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Phonological awareness and reading abilities in elementary-school students with severe-to-profound prelingual hearing loss and unilateral cochlear implants

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Abstract

Background: Research findings on the reading outcomes of cochlear implants are inconsistent. Controversy was observed in the reading performance of implanted children, both in relation to hearing aid users and normally hearing children. This cross-sectional study aims to evaluate the phonological awareness and reading skills of school-aged, severe-to-profound, prelingually deafened children using cochlear implants and to identify any associations between these skills and age of implantation, language development, and the chosen side of implantation. Patients who met the selection criteria were assessed using standardized phonological awareness and reading tests, and their scores were compared to normative data.

Results: Patients' average scores were significantly behind age-matched normative data. Phonological awareness was strongly correlated to reading skills, and both were positively correlated to language abilities. Age at implantation was not correlated to phonological skills yet it was positively correlated to reading scores for patients over 9 years old.

Conclusion: Many cochlear implanted children are still struggling with reading. Phonological development should be considered in the rehabilitation of this group of patients as it was found to be closely associated with reading proficiency.

Keywords: Cochlear implant, Reading, Phonological awareness

Introduction

Cochlear implant (CI) has become the standard of care for the majority of children with bilateral severe-to-profound congenital sensorineural hearing loss who receive only a minor benefit from hearing aids. CI was linked to facilitating skills necessary for reading development [1]. It has enhanced the quality of auditory perception, phonological representation of speech, and oral language development [2]. Yet, considerable individual variability in language acquisition, for example, exists in CI children with a full range of outcomes [3, 4].

Compared to deaf children without CI, many studies showed that, due to better spoken language, CI children are better readers [5–7]. However, other studies reported that the effect of CI on literacy development was not significantly better than that of hearing aids [8, 9].

Compared to their peers without hearing loss, and despite the fact that they commonly attend mainstream schools, many CI children are still delayed in literacy acquisition [2, 7, 9, 10]. Bouton et al. [11] attributed reading deficits in CI children to less efficient phonological representations, atypical reading procedures, or both. Nevertheless, there is also evidence that many (up to

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nearly 70% in some studies) CI children achieve reading scores within or even above the average range for their normally hearing counterparts [1, 8, 12–16]. Marschark et al. [13] attributed the improved reading skills in CI children to improvements in phonological skills or general language abilities.

Magee [17] believed that phonological awareness (PA) may not be a reading prerequisite as it is in children with typical hearing but is rather developed as reading abilities improve. They also added that while some deaf individuals rely on PA, others use orthographic processes alternatively to make judgments of phonological similarity, and such an ability is also acquired through reading experiences.

Other child-related and environmental variables that have been found to be highly predictive of better reading outcomes in CI children were listed by Sarant et al. [15]. These included female gender [12], better cognitive abilities [1, 3, 14, 18], auditory and visual memory [1], speech perception and production skills [14], earlier implantation [1, 8], consistency of CI use [13], higher socioeconomic standard of the family [12, 19], positive family environment, earlier born children [15], spoken language as the predominant mode of communication rather than sign language [18, 20], and oral language competency [1, 19].

Research has primarily focused on the outcomes of auditory performance, speech, and language development in CI children, with notably less focus on reading attainment, despite being a fundamental educational achievement and a crucial skill to academic success. Early identification and intervention for reading abilities is undoubtedly essential to make use of brain plasticity and mitigate the academic delay expected in this population.

The primary objective of this study was to evaluate the PA and reading abilities of school-aged, deaf children with unilateral CI compared to age-matched normative data. The secondary objective was to identify any associations between PA and reading scores and age of implantation, language development, and the chosen side of implantation.

Methods

Study design and duration

This cross-sectional study was carried out in the period between October 2019 and April 2020.

Sampling

Patients were selected conveniently from children with CI visiting a tertiary hospital outpatient clinic. Out of 45 patients assessed for eligibility, 30 were included. The sample size was calculated using the PASS program, setting the alpha error at 5% and power at 80%. Assuming a difference of 10 in the mean scores of the studied tests among cases compared to reference means for normal children, with an estimated standard deviation of 10, produced a sample size of 30 cases.

Participants

Included children were those with a chronological age between 5 and 11 years old to ensure they were developmentally at or above the age of acquisition of skills chosen for assessment, of average intelligence (total IQ ≥ 90) to exclude slow learners and allow a cognitively matched comparison with data of normally developing peers; diagnosed with bilateral severe (70–95 dB) and/or profound (95 or more dB) prelingual sensorineural hearing loss; implanted with a unilateral CI with or without a unilateral hearing aid (bimodal hearing), with a duration of CI between 4 and 6 years; Arabic-speaking, orally educated, and have a well-developed spoken language adequate to understand test instructions; can communicate using ≥ 4-word sentences; and attend mainstream schools to verify exposure to alphabetic learning. Those with syndromic hearing impairment; those with associated (past or present history of) visual problems and developmental, behavioral, or other medical problems; or those using bilateral CIs or bilateral hearing aids were excluded.

Procedures

Participants were subjected to the following protocol to verify selection criteria and collect outcome data: *parent interview:* to obtain information related to the patient's personal history, past history, history of hearing impairment, audiological diagnosis and audiometry records, time, duration, and laterality of the CI operation, and rehabilitation details; *clinical examination* to exclude any syndromic features; *formal testing* which included the *Stanford-Binet Intelligence Scale*-4th edition, Arabic version [21], to provide the total IQ and mental age, *language assessment* by the Modified Preschool Language Scale-4th edition (PLS–4), Arabic version [22], to determine the child's language age and abilities, *Phonological Awareness Test (PAT)* [23], and *Arabic Reading Screening Test (ARST)* [24]. PAT and ARST both provide normative data for hearing children and consist of 20 sub-tests (listed in the results section), all of which were assessed for all participants, and the sum of the scores is considered the total score. Relevant areas of deficiency were also delineated by contrasting the scores for each subtest in both PAT and ARST with their 5th percentile values obtained from normally developing children. Scores below these values indicate a delay.

Data analysis

Data was collected through history taking and clinical assessment. Outcome measures were coded, tabulated, and analyzed with IBM SPSS Statistics software (version 27). Quantitative variables were presented as mean, median, range, and standard deviation (SD). Qualitative variables were presented as frequencies and proportions. The Shapiro-Wilk test was used to determine the distribution characteristics of variables and variance homogeneity. Paired data were analyzed using the paired *t* test and Wilcoxon- sign rank test. Spearman's correlation was used to analyze linear relationships between quantitative variables. The correlation coefficient, denoted symbolically "r," defines the strength (magnitude) and direction (positive or negative) of the linear relationship between two numeric variables. $r = 0–0.19$ is regarded as a very weak correlation, $r = 0.2–0.39$ is regarded as a weak correlation, $r = 0.40–0.59$ is regarded as a moderate correlation, $r = 0.6–0.79$ is regarded as a strong correlation, and $r = 0.8–1$ is regarded as a very strong correlation. A *P* value of ≤ 0.05 was accepted as a statistically significant result.

Results

Patient characteristics

The characteristics of the study population are shown in Table 1.

PAT and ARST results

Participants' average total scores in both PAT and ARST were less than age-matched normal average scores (Tables 2 and 3). The distribution of participants, according to their scores in the different sub-tests, when compared to the 5th percentile of normally developing children, is shown in Tables 2 and 3. In PAT, most participants scored below the 5th percentile in all sub-tests. Between 30 and 43% of participants were at the 5th percentile in some sub-tests, namely 2, 4, 7, 11, and 12. Only 10% of participants scored above the 5th percentile in sub-tests 2 and 3. In ARST, most participants scored below the 5th percentile in all sub-tests. Between 20 and 50% of participants were at the 5th percentile in some sub-tests, namely 1, 2, 3, 4, 11, 12, and 13.

The differences between PAT and ARST total scores and the corresponding age-matched normal average scores were found to be statistically significant by the Wilcoxon signed-rank test ($P < 0.001$). To calculate the difference (%) in total average scores of PAT and ARST between participants and their age-matched normal children (Table 4), the following formula was used: [(age-matched normal average scores − study participants' scores)/age-matched normal average scores] × 100.

Relationship between PAT and ARST and other variables

A statistically significant strong or very strong positive correlation existed between the PAT and ARST results (Table S1, supplemental material).

When the chronological age at implantation was correlated to PAT and ARST results, the sample was divided into two groups based on their median age: above and below the age of 9. No statistically significant correlation was found between patients' age at implantation and the PAT total score and most of its sub-tests (Table S2, supplemental material). A statistically significant moderate positive correlation existed between age at implantation and blending syllables into words ($r = .56$, $P = 0.02$), isolating initial phonemes ($r = .52$, $P = 0.04$), and phoneme-grapheme correspondence ($r = .55$, $P = 0.02$) for the group of patients below 9 years old at the time of assessment, and a statistically significant moderate or strong positive correlation existed between age at implantation and isolating final phonemes ($r = .58$, $P = 0.02$), isolating middle phonemes ($r = .64$, $P = 0.01$), recognizing rhyming words ($r = .67$, $P = 0.008$), and phoneme-grapheme correspondence ($r = .67$, $P = 0.009$) for the group of patients above 9 years old.

No statistically significant correlation was found between patients' age at implantation for the group of patients below 9 years old and all of the ARST sub-tests and total score (Table S3, supplemental material). However, for the group older than 9 years old, the age at implantation was statistically significant and positively correlated with almost all sub-tests (mostly a moderate or strong correlation) as well as the total score of the ARST ($r = .62$, $P = 0.02$).

A statistically significant moderate positive correlation existed between both PAT and ARST total scores and receptive, expressive, and total language ages ($r = .56$, .58, .58, $P = 0.001$ and $r = .55$, .56, .55, $P = 0.002$, respectively) (Tables S4 and S5, supplemental material). All PAT sub-tests were statistically significantly positively correlated to participants' language ages, with the exception of the "segmenting words into onsets and rimes" sub-test and receptive language age, as well as the "deleting final phonemes" sub-test and receptive, expressive, and total language ages. All ARST sub-tests were statistically significantly positively correlated to participants' language ages, with the exception of the "sentence sequencing task" sub-test and both receptive and total language ages, as well as the "sentence reading comprehension" sub-test and expressive language age, and the "story reading and comprehension" sub-test and receptive language age.

As shown in Table 5, there was no statistically significant difference between both PAT and ARST total scores and the chosen side for implantation.

Table 1 Characteristics of the study participants

Variables	Study participants ($n = 30$)	Participants < 9 years ($n = 12$)	Participants ≥ 9 years ($n = 18$)
Age (years)			
mean ± SD	9 ± 1.6	7.3 ± 1.1	10.1 ± 0.7
median (Range)	9.1 (5.3–11)	7.3 (5.3–8.8)	10.25 (9–11)
Gender: number (%)			
Male	15 (50%)	5 (41.6%)	10 (55.5%)
Female	15 (50%)	7 (58.3%)	8 (44.4%)
Total IQ: mean ± SD	94.6 ± 6.1	94.1 ± 5.6	94.9 ± 6.4
Mental age (years): mean ± SD	8.5 ± 1.8	6.8 ± 1.1	9.6 ± 1.0
Age at diagnosis of HL (months)			
mean ± SD	11 ± 7.7	9.1± 6.5	11.1± 7.8
median (range)	9 (2–36)	7.5 (3–24)	10.5 (2–36)
Causes of HL: number (%)			
Congenital	29 (96.7%)	12 (100%)	17 (94.4%)
Post-meningitic	1 (3.3%)	0 (0%)	1 (5.6%)
Family history of HL: number (%)			
Positive	11 (36.7%)	4 (33.3%)	7 (38.8%)
Negative	19 (63.3%)	8 (66.6%)	11 (61.1%)
Age at CI surgery (years)			
mean ± SD	4 ± 1.2	2.9 ± 0.8	4.7 ± 0.8
median (range)	4.0 (1.1–6)	3.1 (1.1–4.1)	4.9 (3–6)
Side of CI: number (%)			
Right	17 (56.7%)	7 (58.3%)	10 (55.5%)
Left	13 (43.3%)	5 (41.6%)	8 (44.4%)
Duration of CI (years)			
mean ± SD	5.1 ± 0.6	4.5 ± 0.4	5.5 ± 0.3
median (range)	5.1 (4–6)	4.3 (4–5.4)	5.6 (4.6–6)
Pre-implantation audiometric hearing threshold (dB)	**Right ear:** (82.0–99.7) ± (8.7–11.6)	**Right ear:** (80.8–93.7) ± (11.0–10.2)	**Right ear:** (82.0–103.6) ± (6.9–8.0)
mean (at 250 Hz–at 4000 Hz) ± SD	**Left ear:** (83.7–100.3) ± (11.1–12.5)	**Left ear:** (80.8–97.5) ± (12.9–12.3)	**Left ear:** (85.8–103.0) ± (9.8–9.7)
Post-implantation (aided) audiometric hearing threshold (dB)			
mean (at 500 Hz–at 4000 Hz) ± SD	**Implanted ear:** (20.8–28) ± (5.9–7.1)	**Implanted ear:** (28.7–23.3) ± (6.4–7.7)	**Implanted ear:** (27.5–21.9) ± (7.7–5.7)
Auditory and language therapy starting age (years): median (range)	2 (0.5–4)	1.6 (0.5–3.7)	2 (1–4)
Regularity of therapy sessions: number (%)			
Regular	26 (86.7%)	10 (83.3%)	16 (88.8%)
Irregular	4 (13.3%)	2 (16.6%)	2 (11.1%)
Frequency of therapy sessions (number per week): median (range)	3 (2–7)	3 (2–7)	3 (2–6)
Age at first word (years): median (range)	2.3 (0.8–3.5)	2.3 (1–3.5)	2.2 (0.8–3.5)
Age at first sentence (years): median (range)	4.0 (2.1–6.0)	3.7 (2.1–4.6)	4.2 (2.4–6.0)
Language age (years)			
Receptive language age: mean ± SD	5.7 ± 0.6	5.4 ± 0.6	5.7 ± 0.7
Expressive language age: mean ± SD	5.0 ± 0.9	4.5 ± 0.6	5.1 ± 0.9
Total language age: mean ± SD	5.2 ± 0.7	4.8 ± 0.5	5.3 ± 0.6

HL hearing loss, *IQ* intelligence quotient, *CI* cochlear implantation, *dB* decibel, *Hz* hertz

Table 2 Results of the Phonological Awareness Test scores

Phonological Awareness Test	Patients ($n = 30$) number (%)		
	< 5th percentile	At 5th percentile[a]	> 5th percentile
1. Segmenting sentence into words	26 (86.7%)	4 (13.3%)	0 (0.0%)
2. Blending syllables into words	17 (56.7%)	10 (33.3%)	3 (10.0%)
3. Segmenting words into syllables	22 (73.3%)	5 (16.7%)	3 (10.0%)
4. Isolating initial phonemes	17 (56.7%)	13 (43.3%)	0 (0.0%)
5. Isolating final phonemes	22 (73.3%)	8 (26.7%)	0 (0.0%)
6. Isolating middle phonemes	22 (73.3%)	8 (26.7%)	0 (0.0%)
7. Blending onsets and rimes into words	21 (70.0%)	9 (30.0%)	0 (0.0%)
8. Segmenting words into onsets and rimes	21 (70.0%)	7 (23.3%)	2 (3.3%)
9. Blending individual phonemes into words	25 (83.3%)	4 (13.3%)	1 (3.3%)
10. Segmenting words into phonemes	22 (73.3%)	7 (23.3%)	1 (3.3%)
11. Recognizing rhyming words	19 (63.3%)	11 (36.7%)	0 (0.0%)
12. Generating rhyming words	20 (66.7%)	10 (33.3%)	1 (3.3%)
13. Deleting initial phonemes	26 (86.7%)	4 (13.3%)	0 (0.0%)
14. Deleting final phonemes	26 (86.7%)	4 (13.3%)	0 (0.0%)
15. Deleting middle phonemes	26 (86.7%)	4 (13.3%)	0 (0.0%)
16. Substituting initial phonemes	26 (86.7%)	4 (13.3%)	0 (0.0%)
17. Substituting final phonemes	27 (90.0%)	3 (10.0%)	0 (0.0%)
18. Substituting middle phonemes	26 (86.7%)	4 (13.3%)	0 (0.0%)
19. Phoneme grapheme correspondence	26 (86.7%)	4 (13.3%)	0 (0.0%)
20. Producing multisyllabic words	27 (90.0%)	3 (10.0%)	0 (0.0%)
Total score:			
mean ± SD	35.7 ± 31.5		
median (range)	29.8 (0–115)		

[a] The 5th percentiles are for age-matched normal children, determined according to El-Sady et al. [23]

Discussion

This study evaluated the phonological skills and reading abilities of CI children. The majority of participants scored below the average normal scores. Both PA and reading skills were strongly correlated to each other, as well as moderately correlated to language development, but not associated with the chosen side of implantation. The age of implantation was correlated to reading development only for older participants.

PAT and ARST results

Since the study involved CI children of different age groups with variable PA and reading profiles, all sub-tests of the PAT and the ARST were tested in all participants, whenever applicable. We used validated tests originally designed to assess normally hearing children, and not simplified versions, to capture the full range of skills, including advanced ones.

Findings are echoing similar results from previous studies where CI children significantly underperformed their normally hearing peers at PA [18, 25, 26] and reading tasks [2, 7, 9, 10]. Better reading performance in normally hearing students was usually attributed to stronger alignment of auditory and visual inputs, more phonological skills, greater speech and language capabilities, wider representation of words, richer vocabulary, and better verbal comprehension [2, 12, 14, 25]. These skills are expected to be less developed in CI children due to the period of auditory deprivation. As shown in the results, for instance, participants have not yet developed age-appropriate language, and accordingly, learning to read changes to an exercise of learning language itself [27]. Furthermore, despite its benefits, their integration into regular schools might have hampered the individualized support that suits their learning pace, and hindered their reading acquisition accordingly.

Conversely, other studies reported higher general levels of reading and/or PA skills in CI children, attaining levels equivalent to hearing peers of their age [13, 16], a finding that was frequently attributed to their enhanced language skills following CIs.

The high standard deviations of participants' scores in the current study reflect the considerable intra-group variability in performance, as some participants were

Table 3 Results of the Arabic Reading Screening Test scores

Arabic Reading Screening Test	Patient ($n = 30$) number (%)		
	< 5th percentile	At 5th percentile[a]	Not applicable[b]
1. Isolated grapheme	16 (53.3%)	14 (46.7%)	0 (0.0%)
2. Connected grapheme	20 (66.7%)	10 (33.3%)	0 (0.0%)
3. Isolated grapheme with short vowels	22 (73.3%)	8 (26.7%)	0 (0.0%)
4. Connected grapheme with short vowels	24 (80.0%)	6 (20.0%)	0 (0.0%)
5. Logographic reading	25 (83.3%)	5 (16.7%)	0 (0.0%)
6. Decoding alphabetic reading	27 (90.0%)	2 (6.7%)	1 (3.3%)
7. Decoding alphabetic reading	26 (86.7%)	3 (10.0%)	1 (3.3%)
8. Decoding alphabetic reading	26 (86.7%)	3 (10.0%)	1 (3.3%)
9. Decoding sentences	26 (86.7%)	3 (10.0%)	1 (3.3%)
10. Pseudowords	26 (86.7%)	4 (13.3%)	0 (0.0%)
11. Word reading comprehension	15 (50.0%)	15 (50.0%)	0 (0.0%)
12. Verb reading comprehension	16 (53.3%)	13 (43.3%)	1 (3.3%)
13. Sentence reading comprehension	23 (76.7%)	6 (20.0%)	1 (3.3%)
14. Sentence formulation task	28 (93.3%)	1 (3.3%)	1 (3.3%)
15. Sentence sequencing task	25 (83.3%)	4 (13.3%)	1 (3.3%)
16. Visual closure	24 (80.0%)	5 (16.7%)	1 (3.3%)
17. Synonym and antonyms	28 (93.3%)	1 (3.3%)	1 (3.3%)
18. Hyponyms	25 (83.3%)	4 (13.3%)	1 (3.3%)
19. Sentence completion task and repair task	26 (86.7%)	3 (10.0%)	1 (3.3%)
20. Story reading and comprehension	26 (86.7%)	3 (10.0%)	1 (3.3%)
Total score			
mean ± SD	122.4 ±110.7		
median (range)	62 (0–391)		

[a] The 5th percentile was determined according to Khaled et al. [24]

[b] In ARST, some sub-tests are not applicable to certain age groups. This was the case for one participant, whose age was 5 years and 3 months

Table 4 The difference between participants' PAT and ARST total average scores and their age-matched normal average scores

		Study participants' scores	Age-matched normal average scores	Difference (%)
PAT	**mean ± SD**	**35.7 ± 31.5**	**87.2 ± 15.9**	**59.9 ± 33.2**
	median (range)	**29.8 (0–115)**	**94 (42–94)**	**66.2 (−22–100)**
ARST	mean ± SD	122.4 ± 110.7	319.9 ± 57.5	63.6 ± 31.9
	median (range)	62 (0–391)	323 (96–343)	77.2 (−14–100)

PAT Phonological Awareness Test, *ARST* Arabic Reading Screening Test

Table 5 Comparison between right- and left-sided cochlear implantees in terms of their PAT and ARST total scores

Total scores	Side of CI	number	mean ± SD	*t*	*P*
PAT	Right	17	42.8 ± 2.17	0.099	0.92
	Left	13	43 ± 4.24		
ARST	Right	17	102.9 ± 9.67	0.087	0.93
	Left	13	103.2 ± 8.06		

PAT Phonological Awareness Test, *ARST* Arabic Reading Screening Test

reading at or above their chronological age's expected level. This observation is also in accordance with other studies [7, 14, 28].

Relation between PA and reading

PA is the metalinguistic ability to reflect on and/or consciously manipulate the sound structure of language [29] and is usually assessed via tasks that require segmenting, blending, isolating, deleting, or substituting phonological units. It is frequently regarded as a pre-literacy skill [30]. However, the underlying cause of reading deficits in CI children is sometimes debatable, particularly when it comes to the link between PA and reading attainment. While some [31, 32] argued that phonological skills are crucial to good reading outcomes in deaf children, others [33] believed they are less important. Cupples et al. [34] believe that the inconsistent findings reported across studies are probably due to a failure to control other variables that can influence children's PA and/or reading outcomes.

Despite the fact that phonological representations develop differently in hearing and deaf children who use spoken language, poor phonological development has been found to correlate with poor reading skills in both typically hearing children [29] and the deaf population, including CI users [16, 34, 35]. Such findings are in line with the results of this study.

When Geers and Hayes [3] investigated the role of PA in reading acquisition, they found that high school students with CIs scored better on reading measures than on PA ones. Yet, participants of the current study, who were all elementary students, scored comparably in both PA and reading tasks. It would be interesting to follow up these patients to see how their performance in both tests has differed over the years.

Association of PA and reading with the age of CI

While many studies [6, 12] claim that early implantation is linked to better prognosis in speech and language skills and, subsequently, reading outcomes, some studies [34, 36, 37] report that it has not always guaranteed better outcomes.

Due to the wide age range in the current study, age is predictably an intervening factor. To minimize its effect, we stratified the study group into two: "at or above" and "below" the age of 9 years, which is the median chronological age. The age of receiving CIs was not correlated to PA scores in both age groups, yet it was positively correlated to reading for the older group. The positive correlation between age at implantation and reading competency in the current study might infer that the older deaf patients are implanted, the better reading performance they would develop, but this must be interpreted cautiously. The lack of a negative correlation may be related to the fact that participants received their CIs at an average chronological age of 4 years (or even older for the group of patients $\geq$ 9 years), which is not young enough to demonstrate the benefits of early implantation because the first 2 years of life are crucial for the auditory input needed for language development. Another explanation may be related to the interference of other confounding variables that influence the reading performance of CI children, e.g., CI technology and device adjustment, efficiency of the rehabilitation program, educational placement, family support, and pre-implant language abilities [19] (e.g., for an older child to receive a CI that is covered by health insurance in Egypt, more advanced language requirements are needed. As shown in Table 1, on average, the group of patients at or above the age of 9 years uttered their first sentence before they received their CI). Thus, the age of implantation should be viewed as just one of several factors influencing prognosis [36]. Moreover, Geers et al. [10] suggested that the effect of age of surgery may be attenuated over time and become non-predictive of outcomes in older CI children.

Association of PA and reading with language abilities

Oral language is fundamental to reading for deaf children. This study showed that the more advanced their language skills were, the higher CI children scored in PA and reading tests. This is in line with Harris et al. [35], who also found a very strong correlation between the language of deaf children (both hearing aid and CI users) and their reading scores. They proposed that good language size is a mediating factor in the relationship between children's PA and reading skills in both normally hearing and deaf children. Wass et al. [38] also indicated that receptive vocabulary is the most significant predictor of reading comprehension in CI children.

It is necessary to note, though, that no data was available about participants' language profiles at the time of receiving CI or at any time before the study started. Nonetheless, the age at which they uttered their first words and sentences can provide insight into their language development. Information about the changes in the progression of language, PA, or reading skills over time, how they were compared to normally developing peers, or how they were linked to one another, was not known. Thus, a longitudinal study would be informative to explore how language, PA, and reading skills evolve and are related to one another over the years, and whether the gap between chronological age and reading skills in children with CI widens or reduces with age.

Choosing the ear to be implanted

Yalcinkaya [39] recommended that the left ear be chosen for implantation, as the left hemisphere can undertake the liabilities of the right hemisphere and not vice versa. The author noticed that, in prolonged follow-up, children whose right ears were implanted showed marked improvement in speech perception and language, but they were delayed in advanced reading skills. In the current study, implanting the right or left cochlea showed comparable results in PA and reading tests. Nevertheless, a true comparison of the left versus right ear would necessitate recruiting participants with bilateral implantations or at least controlling other confounding factors that might interfere with outcomes.

Conclusion and future directions

In conclusion, deaf children using CIs are at increased risk of reading disorders. Although CI has enhanced the overall level of reading skills, it has not eliminated such difficulties for all children.

Since PA and reading ability were found to be closely associated, placing more emphasis on phonological growth during rehabilitation is recommended.

A longitudinal study tracking PA and reading skills in CI children from the prereading/preschool period to adulthood is needed to better understand the development of these skills over time.

Abbreviations

CI: Cochlear implant; PA: Phonological awareness; PASS: Power analysis and sample size; IQ: Intelligence quotient; dB: Decibel; PAT: Phonological Awareness Test; ARST: Arabic Reading Screening Test; SPSS: Statistical Package for Social Sciences.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s43163-022-00291-1.

Additional file 1: Tables S1–S5. **Table S1.** Correlation between the ARST results (sub-tests and total score) of the study participants and their PAT results (sub-tests and total score). **Table S2.** Correlation between the study participants' PAT results and their age at the time of cochlear implantation. **Table S3.** Correlation between the study participants' ARST results and their age at the time of cochlear implantation. **Table S4.** Correlation between the study participants' PAT results and their language ages. **Table S5.** Correlation between the study participants' ARST results and their language ages.

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Authors' contributions

E.H. came up with the idea and interpreted the results; S.T was responsible for the data collection and analysis; M.S. interpreted the results, wrote the manuscript and contacted the journal; and N.G. supervised the whole work and revised the writing. The authors read and approved the final manuscript.

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Availability of data and materials

The datasets used and analyzed in this study are available from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate

The study was approved by the Research Ethics Committee (REC), Faculty of Medicine, Ain Shams University; approval code (FMASU MS 21/2020). The parents of the recruited children gave their informed consent.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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