic and audiological variables, was conducted to assess the unique contribution of ASA on language skills.

Results The percentages of CI children with adequate ASA performances ranged from 50% to 29.4%. Bilateral CI children performed better than their monolateral peers did. ASA skills revealed to give an independent contribute to linguistic skills, accounting alone for the 25% of the observed variance.

Conclusions The present findings are clinically relevant as they highlight the importance to assess ASA skills as early as possible, due to their important role in language development. Using simple clinical instruments, ASA skills could be studied at early developmental stages. This may provide us additional information to traditional auditory testing and may allow us to implement specific training programs that could positively contribute to the development of neural mechanisms of ASA and, consequently, induce improvements in language skills.

Key words: Cochlear Implants, Child, Auditory Selective Attention, Language Skills

1. Introduction

Selective attention represents a fundamental cognitive capacity, that allows the brain to process targeted aspects of the environment, whilst simultaneously suppressing unwanted or distracting aspects [1]. It is critical for regulating external sensory inputs that occur within and across different sensory modalities such as vision and somatosensory processing [2].

When this ability is referred to acoustic information, it is named auditory selective attention (ASA) [3]. ASA is crucial for everyday life as we live in a noisy environment where background sounds and human voices continuously overlap, requiring us to focus on significant stimuli in a particular moment, to avoid dangers (e.g. an incoming car if we are walking along the road) or to communicate with people (e.g., when listening to our own mother who is telling us a story) without being continuously distracted by irrelevant auditory signals.

In typical development, ASA is associated with children's lexical skills, explaining alone from 9% to 12% of variance in vocabulary scores obtained from six to seven years old children. ASA can be considered as an indipendent mediator in comparison to well-established factors that are significantly influencing vocabulary development (e.g., the verbal short term memory) [4]. Moreover, children with specific language impairment seem to show deficits in sustained selective attention tasks presented in the auditory modality under the high attentional load conditions, while showing similar performance to their typical developing peers on visual tasks regardless of the attentional load [5].

ASA is also highly relevant to the school setting in which instruction and completion of assignments may occur in a noisy environment with competing speech streams [6]. In situations that simulate noisy classroom settings, only children with good ASA are protected against the effects of noise in tasks where creative idea generation is required, in terms of showing performances similar to that they obtain in silence [7].

ASA depends on the ability to enhance the representation of an auditory source of interest. For this purpose, the listeners have to analyse the acoustic scene and to form a perceptual auditory object, i.e., a perceptual entity distinguished from other perceptual entities [8]. Simultaneously, listeners must suppress sources that are not the focus of attention, whilst still maintaining some awareness of them, to enable rapid refocus of attention when necessary. Since attention is object based, competing sources in a complex scene may cause many different forms of perceptual interference, making imperceptible portions of the auditory target or directing the listener's attention towards an interfering auditory object [8].

The appropriate formation of an auditory object depends on proper characteristics of the auditory signals such as intensity, temporal/spectral structure, the onset/ offset time, spatial cues and timbre features [9], as well as on subjective skills in processing binaural auditory information such as summation, squelch and head shadow effects [10]. Consequently, deaf and hard of hearing (DHH) subjects may show limited ability in auditory object formation due to the type, severity and symmetry of the hearing deficit. This fact may variously affect their ability to detect acoustic signals and to perform a fine analysis of their temporal and spectral cues [11]. In turn, this may make it harder for them to perceptually segregate single components of the auditory scene [12]. The distorted formation of the auditory object negatively impacts the comparison and the differentiation of objects and consequently reduces the ability to suppress irrelevant ones [8].

The perceptual limitations resulted from the effects of peripheral degradations in the auditory system might be modest and overcame by modern auditory devices in quiet environments [13]. In noise, instead, DHH subjects face more challenging contexts that require an increased cognitive load to fill the perceptive gaps for processing acoustic information. The cognitive load is relative both to the use of top-down strategies to select the correct auditory object and to fill in continuously the gaps left by inaudible parts in the acoustic streams of information [8].

Studies on DHH adult populations show that even subjects using hearing aids or cochlear implants (CIs) experience such difficulties [14-15]. In particular, adult DHH CI users need to base the analysis of the auditory scene on the degree of perceptual differences between the stream, owing the limited spectral and temporal resolution of CI processing [13]. They also face with limited binaural squelch and summation effects or acoustic segregation [16]. This leads to the formation of a less robust auditory object and may explain the difficulties that CI users still face in understanding speech in more challenging listening environments with multiple speakers, background noise and reverberation [17].

Limited dichotic auditory attention performance has been reported even in bilaterally implanted DHH children [18-19], with performance comparable to that of adult DHH CI users [19]. In fact, DHH children with bilateral CIs show a limited amount of unmasking when performing the dichotic test, characterised by the ability to ignore an interferer when presented to the ear opposite to the target and by binaural unmasking when the interferer is presented to both ears [19]. According Misurelli et al. [19], these limitations might be caused by the poor peripheral encoding of speech signals that affect synchronous fusion of auditory images and central representation of the interferer.

No study up to now has investigated the influence of these limited ASA skills on language development in congenitally DHH CI children. In this context, the aim of the present study was to investigate and determine the unique contribution of ASA on the linguistic levels reached by a group of congenitally and profoundly deaf children of school age. Here, the effects of ASA was studied in respect to other personal and audiological variables that are traditionally considered to influence post-operative CI outcomes, e.g., non-verbal intelligence quotient (NVQI), age at diagnosis/implantation, family economic income (EI), maternal level of education (MLE) and auditory skills.

Differences in ASA may represent a further factor that may explain the high variability in linguistic outcomes after cochlear implantation in DHH children and this aspect needs to be investigated.

2. Materials and methods

The present research was a cross sectional study, based on the rules of the STrengthening the Reporting of OBservational studies in Epidemiology (STROBE) statement (https://www.strobe-statement.org/, last access 10/02/2022). The protocol was approved by the local ethics committees of the two Italian Cochlear Implant Centers that cooperated for the study's implementation and realization (Cochlear Implant Center, Department of Sense Organs - University "Sapienza" of Rome and the Hospital "Guglielmo da Saliceto" of Piacenza). The recruited families gave written informed consent for their own child's assessment before commencing any study-related procedure.

2.1 Participants

Thirty-four DHH CI children (21 females, 13 males) with a median age of 10.05 years (range 8 to 13.5 years) were included. They came from different Regions of Italy (North, Centre and South) and were enrolled in two Cochlear Implant Centers. Table 1 showed their main demographic and clinical characteristics.

All children had bilateral congenital profound sensorineural hearing loss, with a median preoperative pure tone average (PTA) of 101.5 dB HL (range 93 to 110 dB HL). Etiology of their hearing loss was as follows: unknown (n=15), Connexin 26 mutation (n=17), ototoxicity (n=1) cytomegalovirus infection (n=1). The median chronological age at diagnosis was 11.5 months (range 2 to 60 months), while median age at implantation was 18.5 months (range 7 to 66 months). The median duration of device use at the time of assessment was 8.7 years (range 6-12.8 years).

Seventeen recipients were implanted with Cochlear devices that were fitted with ACE strategy, whilst 17 participants received Advanced Bionics devices and used Hi-Res 120 strategy. Eighteen children were bilateral CI recipients (9 simultaneous versus 9 sequential implantation), while 16 were monolateral CI users.

All CI recipients had normal cochlear conformation, with full insertion of electrode array. The absence of Central Auditory Processing Disorders and normal NVQI were verified by using the Raven's Colored Progressive Matrices-CMP [20] for children up to 11 years of age and the Raven's Progressive Matrices-RPM [20] for children between 12 to 13 years of age. The sample's median normalized score at CPM and CMP was 80 (range 37 to 97).

Finally, all DHH CI children lived in monolingual native Italian-speaking environment, participated in oral rehabilitation programs, used auditory-verbal communication and were included in mainstream schools with a support teacher provided by the normal legislative procedure of Italian Ministry of Education.

Information concerning family economic income (EI) and maternal level of education (MLE) were gathered from their parents. EI was defined on the base of Italian economic family status indicator named as ISEE index (Indicatore della Situazione Economica Equivalente: Equivalent Economic Situation Index). The ISEE index based the allocation in the EI brackets computing the annual income, the real estate asset, the number of family members and the city of residence (https://www.inps.it/nuovoportaleinps/default.aspx?itemdir=50088#h3heading3). Based on this index, 5 EI brackets were defined: low, middle-low, middle, middle-high and high. MLE was defined based on years of formal education in three levels: low (8 years –junior secondary school diploma), middle (13 years, senior secondary school diploma) and high (18 years, University degree). EI and MLE are detailed reported in Table 1.

2.2 Assessment

2.2.1 ASA assessment

ASA skills were assessed using the “Batteria per la Valutazione dell’Attenzione Uditiva e della Memoria di Lavoro Fonologica nell’età evolutiva-VAUM-ELF” [21]. Four dichotic listening tasks, that differed each other for the weight of the distraction’s factor and for the level of cognitive workload, were used. For the distraction’s factor, there was a condition with a medium linguistic interferer (the dichotic message was a piece of television News-N, less attractive for children) and another with a high linguistic interferer (the dichotic message was a Tale-T, more attractive for children). Regarding the cognitive workload, there were two consecutive conditions: an easier condition (ASA1) with a fixed target (the word “*cane*: dog)” and a more difficult condition (ASA2), where the target was a semantic category, specifically the “name of an animal”. The four tasks that derived by the combination of linguistic interference and the cognitive workload conditions were: the fixed target CANE with the piece of television News as competitive message (ASA1-N); the fixed target CANE with the Tale as competitive message (ASA1-T); the target “name of an animal” with the piece of television News (ASA2-N) as competitive message; the target “name of an animal” with Tale as competitive message (ASA2-T). The difficulty of the task progressively increased from ASA1-N to ASA2-T. For every task, lists of bisyllabic words (8 target stimuli and 19 distractors) were used. The target stimuli were presented only once, while the distractors were repeated twice in random order, for a total of 46 words in each list. The duration of each test condition was 1 minute and 15 seconds. The participant was requested to listen to the list and to raise the right hand when the target stimulus was presented, ignoring all the other words.

The tests were performed in a double-walled sound-treated booth, in sound field modality. The lists and the distractive messages were recorded and presented at the same level (65 dB SPL) through two loudspeakers positioned at 45° azimuth from the subject’s head at a distance of 1 meter-one loudspeaker for the distractive message and the other one for the target message. The lists containing the target were presented to the dominant ear: to the CI side in monolateral users and to the side with the best listening performance in bilateral or bimodal CI users.

The score was calculated on number of total errors (omissions or wrong target). Normal hearing children were shown to be able to perform ≤ 1 error at ≥ 8 years of age [21]. So, after this age, a score of 2 or more errors was indicative of selective attention difficulties.

2.2.2 Auditory skills assessment

Speech recognition in quiet was assessed by using standard phonetically balanced bisyllabic words for Italian pediatric population [22]. A 10-item test list was preceded by a practice list. Items were administered in a sound-proof room, via a loudspeaker placed ad 1m distance from a table where the child was sitting next to a speech therapist. Speech stimuli were presented at 0° azimuth at 65 dB

SPL, both in quiet and with speech noise fixed at +5 Signal-to-Noise (S/N) ratio. The participant's score was calculated as the percentage of correctly repeated words.

The Categories of Auditory Performance-2 (CAP-2) was used to evaluate pediatric CI recipients' auditory outcomes in daily life. This tool has been a reliable measure of outcome, with a good inter-user reliability (correlation coefficient >.75) [23,24]. The CAP-2 scale consisted of 9 categories in order of increasing difficulty:

0. No awareness of environmental sounds
1. Awareness of environmental sounds
2. Responds to speech sounds
3. Identification of environmental sounds
4. Discrimination of some speech sounds without lipreading
5. Understanding of common phrases without lipreading
6. Understanding of conversation without lipreading
7. Use of phone with known listener
8. Follows group conversation in a reverberant room or where there is some interfering noise, such as a classroom or restaurant
9. Use of phone with unknown speaker in unpredictable context.

2.2.3. Language skills assessment

The DHH CI children were tested individually in a quiet room, by two female speech therapists. All children communicated verbally, so all tests were performed using spoken language.

Two Italian Standardized Language tests were administered to assess lexical and morphosyntactic domains. Lexical comprehension was evaluated with the Italian version of Peabody Picture Vocabulary Test (PPVT), where normal standardized scores ranged from 85 to 115 [25]. Morphosyntactic comprehension was assessed with the Italian version of the Test for Reception of

Grammar (TROG)-2 [26]. Based on its standard normative data, a score < 1 SD from the mean was considered as pathologic and this was indicated in the test's manual as the percentile ≤16°.

Italian version of PPVT [25] was an assessment tool that measured the receptive vocabulary in children. It consisted of 175 black and white stimulus items, displaying 4 pictures per page with increasing difficulty. The examiner said a word, and then the examinee responded by pointing out to the picture that s/he thought to correspond to the word presented by the examiner. The raw score was calculated by subtracting the number of errors from the highest number in the examinee's ceiling set. Test-retest reliability and internal consistency of the test were 0.93 and 0.94, respectively.

TROG-2 [26] was a fully revised and re-standardized version of the widely used TROG, originally developed to investigate morpho-syntactic comprehension skills in children. The TROG-2 consisted of 20 blocks, each testing a specific grammatical construction, having an increasing order of difficulty. Each block contained four test items and the child needed to respond correctly to all of them to level up. Each test stimulus was 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, and the participant's task was to point out to the drawing that corresponded to the meaning of the sentence. The score was calculated as total number of achieved blocks. Split-half reliability and internal consistency of the test were of 0.88 and 0.90, respectively.

2.3 Statistical analysis

Analyses were carried out using a PC version of Statistical Package for Social Sciences 25.0 (SPSS, Chicago, IL, USA). Sample characteristics were reported as average and standard deviation or median and minimum-maximum values, following the analysis of normality. DHH CI children's outcomes were compared with scale norms from the test batteries (obtained from nationally representative samples with typically developing, normally hearing children). The percentage of children performing within the normal range in the ASA tasks was reported. Wilcoxon test was used to assess if there were statistically significant differences between ASA performances based on the degree of the task complexity (medium vs high linguistic interferers to competitive message and low vs high cognitive workload).

The Spearman Rank Correlation Coefficient was calculated to investigate the relations between the scores at the language and ASA tests, demographic characteristics (chronological age, NVQI), and audiological variables (age at diagnosis, age at implantation, duration of CI use, mono or bilateral listening, bisyllabic words recognition in quiet and in noise, CAP). Mann-Whitney and Kruskal-Wallis tests were performed to assess differences between gender, listening mode (mono and bilateral users) and mother level of education and economic income degree subgroups.

All variables with p-values less than 0.05 in either direction were considered as significant and were afterwards used in a stepwise hierarchical multiple regression [27] to determine their contribution in predicting linguistic skills. The contribution was assessed in stages, allowing the systematic removal of different sources of information as well as the identification of the unique proportions of variance in the outcomes that could be identified with particular predictors. Variables entered on later stages are thus tested for their unique contribution after removing the contributions of earlier-entered variables.

3. Results

3.1 ASA skills

Median values and range of errors at the ASA tasks were reported in Table 2. The percentages of CI children with adequate performance were 50% in ASA1-N, 52.9% in ASA1-T, 38.2% in ASA2-N and 29.4% in ASA2-T. Both omission errors (61.4%) and wrong target errors (38.6%) were observed and their difference was statistically significant ($Z=-4.9$, $p<0.001$, $\eta 2=0.706$; Cohen's $d=3.101$).

No statistically significant differences were found in CI children's responses when comparing tasks with medium and high linguistic interferers (ASA1-T vs ASA1-N: $Z=-1.14$; $p=0.25$; ASA2-T vs ASA2-N: $Z=-1.32$; $p=0.18$).

Performances differed significantly for cognitive workload: the number of errors from the tasks with semantic category was significantly higher than those from the task with the fixed target (ASA1-T vs ASA2-T: $Z=-3,15$, $p=0.002$, $\eta 2=0.292$; Cohen's $d=1.284$; ASA1-N vs ASA2-N: $Z=-3,59$, $p<0.001$, $\eta 2=0.379$; Cohen's $d=1.563$).

Bilateral CI children performed better than monolateral CI children (U value SA1-N=79, $p=0.021$, $\eta 2=0.143$; Cohen's $d=0.816$; U value SA1-T=73, $p=0.013$, $\eta 2=0.171$; Cohen's $d=0.908$; U value SA2-N=73.5, $p=0.014$, $\eta 2=0.168$; Cohen's $d=0.9$; U value SA2-T=76.5, $p=0.018$, $\eta 2=0.154$; Cohen's $d=0.854$).

3.2 Listening and linguistic skills

Detailed scores for listening and linguistic skills were reported in Table 3.

Median bisyllabic words recognition percentages were 100% (range 60 to 100%) in quiet and 80% (range 10 to100%) in the presence of speech noise at +5 S/N ratio. Thirty children (88%) showed very high auditory performances (CAP≥7), reflecting the ability to communicate in more complex situations, such as noisy or reverberant environments or conversation at phone. The remaining four children (12%) showed a need to stay in a quiet setting; despite being poorer performers, they had anyway the ability to understand language without lipreading (CAP 4-6).

Standard Peabody median score was 90 (range 55 to 125) with 64.7% of children falling within the normal range for lexical comprehension. The median standard score at TROG-2 was 30° percentile (range 1° to 90°) with 67.6 % of children achieving normal scores for morpho-syntactic comprehension.

3.3 Relationships between ASA and language skills

ASA findings correlated significantly with all language tests (Table 4). The strength of their correlations with both lexical and morphosyntactic comprehensions were moderate. Likewise, all

ASA subtests were strongly correlated to each other (all Rho scores >0.8, p<0.001) and the same was true for the test of language assessment (all Rho scores >0.75, p<0.001)

Owing these statistically significant correlations, a principal component analysis (PCA) was adopted to reduce the number of variables for further analysis [28]. The purpose of PCA was to derive weighted linear combinations of the individual measures that were strongly correlated, thus reducing redundancy in multiple regression analysis where the principal components were used as outcome variables. Components were more robust and representative of the study domain than any single test measure. Two new categories were identified: the linguistic component-LC (Peabody, TROG-2) and the ASA component-ASAC (ASA1-N/T, ASA2-N/T). Their Principal Components Loadings were shown in Table 5. In both analyses, PCA gave rise to one single component: KMO values for LC and ASAC were 0.71 and 0.743 respectively, while Bartlett p values were <0.001 for both.

A new bivariate analysis was then performed to evaluate the correlations between the new components, and the results were still statistically significant (Rho= -0.696, p<0.001).

3.4 The unique contribution of ASA on language skills

A regression analysis was conducted to assess the unique contribution of ASA on language skills.

LC was used as the dependent variable and ASAC as the independent variable. For identification of other variables to be included in the regression analysis, significant factors in influencing LC were identified using Spearman correlation, Mann Whitney or Kruskal-Wallis tests depending on the nature of the variables.

Spearman correlation test showed statistically significant effects of NVQI assessed by CPM as well as of age at diagnosis/implantation and listening skills (Table 6).

The Mann Whitney test did not reveal any statistically significant differences in language performances neither because of gender (U=110.5, p=0.347), nor because of mono/bilateral listening mode (U=110, p=0.241). Mother’s degree of education was analyzed depending on the achievement of a junior, high secondary school or university degree. The Kruskal-Wallis test showed that children from families with mothers of senior secondary school or university degree (13 and 18 years, respectively) had better linguistic skills than those with junior secondary school diploma ($H=14.6$, $p=0.001$ $\eta2=0.389$; Cohen's $d=1.596$).

ASAC and all these significant variables were added in the regression model as independent factors, using the stepwise method (Table 7). At the first step, only significantly effective demographic data, mother's level of education-MLE, and the children's characteristics (NVQI, age at diagnosis and at CI) were included. The only significant predictors were NVQI and age at diagnosis, which explained the 46% of variances. The earlier was the diagnosis and the higher was the intelligence quotient of the child, the better were the linguistic outcomes after cochlear implantation. At the second step, the speech perception in quiet/noise and CAP scores were included in the model. These variables together accounted for 8% of an additional variance in CI children's language competencies. The MLE and CAP scores were significant predictors: children with higher CAP scores and with mothers of a longer educational pathway, obtained the highest scores at language tests. Finally, at the third step of the model, the ASAC was added into the model in order to measure its unique contribution. This accounted for 25% of an additional variance and together with the other significant predictors -performance intelligence quotient, speech in noise and CAP- reached the 79% of the observed variances in linguistic skills of CI children.

4. Discussion

ASA is critical for learning and development during childhood. From the first day of birth, children receive spoken language in a complex listening environment where background noise is always present and may impair their ability to learn from the linguistic input, either by limiting the available resources for learning, or by making listening particularly straining [29]. Furthermore, background noise may distract children by leading to attentional shifts and information encoding failures, even with readily perceptible targets. Children struggle to learn words in background noise, particularly when the background noise consists of non-target speech [30]. Noise has detrimental effects also on school achievements, since in school settings, the need to pay attention and to follow instructions or assignments that may occur in the presence of competing speech streams is essential [31]. The hearing children that are more skilled in processing the target stimuli while suppressing the information from other concurrent stimuli develop better verbal working memory, lexical and academic skills [4, 6-7].

DHH post-lingual adults and children with CIs show impaired ASA due to the CI's limited spectral resolution [15, 18-19]. The present study confirms poor ASA skills in a DHH CI paediatric population with worst outcomes in monolateral CI users. Only 1 out of 2 DHH CI children achieves adequate performance for the less demanding ASA task (fixed target with medium linguistic interferer) and about 1 out of 3 performs within the normal range for the more complex task (changing target and high linguistic interferer), despite most of the children of the sample show good speech perception skills (CAP-2 $\geq$ 7). Most of the errors are represented by omission of the target and this fact allows us to speculate that the degree of perceptual discrimination between the target and the competitive message could be at the basis of the difficulty. Due to the limited spectral resolution, DHH CI children may sometimes fail in forming the perceptual auditory object when the perceptual acoustic similarity between the target and the dichotic message makes the entire auditory target or it's portions imperceptible.

Present bilateral DHH CI children perform better than their monolateral peers on ASA tasks, similarly with the studies by Gordon et al. [32] and Misurelli et al. [19]. Having a bilateral CI helps DHH CI children to achieve their best performance in spatial hearing and in masking release, probably because of the availability of interaural level and timing cues, that are missing in monolateral listening condition [19, 32]. This in turn, despite high variability in the amount of release from masking between bilateral subjects [33], may condition language acquisition, since DHH children with bilateral CIs achieve significantly better vocabulary outcomes and significantly higher linguistic scores in comparison to monolateral users [34].

Regarding the contribution of ASA to linguistic skills, similarly with findings in children with typical development by Majerus et al. [4], ASA represents an independent contributor to oral language skills development in this sample of DHH CI children. ASA accounts for a 25% of variance to oral language outcomes in addition to the factors such as cognitive level, maternal education level, early intervention, listening mode and speech perception skills that are traditionally considered when studying postoperative outcomes in paediatric CI users [35-36]. As in hearing children, ASA seems to be implicated in language processing of DHH CI children. When children interact with other people and listen to spoken language, speech represents a complex acoustic signal, with rapidly changing stream of information having few objective boundaries. From this continuous stream of auditory input, then, children face the challenge of parsing word boundaries and extracting meaning. Furthermore, many speech sounds are discriminated mainly by subtle spectral or temporal differences on the order of tens of milliseconds and many morphemes have low perceptual salience in the context of continuous speech stream. Furthermore, the presence of environmental noise and distracting speech sounds complicate the perceptual task. Hence, it is reasonable that the ability to direct selectively the attention on a target message while ignoring and suppressing distracting information could help children to process language in a more facilitated way and this, in turn, could support them to develop better linguistic skills.

This research aims to be a first attempt in determining the impact of ASA on linguistic skills attained by DHH CI children but has several limitations due to the small study sample size and the absence of tasks aiming to understand the cognitive and psychoacoustic processes that may explain the nature of its findings and the specific mechanisms of ASA in paediatric DHH CI population. For example, the development of the four components of attention, represented by arousal, orientation, allocation, and maintenance, have been studied in hearing populations and might be investigated in deaf children with CI as well [37]. Also, the use of purposely developed tasks, together with the event-related brain potential technique, may allow to examine the spectral and temporal dynamics of selective attention as observed in young typical developing hearing children by Astheimer and

Sanders [38] or in hearing children with specific language impairment by Stevens et al. [39] and may give us new insights in how ASA works in DHH CI children.

Nevertheless, the present findings are clinically relevant as they highlight the importance to assess ASA skills as early as possible, reflecting their important role in language development. With simple clinical instruments, as in the present study, ASA skills could be studied at early developmental stages, even in children as young as 3 years [40]. This may provide us additional information to findings from traditional auditory tests and may allow us to gain insight into early implementation of specific training programs, that could induce improvements on standardized measures of language and contribute positively to the development of neural mechanisms of ASA [41]. In English-speaking children with specific language impairment, it has been observed that they may have difficulties with linguistic forms that are perceptually less salient, such as the past tense–ed inflection, possessive s or articles [42] and that improvements in the neural mechanisms of selective attention may facilitate perception and processing of these more vulnerable linguistics forms [41]. The early detection of ASA difficulties and the development of specific programs to train auditory attention in DHH CI children may represent a new challenge for clinicians in finding new tools for improving outcomes after cochlear implantation.

Finally, these findings suggest that even at the early postoperative phases, it is of the utmost importance to support DHH CI children with the most appropriate technology such as assistive listening devices [43-44] or adaptive microphone systems [45] in order to improve S/N ratio in challenging listening environments, and to study the long-term effects on linguistic and academic skills.

References

1. Melara RD, Marks LE, Potts BC (1993) Early-holistic processing or dimensional similarity? J Exp Psychol Hum Percept Perform 19: 1114–1120. https://doi.org/10.1037/0096-1523.19.5.1114

2. Forster S, Lavie N (2009) Harnessing the wandering mind: the role of perceptual load. Cognition 111: 345-355. doi: 10.1016/j.cognition.2009.02.006

3. Woods DL, Stecker GC, Rinne T, Herron TJ, Cate AD, Yund EW, Liao I, Kang X (2009) Functional maps of human auditory cortex: effects of acoustic features and attention. PLoS One 4: e5183. doi: 10.1371/journal.pone.0005183.

4. Majerus S, Heiligenstein L, Gautherot N, Poncelet M, Van der Linden M (2009) Impact of auditory selective attention on verbal short-term memory and vocabulary development. J Exp Child Psychol 103: 66-86. doi:10.1016/j.jecp.2008.07.004

5. Spaulding TJ, Plante E, Vance R (2008) Sustained selective attention skills of preschool children with specific language impairment: evidence for separate attentional capacities. J Speech Lang Hear Res 51: 16-34. doi: 10.1044/1092-4388(2008/002). PMID: 18230853

6. Stevens C, Bavelier D (2012) The role of selective attention on academic foundations: a cognitive neuroscience perspective. Dev Cogn Neurosci 2 Suppl 1: S30-S48. doi:10.1016/j.dcn.2011.11.001

7. Massonnié J, Rogers CJ, Mareschal D, Kirkham NZ (2019) Is Classroom Noise Always Bad for Children? The Contribution of Age and Selective Attention to Creative Performance in Noise. Front Psychol 10: 381. https://doi.org/10.3389/fpsyg.2019.00381

8. Shinn-Cunningham BG (2008) Object-based auditory and visual attention. Trends Cogn Sci 12: 182–186. https://doi.org/10.1016/j.tics.2008.02.003

9. Bregman AS (1990) Auditory Scene Analysis: The Perceptual Organization of Sound. The MIT Press, Cambridge, MA

10. Bronkhorst AW, Plomp R (1988) The effect of head-induced interaural time and level differences on speech intelligibility in noise. JASA 83: 1508–1516. 10.1121/1.395906

11. Carlyon RP, Long CJ, Deeks JM, McKay CM (2007) Concurrent sound segregation in electric and acoustic hearing. J Assoc Res Otolaryngol 8: 119-133. doi: 10.1007/s10162-006-0068-1

12. Gaudrain E, Grimault N, Healy EW, Bera JC (2007) Effect of spectral smearing on the perceptual segregation of vowel sequences. Hearing Research 231: 32-41. doi.org/10.1016/j.heares.2007.05.001

13. Wouters J, McDermott HJ, Francart T (2015) Sound Coding in Cochlear Implants: From electric pulses to hearing. IEEE 32: 67-80. 210.1109/MSP.2014.2371671

14. Marrone N, Mason CR, Kidd G (2008) Evaluating the benefit of hearing aids in solving the cocktail party problem. Trends Amplif 12: 300–315. doi: 10.1177/1084713808325880

15. Paredes-Gallardo A, Innes-Brown H, Madsen SMK, Dau T, Marozeau J (2018) Auditory Stream Segregation and Selective Attention for Cochlear Implant Listeners: Evidence From Behavioral Measures and Event-Related Potentials. Front Neurosci 12: 581. doi:10.3389/fnins.2018.00581

16. Ching TY, Incerti P, Hill M, van Wanrooy E. An overview of binaural advantages for children and adults who use binaural/bimodal hearing devices. Audiol Neurootol. 2006;11 Suppl 1:6-11. doi: 10.1159/000095607. Epub 2006 Oct 6. PMID: 17063004

17. Weissgerber T, Rader T, Baumann U (2017) Effectiveness of Directional Microphones in Bilateral/Bimodal Cochlear Implant Users-Impact of Spatial and Temporal Noise Characteristics. Otol Neurotol 38:e551-e557. doi: 10.1097/MAO.0000000000001524

18. Koopmann M, Lesinski-Schiedat A, Illg A (20209 Speech Perception, Dichotic Listening, and Ear Advantage in Simultaneous Bilateral Cochlear Implanted Children. Otol Neurotol 41: e208-e215. doi: 10.1097/MAO.0000000000002456

19. Misurelli SM, Goupell MJ, Burg EA, Jocewicz R, Kan A, Litovsky RY (2020) Auditory Attention and Spatial Unmasking in Children With Cochlear Implants. Trends Hear 24: 2331216520946983. doi: 10.1177/2331216520946983

20. Raven J & Raven J (2003) Raven Progressive Matrices. In: McCallum RS (ed) Handbook of Nonverbal Assessment. Springer, Berlin, pp 223–237. https://doi.org/10.1007/978-1-4615-0153-4_11

21. Bertelli B, Bilancia G (2006) Batterie per la Valutazione dell'Attenzione Uditiva e della Memoria di Lavoro Fonologica nell'Età Evolutiva-VAUMeLF. Giunti Psychometric Edition, Florence

22. Cutugno F, Prosser S, Turrini M (2000) Audiometria vocale. GN ReSound, Itay 24

23. Archbold S, Lutman ME, Marshall DH (1995) Categories of Auditory Performance. Ann Otol Rhinol Laryngol Suppl 166: 312-314. PMID: 7668685

24. Gilmour L (2010) The inter-rater reliability of categories of auditory performance-II (CAP)-II (Masters Thesis). Institute of Sound and Vibration Research, University of Southampton

25. Dunn LM, Dunn LM (1981) Peabody picture vocabulary test revised. In: Stella G, Pizzioli C, Tressoldi PE (eds) Italian adaptation (2000), Omega Edition, Turin

26. Bishop DVM (2009) TROG-2: Test for Reception of Grammar— Version 2. In: Suraniti S, Ferri R. Neri V (eds) Italian adaptation, Giunti Psychometric Edition, Florence

27. Hosmer DW, Lemeshow S (2013) Applied logistic regression. Wiley, New York

28. Jolliffe IT, Cadima J (2016) Principal component analysis: a review and recent developments. Philos Trans A Math Phys Eng Sci 374:20150202. doi: 10.1098/rsta.2015.0202

29. Hornsby BW (2013) The effects of hearing aid use on listening effort and mental fatigue associated with sustained speech processing demands. Ear and Hearing 34: 523–534. doi: 10.1097/AUD.0b013e31828003d8

30. McMillan B, Saffran JR (2016) Learning in complex environments: The effects of background speech on early word Learning. Child Development 87:1841-1855. doi: 10.1111/cdev.12559

31. Klatte M, Bergström K, Lachmann T (2013) Does noise affect learning? A short review on noise effects on cognitive performance in children. Front Psychol 304: 578. doi: 10.3389/fpsyg.2013.00578

32. Gordon KA, Deighton MR, Abbasalipour P, Papsin BC (2014) Perception of binaural cues develops in children who are deaf through bilateral cochlear implantation. PLoS One 9:e114841. doi: 10.1371/journal.pone.0114841

33. Misurelli SM, Litovsky RY (2015) Spatial release from masking in children with bilateral cochlear implants and with normal hearing: Effect of target-interferer similarity. J Acoust Soc Am 138: 319-331. doi:10.1121/1.4922777

34. Sarant J, Harris D, Bennet L, Bant S (2014) Bilateral versus unilateral cochlear implants in children: a study of spoken language outcomes. Ear Hear 35: 396-409. doi: 10.1097/AUD.0000000000000022

35. Geers AE (2006) Factors influencing spoken language outcomes in children following early cochlear implantation. Adv Otorhinolaryngol. 64: 50-65. doi: 10.1159/000094644. PMID: 16891836

36. Quittner AL, Cruz I, Barker DH, Tobey E, Eisenberg LS, Niparko JK (2013) Childhood Development after Cochlear Implantation Investigative Team. Effects of maternal sensitivity and cognitive and linguistic stimulation on cochlear implant users' language development over four years. J Pediatr 162: 343-8.e3. doi: 10.1016/j.jpeds.2012.08.003

37. Gomes H, Molholm S, Christodoulou C, Ritter W, Cowan N (2000) The development of auditory attention in children. Front Biosci 5: D108-20. doi: 10.2741/gomes. PMID: 10702373

38. Astheimer L, Sanders L (2012) Temporally selective attention supports speech processing in 3- to 5-year-old children. Dev Cogn Neurosci 2: 120-128. doi: 10.1016/j.dcn.2011.03.002

39. Stevens C, Sanders L, Neville H (2006) Neurophysiological evidence for selective auditory attention deficits in children with specific language impairment. Brain Res 1111:143-152. doi: 10.1016/j.brainres.2006.06.114

40. Sanders LD, Stevens C, Coch D, Neville HJ (2006) Selective auditory attention in 3- to 5-year-old children: an event-related potential study. Neuropsychologia 44: 2126-2138. doi: 10.1016/j.neuropsychologia.2005.10.007

41. Stevens C, Fanning J, Coch D, Sanders L, Neville H (2008) Neural mechanisms of selective auditory attention are enhanced by computerized training: electrophysiological evidence from language-impaired and typically developing children. Brain Res 1205: 55–69. https://doi.org/10.1016/j.brainres.2007.10.108

42. Leonard, L (1998) Children with specific language impairment. Massachusetts Institute of Technology; Cambridge, MA

43. Rocha BDS, Scharlach RC (2017) The use of the Frequency Modulation System by hearing-impaired children: benefits from the family's perspective. Codas 29: e20160236. doi: 10.1590/2317-1782/20172016236. PMID: 29069130

44. Mehrkian S, Bayat Z, Javanbakht M, Emamdjomeh H, Bakhshi E (2019) Effect of wireless remote microphone application on speech discrimination in noise in children with cochlear implants. Int J Pediatr Otorhinolaryngol 125: 192-195. doi: 10.1016/j.ijporl.2019.07.007

45. Johnstone PM, Mills KET, Humphrey E, Yeager KR, Jones E, McElligott K, Pierce A, Agrawal S, Froeling C, Little JP (2018) Using Microphone Technology to Improve Speech Perception in Noise in Children with Cochlear Implants. J Am Acad Audiol 29:814-825. doi: 10.3766/jaaa.17035

Variables	Median	Interval
Age at assessment (years)	10.05	8-13.5
Age at diagnosis (months)	11,50	2-60
Age at CI (months)	18,5	7-66
Pre-CI PTA (dB HL)	101	93-110
Post-CI PTA (dB HL)	32	15-35
CPM normal score (percentile)	80	37-97

		n (%)
Gender	Male	13 (38.2)
	Female	21 (61.8)
Listening mode	Monoaural CI	19 (55.9)
	Bilateral CI	15 (44.1)
EI level	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)

Table 1: Demographic and clinical characteristics of the study population (n=34)

	Median	Interval
Quiet Bys word recognition (%)	100	60-100
+5 S/R ratio Bys word recognition (%)	80	10-100
CAP (n. of category)	7	4-8
Peabody (normal standardized scores)	90	55-125
Boston Naming test (z scores)	-0.8	-7.7-0.9
Trog-2 (percentile)	30°	1°-90°

Table 2: Listening and Language outcomes of the study population (n=34)

Test	Median	Interval
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

Table 3: Auditory attention skills of the study group (n=34)

	SA1-N		SA1-T		SA2-N		SA2-T	
	rho	p	rho	p	rho	p	rho	p
Peabody	-.51	**.002**	-.49	**.004**	-.46	**.006**	-.49	**.003**
TROG-2	-.51	**.002**	-.55	**.001**	-.40	**.018**	-.47	**.005**
Boston Naming test	-.77	**<.001**	-.73	**<.001**	-.87	**<.001**	-.84	**<.001**

Table 4: Spearman correlations between Auditory Selective Attention tasks and language skills. Statistically significant values were set at p<0.05 and are highlighted in bold.

Components		**Loadings**
Linguistic	Peabody	.92
	Boston Naming Test	.77
	TROG-2	.87
	Total variance explained 73.4%	
Auditory Selective Attention	SA fixed target/tale	.95
	SA semantic target/tale	.94
	SA fixed target/news	.93
	SA semantic target/news	.96
	Total variance explained 89.9%	

Table 5: Principal Components Loadings for Auditory Selective Attention (ASAc) and Linguistic (Lc) components.

	Language Component	
	rho	*p*
Age at assessment	-0.20	0.25
CPM	0.47	**0.005**
Age at diagnosis	-0.51	**0.002**
Age at CI	-0.42	**0.013**
Time of CI use	0.073	0.68
Post-CI PTA	-0.08	0.96
CAP	0.59	**<0.001**
Speech in quite	0.43	**0.01**
Speech noise	0.52	**0.001**

Table 6: Spearman correlations between Language Component and demographic and audiological quantitative variables. Statistically significant values were set at p<0.05 and are highlighted in bold.

	STEP 1	STEP 2	STEP 3
Variables	β (p)	β (p)	β (p)
Maternal Level Education	0.24 (0.13)	**0.3 (0.04)**	0.19 (0.06)
CPM	**.36 (.02)**	0.23 (0.11)	**0.37 (0.007)**
Age at diagnosis	**-0.43 (0.007)**	-0.17 (0.3)	0.03 (0.8)
Age at CI	-0.21 (0.51)	0.41 (0.8)	0.02 (0.9)
Speech in quite		-0.03 (0.8)	0.1 (0.36)
Speech in noise		0.3 (0.9)	**-0.59 (0.002)**
CAP		**0.55 (<0.001)**	**0.67 (<0.001)**
ASAc			**-0.67 (<0.001)**
ΔR^2		.10	.20
R^2	0.46	.54	.79

Table 7- Hierarchical regression analysis to establish the contribute of ASAc on language skills