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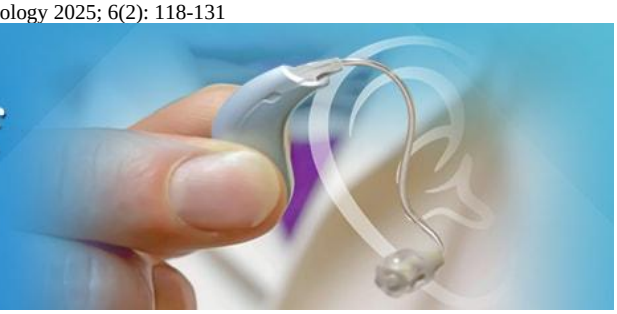

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**Priyanjali Harit**
Audiologist & SLP, Army Hospital, (R & R), New Delhi, India

**Correspondence**
**Priyanjali Harit**
Audiologist & SLP, Army Hospital, (R & R), New Delhi, India

# Silent Strain: Exploring literacy outcomes, challenges and listening efforts in prelingual adults using cochlear implants

## Priyanjali Harit

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**Abstract**
Hearing plays a critical role in the development of spoken language, cognitive growth, social skills, and academic achievement. Prelingual individuals with severe-to-profound hearing loss face significant challenges in acquiring language and literacy skills. Although cochlear implants (CIs) provide improved auditory access and facilitate language development, outcomes vary, particularly for those implanted after critical language acquisition periods. This study aimed to explore literacy achievements, challenges, and listening fatigue among prelingual adults using CIs from early childhood. A total of 63 adults aged 18-25 years, all with bilateral severe-to-profound hearing loss and unilateral cochlear implants used for at least 15 years, participated. Data were collected through a structured literacy survey covering reading, writing, and digital literacy, detailed case histories, and the Vanderbilt Fatigue Scale-Adult version (VFS-A-10) to assess listening effort. Findings highlight that literacy development in CI users is influenced by auditory exposure, early language experience, cognitive skills, educational support, and socio-emotional factors. Participants exhibited variability in reading and writing skills, digital literacy, and experienced listening-related fatigue, especially in challenging acoustic environments. Understanding these interrelated factors is essential for developing targeted educational strategies, rehabilitation programs, and supportive interventions to optimize literacy, reduce cognitive load, and enhance academic and social outcomes in prelingual adults with cochlear implants.

**Keywords:** Green computing, eco-friendly technology, carbon emissions, carbon foot print, e- waste, degradation

## 1. Introduction
Hearing is the foundation for the development of effective spoken language skills, having direct influence on social development, cognitive development and academic growth. Individuals with prelingual severe to profound hearing loss often encounter significant challenges in developing language and literacy skills. Even after receiving cochlear implants, many of these individuals shows delayed or deviant developmental pattern while acquiring language and literacy skills (Nicholas & Geers, 2003) [9]. Cochlear implants (CIs) have significantly enhanced auditory access for individuals with severe-to-profound hearing loss and have shown promising results in language development in many of these cases. However, the suboptimal outcomes were reported, especially for those who receiving cochlear implants after the critical period for language acquisition (Alawneh *et al*., 2002) [1]. The majority of previous literature (Tomblin *et al*., 2005; Suskind, 2015) [37, 35] emphasised on early intervention and language development for better outcomes with cochlear implants to achieve adequate language and literacy skills. However, there is a huge gap of research understanding on the relationship between prelingual adults with cochlear implants and their literacy achievements and challenges, digital competencies and listening fatigue related to sustained listening efforts.

Literacy development in cochlear implant users is a complex and multifaceted process influenced not only by auditory exposure, but also by early language exposure, cognitive skills of an individual, targeted rehabilitation services, parental support, learning environment at home, and educational support systems. The interaction of these factors determines the extent to which the cochlear implant users can effectively decode, comprehend, and produce written language. Individuals with prelingual hearing loss tends to

show limited vocabulary, affected syntactic processing, and slower phonological awareness, which might lead to delayed literacy acquisition. Addition to these factors, socio-emotional factors, such as self-confidence and motivation, also play a critical role in literacy development in individuals with cochlear implants (Punch & Hyde 2011) [30].

Listening with a cochlear implant, particularly in acoustically challenging environments such as in presence of background noise or group discussions, often requires considerable cerebral effort (Hornsby *et al*., 2023) [15]. This sustained cognitive load, known as listening effort, may contribute to listening-related fatigue, which in turn can affect learning, reading omprehension, and overall engagement with print and digital media. In order to design the educational and therapeutic strategies for students with cochlear implants, it is crucial to understand how listening effort interacts with literacy development. With global trend shifting towards intensive use of digital text and multimedia for communication and learning, it is also essential to explore digital literacy skills of individuals with cochlear implants.

With significant gap in the previous research, the present study tried to explore and understand the pattern of literacy development, academic achievements, challenges and barriers faced during academic progression, listening effort among individuals with cochlear implants. The Prelingual adults with cochlear implants often encounter difficulties that limits their ability to fully engage in academic and social environment. There is scarcity of information in existing literature on these issues and by examining the interplay between literacy skills, challenges and listening fatigue, the present study seeks to shed light on how auditory processing demands influence cognitive load and learning outcomes. Also, the findings from the study will contribute to tailored educational settings and strategies, clinical support by addressing academic need of individuals with cochlear implants and thus improving their quality of life.

## 2. Aim of the Study

The present study aimed to explore the literacy achievements, challenges and barriers faced by prelingual adults who have used cochlear implants since early childhood. Additionally, to better understand their device contribution to the literacy development, the listening fatigue levels of the participants were also evaluated.

### 2.1. Objectives of the Study

a) To develop and administer the literacy survey questionnaire for prelingual adults using cochlear implants.
b) To explore and understand the literacy achievements (reading, writing and digital literacy) of prelingual adults using cochlear implants.
c) To identify the educational barriers faced by prelingual adults using cochlear implants in achieving literacy.
d) To assess the level of listening fatigue experienced by prelingual adults using cochlear implants.

## 3. Methodology

### 3.1 Participants

A total of 63 prelingual adults with hearing impairment within the age range of 18 to 25 years were included in the study. All the participants were having bilateral severe-to-profound sensorineural hearing loss and were using unilateral cochlear implant (only in the one ear). All the participants had undergone cochlear implantation before the age of 6 years and have used the device for minimum of 15 years prior to data collection, to ensure long-term auditory exposure post cochlear implantation. None of the participants had any additional co-morbidities such as cognitive decline/deficiency, neurological issues, or any physical impairment that could influence language or literacy development. All the participants included in the study have completed minimum 10 years of formal education irrespective of attending a mainstream school, open schooling or special schools for hearing impaired.

### 3.2 Procedure

The study was carried out in 4 phases as mentioned below: -

- **Phase 1:** development of literacy survey questionnaire to evaluate literacy achievements and challenges faced by prelingual cochlear implant adults.
- **Phase 2:** detailed case history and other relevant information was collected
- **Phase 3:** administration of the developed literacy survey questionnaire
- **Phase 4:** administration of Vanderbilt fatigue scale-Adult version-10items (VFS-A-10)

#### 3.2.1. Phase 1: Development of the literacy survey questionnaire

A literacy survey questionnaire was developed as a part of the present study with each domain consisting of 10 questions targeting their reading and writing habits, reading and writing skills, confidence level, support received and challenges faced by the participants in literacy development. The questions selected under each category were carefully chosen and shared with 5 experienced audiologist and speech language pathologists (ASLPs) and was modified according to the suggestions given.

Domain 1 of the literacy survey questionnaire was designed to target reading literacy skills such as participant's reading habits, reading understanding abilities, and the challenges they may face while reading as shown in table. 1. Questions were constructed to understand reading skills in both printed and digital reading formats to capture a comprehensive picture of literacy in various contexts. There are total of 10 multiple-choice questions, with one open-ended question to gather more in-depth responses regarding reading skills. The first two questions (question 1 and 2) focused on the frequency of reading printed and digital content, helping to understand the participants exposure to different reading means. Questions 3 through 5 assess reading comprehension, difficulties with sentence structure, and confidence in reading aloud. These questions provide insight into cognitive and emotional aspects of reading. Questions 6 and 7 explore the school support and specific reading challenges faced by the participants such as vocabulary difficulties, slow reading speed, or lack of interest. Questions 8 and 9 examine environmental and psychological factors, including the impact of background noise and mental fatigue on reading performance. The last question (question 10) in this domain asks respondents to self-rate their reading comprehension and offers an opportunity for them to explain their answer. This allows for a deeper understanding of individual experiences and perceptions related to literacy achievements and challenges.

**Table 1:** Questions and response options of Domain 1 (reading literacy skills) of the Literacy survey questionnaire.

| **Domain 1:** Reading literacy skills | | |
|---|---|---|
| **Item No.** | **Questions** | **Response options** |
| 1 | How often do you read printed books/newspapers/magazines? | a. Daily,<br>b. few times week<br>c. rarely<br>d. never |
| 2 | How often do you read digital content (e.g., websites, emails, social media posts, e-books)? | a. Daily,<br>b. few times week<br>c. rarely<br>d. never |
| 3 | Can you easily understand the meaning of what you read in newspapers or textbooks? | a. Always<br>b. Often<br>c. Sometimes<br>d. Rarely |
| 4 | Do you find it difficult to read long or complex sentences? | a. Yes<br>b. No<br>c. Sometimes |
| 5 | How confident do you feel when reading aloud? | a. very confident<br>b. somewhat confident<br>c. not confident<br>d. I avoid reading aloud |
| 6 | Did your school provide reading support (e.g., remedial classes, special educators)? | a. Yes<br>b. No<br>c. not sure |
| 7 | What challenges do you face while reading? (select all that apply) | a. difficulty understanding vocabulary<br>b. difficulty following grammar<br>c. slow reading speed<br>d. distraction or lack of concentration<br>e. lack of interest<br>f. no major challenges |
| 8 | Does background noise affects your reading ability? | a. Yes<br>b. no |
| 9 | Do you experience mental fatigue while reading for long durations? | a. Yes<br>b. No<br>c. Sometimes |
| 10 | How would you rate your reading comprehension in your preferred language? | a. Excellent<br>b. Good<br>c. Average<br>d. Poor |

Domain 2 of the literacy survey questionnaire was constructed to understand and explore the writing literacy among the prelingual adults using cochlear implants as seen in table. 2. Similar to domain 1, this section of the questionnaire also consists of 10 questions with the options to respond in multiple choices. The questionnaire aims to gather information on writing frequency, confidence levels of the participants, challenges they face white writing, and the information on use of the support systems or assistive technologies.

The first two questions (question 1 and 2) examine how frequently participants engage in writing by hand or by using digital tools. Questions 3 and 4 assess the participants self-reported confidence in spelling and grammar. Question 5 identify specific writing challenges such as spelling, grammar, organization, speed, and vocabulary. Educational background and support are addressed in Question 6, which asks whether schools provided targeted writing assistance. Questions 7 through 9 explore coping strategies and emotional responses to writing, including the use of tools like spellcheck or grammar software, avoidance behaviour, and writing-related anxiety. Question 10 evaluates the participant's perception of their handwriting quality. In this domain of the survey, the holistic view of writing literacy by incorporating cognitive, behavioral, and emotional aspects. The data collected from this survey is useful to identify patterns in reading behaviour, inform educational interventions, and support targeted literacy development programs.

**Table 2:** Questions and response options of Domain 2 (writing literacy skills) of the Literacy survey questionnaire.

| **Domain 2:** writing literacy skills | | |
|---|---|---|
| **Item no.** | **Questions** | **Response options** |
| 1. | How often do you write by hand (e.g., notes, lists, letters)? | a. Daily<br>b. few times a week<br>c. rarely<br>d. never |
| 2 | How often do you write using digital tools (e.g., computer, smartphone)? | a. Daily<br>b. few times a week<br>c. rarely |

| | | |
|---|---|---|
| | | d. never |
| 3 | How confident are you in spelling correctly? | a. very confident<br>b. somewhat confident<br>c. not confident |
| 4 | How confident are you in forming grammatically correct sentences? | a. very confident<br>b. somewhat confident<br>c. not confident |
| 5 | What are the main challenges you face in writing? (select all that apply) | a. spelling errors<br>b. grammar errors<br>c. idea organization<br>d. writing speed<br>e. confidence<br>f. vocabulary<br>g. no major challenges |
| 6 | Did your school provide specific support for writing skills (e.g., extra writing practice, writing assistance)? | a. Yes<br>b. No<br>c. not sure |
| 7 | Do you use any assistive tools for writing (e.g., spellcheck, predictive text, grammarly)? | a. Yes<br>b. No<br>c. Sometimes |
| 8 | Do you avoid writing tasks due to difficulty or fatigue? | a. Yes<br>b. No<br>c. Sometimes |
| 9 | Do you feel anxious or stressed when you are asked to write (e.g., essays, official emails)? | a. Yes<br>b. No<br>c. sometimes |
| 10 | How do you rate your handwriting (if applicable)? | a. very neat<br>b. average<br>c. difficult to read<br>d. I avoid handwriting |

The Digital Literacy Skills in the domain 3 of the literacy survey questionnaire was developed to evaluate participants access to, usage of, and their confidence with the modern digital technologies as seen in table 3. This section also contains 10 questions targeted to understand a broad picture of digital competence, including both technical skills and the ability to navigate online content effectively. The first two questions (question 1 and 2) attempt to understand digital access and frequency of device use, establishing the participants exposure to technology. Question 3 evaluates typing proficiency which directly assess a digital communication and content creation. Question 4 explores the participants ability or inability to use common educational and workplace digital tools such as Microsoft Word or PowerPoint, Google Documents, zoom or google meet. Questions 5 to 7 investigate how individuals interact with digital content, including the use of subtitles/captions for accessibility, challenges in understanding online materials, and whether participants use assistive technologies like screen readers or voice-to-text tools. Question 8 assesses the independent performance of participants in performing digital tasks. Question 9 investigates the dependency of participants on assistive listening devices. The last question on 10 asks the respondents to self-evaluate their overall digital literacy by rating their digital understanding. This part of the questionnaire explains a comprehensive picture of digital literacy, especially relevant in contexts where education, communication, and work are increasingly facilitated by technology. The findings from this section help design training or support programs for individuals with hearing impairment who have limited digital skills.

**Table 3:** Questions and response options of Domain 3 (digital literacy skills) of theLiteracy survey questionnaire.

| **Domain 3:** Digital literacy skills | | |
|---|---|---|
| **Item no.** | **Questions** | **Response options** |
| 1 | Do you own a smartphone or digital device? | a. Yes<br>b. No |
| 2 | How often do you use digital devices (smartphone, tablet, computer)? | a. Daily<br>b. few times a week<br>c. rarely<br>d. never |
| 3 | How confident are you in typing on digital devices? | a. very confident<br>b. somewhat confident<br>c. not confident |
| 4 | Can you use educational or work-related tools (e.g., microsoft word, google docs, zoom)? | a. Yes<br>b. No<br>c. Some |
| 5 | Do you use subtitles or captions while watching videos online? | a. Always<br>b. Often<br>c. Sometimes<br>d. Never |
| 6 | Do you use any accessibility tools (e.g., screen readers, voice-to-text)? | a. Yes |

| | | |
|---|---|---|
| | | b. No<br>c. Sometimes |
| 7 | Do you face difficulty understanding online content? | a. Yes<br>b. No<br>c. Sometime |
| 8 | Do you need help from others to complete digital tasks? | a. Always<br>b. Sometimes<br>c. Rarely<br>d. Never |
| 9 | Do you use any assistive listening devices such as T.V streamer, mini mic, etc | a. Yes<br>b. No |
| 10 | How would you rate your digital understanding? | a. Excellent<br>b. Good<br>c. Average<br>d. Poor |

### 3.2.2. Phase 2: Detailed case history

A comprehensive case history was taken to gather detailed information on demographic background such as age, gender, family structure and linguistic environment at home. Information regarding developmental milestones were gathered to understand the early growth and progress in areas such as motor, cognitive, social, speech and language development, with more attention given to understand the communication skills. Details were also gathered related to cochlear implantation such as age at implantation, type and model of the implant and sound processor, duration and consistency of cochlear implant usage and hearing aid use in the contralateral ear, post-implantation rehabilitation efforts like duration of speech therapy post implantation and speech and language skills.

Detailed academic history was taken from all the participants where the parental inputs were also actively solicited. They were asked about the highest education qualification achieved (below $10^{th}$ grade, $10^{th}$ grade, $12^{th}$ grade, graduate or post graduate), type of educational setting (mainstream schools, special schools or open schooling), they were also asked about their overall performance in academics, and participation in any extracurricular activities. In addition, the participants were also asked about the challenges and general issues they faced in the school environment such as difficulties with classroom listening, difficulties listening in the group or background noise, interactions with classmates, friends and teachers and other academic adjustments and difficulties they faced during the academic years.

### 3.2.3. Phase 3: administration of developed literacy survey questionnaire

To understand the literacy achievements and challenges faced by the prelingual adults using cochlear implants, a survey questionnaire developed as the part of the present study was administered on all the participants where information was gathered under 3 different domains such as reading literacy skills, writing literacy skills and digital literacy skills. The data collection was conducted using two different modalities: face-to-face interviews were carried out with 39 participants who were available in person, while the rest of the 24 participants who were not physically available, the questionnaire was administered telephonically.

The face-to-face interview with the participants was conducted in the room that was adequately lit with minimal distractions which helped maintain focus and created a conducive environment for the discussion. Participant, along with their parent or guardian and the evaluator were present in the room. This one-to-one setting helped in creating a comfortable environment, encouraging participants to respond freely and honestly about their literacy development skills. It also minimized potential interruptions or influences from other individuals, ensuring that the information gathered was accurate.

### 3.2.4. Phase 4: Vanderbilt fatigue scale-Adult version-10items (VFS-A-10)

The Vanderbilt fatigue scale-Adult version-10items (VFS-A-10) developed by Hornsby *et al*. (2023) [15], was used to evaluate the listening fatigue levels of all the participants of the study. The VFS-A-10 (table. 4.) is a validated self-reported questionnaire consist of 10 questions and rating ranges from 0 (never/almost never) to 4 (almost always/always) targeted to evaluate the impact of sustained auditory effort on daily functioning in individuals with hearing impairment. The VFS-A-10 tries to evaluate both physical and mental fatigue associated with auditory processing demands, making it particularly relevant for cochlear implant users who depends on focused listening to understand speech. Participants of the present study were presented with the VFS-A-10 questionnaire and asked to select the single response that best describes how they often experience the given situations in a typical week.

**Table 4:** The Vanderbilt fatigue scale-Adult version-10items (VFS-A-10)

| S. No | | Never/ almost never | Rarely | Sometimes | Often | Almost always/always |
|---|---|---|---|---|---|---|
| 1 | I feel worn out from everyday listening. | 0 | 1 | 2 | 3 | 4 |
| 2 | Struggling to listen and understand makes me feel tired. | 0 | 1 | 2 | 3 | 4 |
| 3 | I get so exhausted from listening that I cannot do the things I enjoy. | 0 | 1 | 2 | 3 | 4 |
| 4 | I schedule my day to avoid getting tired from listening. | 0 | 1 | 2 | 3 | 4 |
| 5 | I get so tired from listening that I start to miss details in a conversation | 0 | 1 | 2 | 3 | 4 |
| 6 | I get so exhausted from listening that I go to bed early. | 0 | 1 | 2 | 3 | 4 |
| 7 | I withdraw when I am unable to follow conversation in noisy places. | 0 | 1 | 2 | 3 | 4 |
| 8 | Feeling tired from listening causes strain on my relationship. | 0 | 1 | 2 | 3 | 4 |
| 9 | I feel emotionally drained when it is hard for me to listen and understand | 0 | 1 | 2 | 3 | 4 |
| 10 | It takes a lot of energy to listen and understand. | 0 | 1 | 2 | 3 | 4 |

## 4 Results

### 4.1. Participant demographics, educational background, and communication modes

A total of 63 prelingual adults using cochlear implants were participated in the study with an age range of 18 to 25 years with a mean age of 21.7 years. The mean implant age (age at which the cochlear implantation was done) of all the participants included in the study was 3.9 years and all of them were unilaterally implanted. According to the case history reports, only 15 participants were regularly using hearing aid in the contralateral ear (opposite ear), while the remaining 48 participants did not use a hearing aid regularly in the contralateral ear post cochlear implantation.

The highest educational qualifications attained by the participants is illustrated in Figure.1. Of the 63 participants, 39 had completed 12th grade, 10 had completed 10th grade, 11 had obtained an undergraduate degree, 1 had completed a postgraduate degree, and only 1 participant had not completed 10th grade.

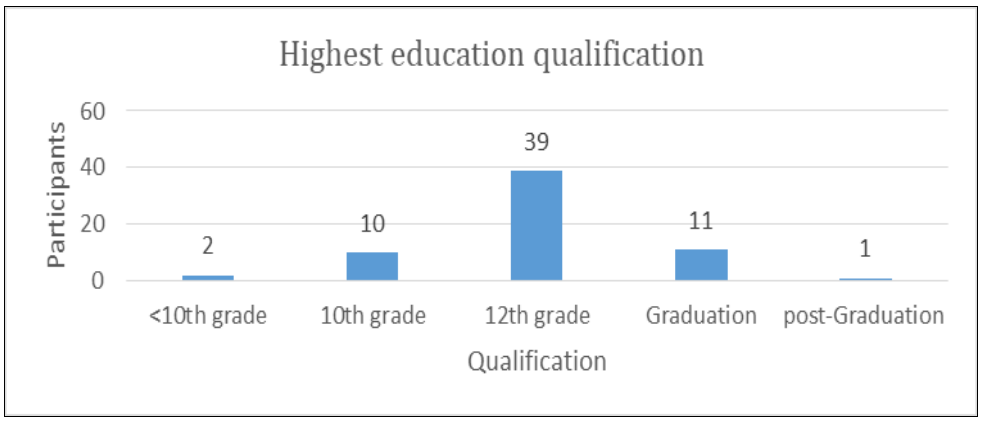


**Fig 1:** Highest education qualification achieved by the participants.

During the case history assessment, it was found that the majority of participants attended regular school up to the 9th grade and completed their 10th and 12th grades through open schooling, without continuing in a regular school setting. As shown in Figure 2, 37 participants completed their 10th and 12th grade examinations through open schooling under the National Institute of Open Schooling (NIOS), while 25 participants continued in regular mainstream schools. Among those in regular schooling, 13 completed their highest education up to the 10th grade, and 12 successfully completed the 12th grade. None of the participant of the present study had studied in the special school.

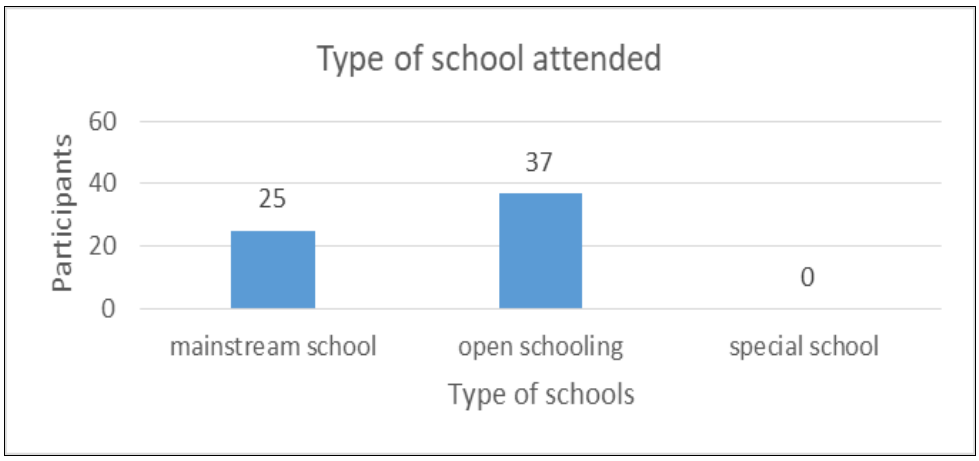


**Fig 2:** Type of school attended by the participants.

The mode of communication used by participants during their academic development is illustrated in Figure 3. Out of the 63 participants, 39 used a combination of verbal and sign language, 22 relied solely on verbal communication, and 2 participants exclusively used sign language.

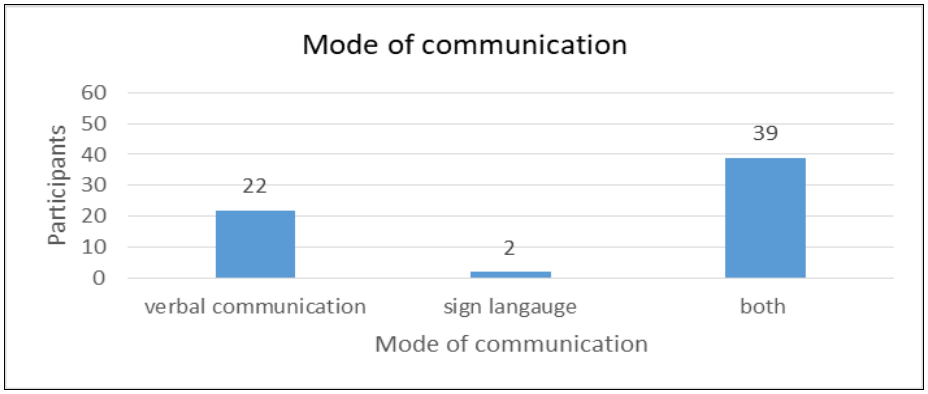


**Fig 3:** Mode of communication preferred by the participants during academic development

### 4.2. Reading literacy skills

The findings from the reading skills survey provide a holistic view of reading habits, comprehension, confidence, challenges, and the support received in academic development (Figure 4). When the questions related to reading habits were asked to the participants, it was found that a majority of participant, 52 for printed material and 57 for digital content, reported reading on a daily basis. This suggests that majority of them have good reading habits, with digital content being read even more frequently than printed materials. In terms of reading comprehension, most participants showed moderate understanding of reading material, irrespective of whether it was in printed or digital format. However, a significant number of participants reported reading struggle with sentence complexity, particularly when reading long and complex sentences. This indicates that they may experience fatigue when reading for extended periods. Additionally, 49 participants reported experiencing mental fatigue during prolonged reading sessions. Low confidence levels were apparent when participants were asked about reading aloud situations, most of the participants express discomfort and most of the time they avoid reading aloud. This highlights a general lack of confidence in reading abilities. All participants reported receiving no institutional support, indicating a complete lack of academic assistance for individuals with hearing impairments or those using cochlear implants in India. The major challenges reported by participants include difficulty understanding vocabulary (59 participants), difficulty focusing while reading for long duration (57), they show lack of interest in reading tasks (54), majority of them had slow reading speed (48), and they reported frequent distractions (42). Only 2 participants reported facing no major issues with their reading skills. Environmental factors were also shown to significantly impact reading abilities in individuals using cochlear implant, as all participants reported that background noise affected their capacity to read effectively. When asked to self-rate their reading comprehension in their preferred language, most participants rated themselves as average or below average, whereas very few (13 participants) reported good self-rated reading skills and just 1 of them rated excellent reading comprehension.

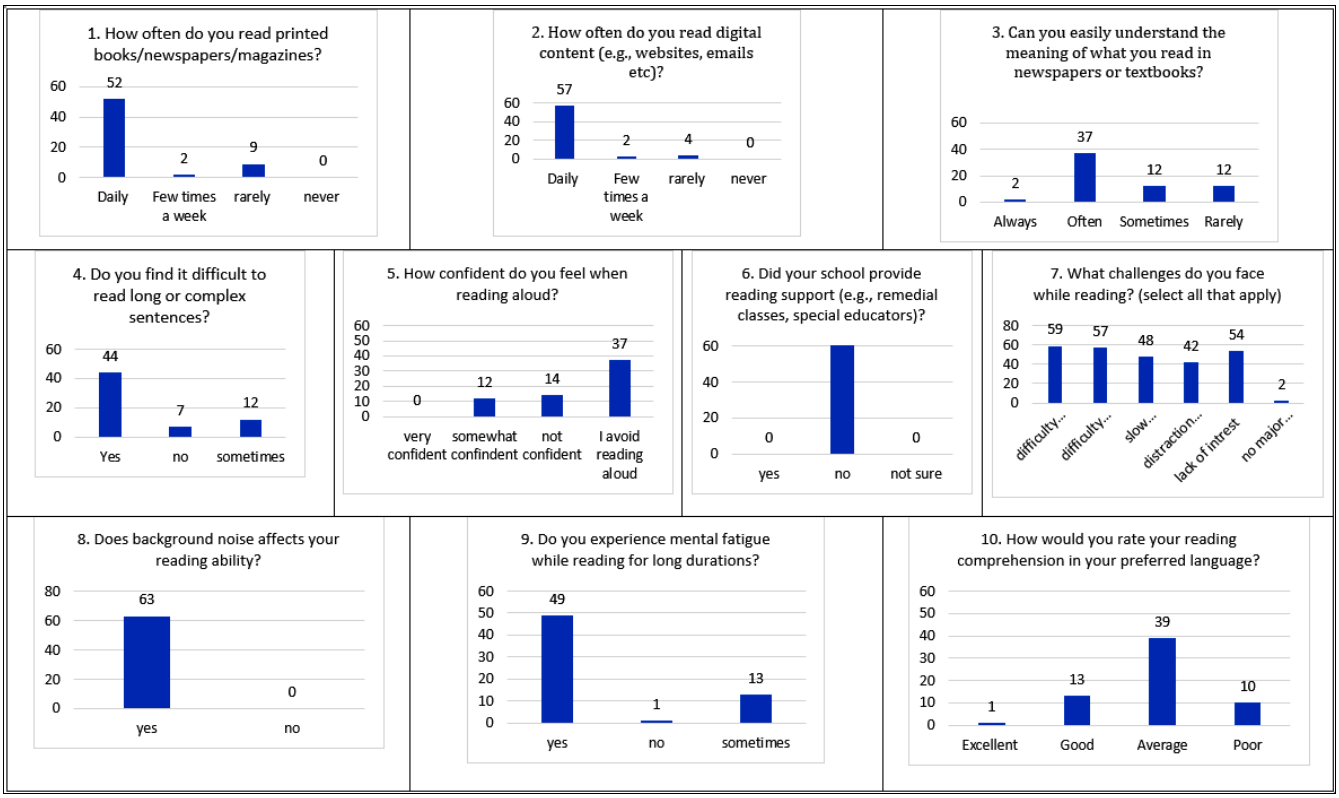


**Fig 4:** Average responses for question 1 to 10 of domain 1 (Reading literacy skills) of the literacy survey questionnaire.

### 4.3. Writing literacy skills

The findings from the written literacy skills section of the survey questionnaire indicate that digital writing is significantly more common than handwriting among prelingual adults using cochlear implants (Figure 5). While only 22 participants reported writing by hand daily, a much larger number (53 participants) reported frequent use digital modality for writing. A prominent concern is the lack of strong confidence in spelling seen in this population, with 42 participants indicating low spelling confidence, which may reflect poor overall writing literacy skills. Similarly, confidence in forming grammatically correct sentences was moderate to low, with 39 participants stating they were 'somewhat confident' and 24 reported 'lack of confidence' under this section. Participants also reported facing wide range of challenges in writing. The most common issues reported was low confidence (48 participants), vocabulary difficulties (45), spelling errors (38), problems with organizing ideas (35), grammar errors (32), and slow writing speed (19). Only 4 participants indicated that they did not face any major writing challenges. In line with the findings from the reading section, there was a clear absence of institutional support for developing writing skills, with most participants stating that their schools did not provide any specific assistance to help them with the writing skills.

Writing fatigue appeared as a common barrier in achieving writing literacy, with many participants (43) avoiding writing tasks due to difficulty or fatigue. Moreover, writing tasks caused significant anxiety, with 51 participants reporting feelings of stress or pressure when asked to complete formal writing assignments such as essays or official emails. Finally, when asked to rate their handwriting, most participants described it as average, suggesting moderate satisfaction with their performance.

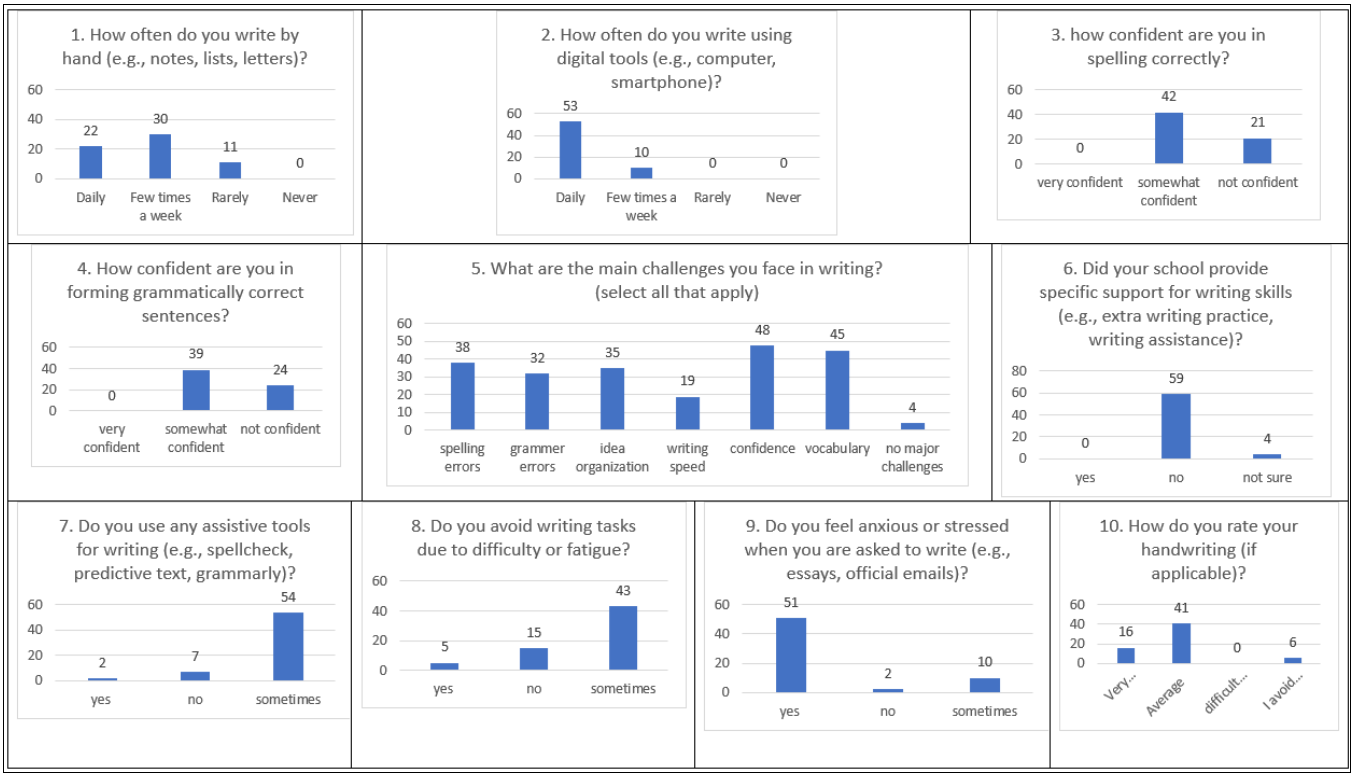


**Fig 5:** Average responses for question 1 to 10 of domain 2 (writing literacy skills) of the literacy survey questionnaire.

### 4.4. Digital literacy skills

Findings from the digital literacy sections revealed that all the participants use digital devices such as smartphone, laptop etc on daily basis (Figure 6). When participants were asked to rate their confidence level to type on the digital devices such as smartphones, tablets or laptops, 11 participants reported that they are very confident and have strong typing skills and can use them accurately without much effort. 39 participants (largest group of participants) reported reasonably fair confidence level with typing but still may face some challenges such as typing errors, slower speed or difficulty using different type of devices. They may use digital device but might not be highly efficient or comfortable in fast-paced digital environments. 13 participants struggle with basic typing. They may find typing to be a slow, frustrating process, which could discourage them from engaging in digital tasks, instead they reported using pictorial way to communicate using digital devices. Their low confidence might stem from lack of formal training or limited exposure to digital devices.

When asked about the efficiency in using educational or work related tools such as Microsoft word, Google docs, online meeting etc, majority of the participants (43) have experience using some of the tools and may know how to use basic features (e.g., typing in Word, opening a Zoom link), but might struggle with more advanced functions (e.g., document formatting, sharing and storing files, using collaborative tools, or adjusting meeting settings). These findings suggests that there is a need for further digital literacy training to bridge the gap between basic use and full competence. When asked about the use of subtitles, accessibility tools and assistive listening technologies, 54 participants reported that they never used subtitles or captions while watching videos. Similarly, 56 participants do not use accessibility tools (e.g., screen readers, voice-to-text). All the participants (63) do not use assistive listening

devices (e.g., TV streamer, mini mic). The low usage of subtitles and accessibility tools indicates that there is lack of awareness about the usage, lack of interest of perceived usefulness, there is a possibility of delayed processing of written subtitles and mismatch between video and written comprehension, and at last there is also a possibility that were not being introduced or taught to the individuals with cochlear implants.

When the questions related to understanding online content and support with the digital task were presents, findings revealed that 59 participants either don't struggle or occasionally struggle with digital content understanding, suggest that participants have moderate to good level of digital comprehension. However, 27 participants face difficulties sometimes indicating digital comprehension challenges, might be due difficult vocabulary, technical language or issues with individual's concentration levels or digital fatigue. Surprisingly, 43 participants out of 63 reported that they rarely need help, suggesting that most of them are functionally independent when using digital tools. These findings indicate that they are capable of managing their digital tasks on their own, reflecting a strong sense of autonomy in adulthood. Moreover, this may also imply that they prefer to work independently and do not appreciate interference or constant guidance while navigating digital platforms.

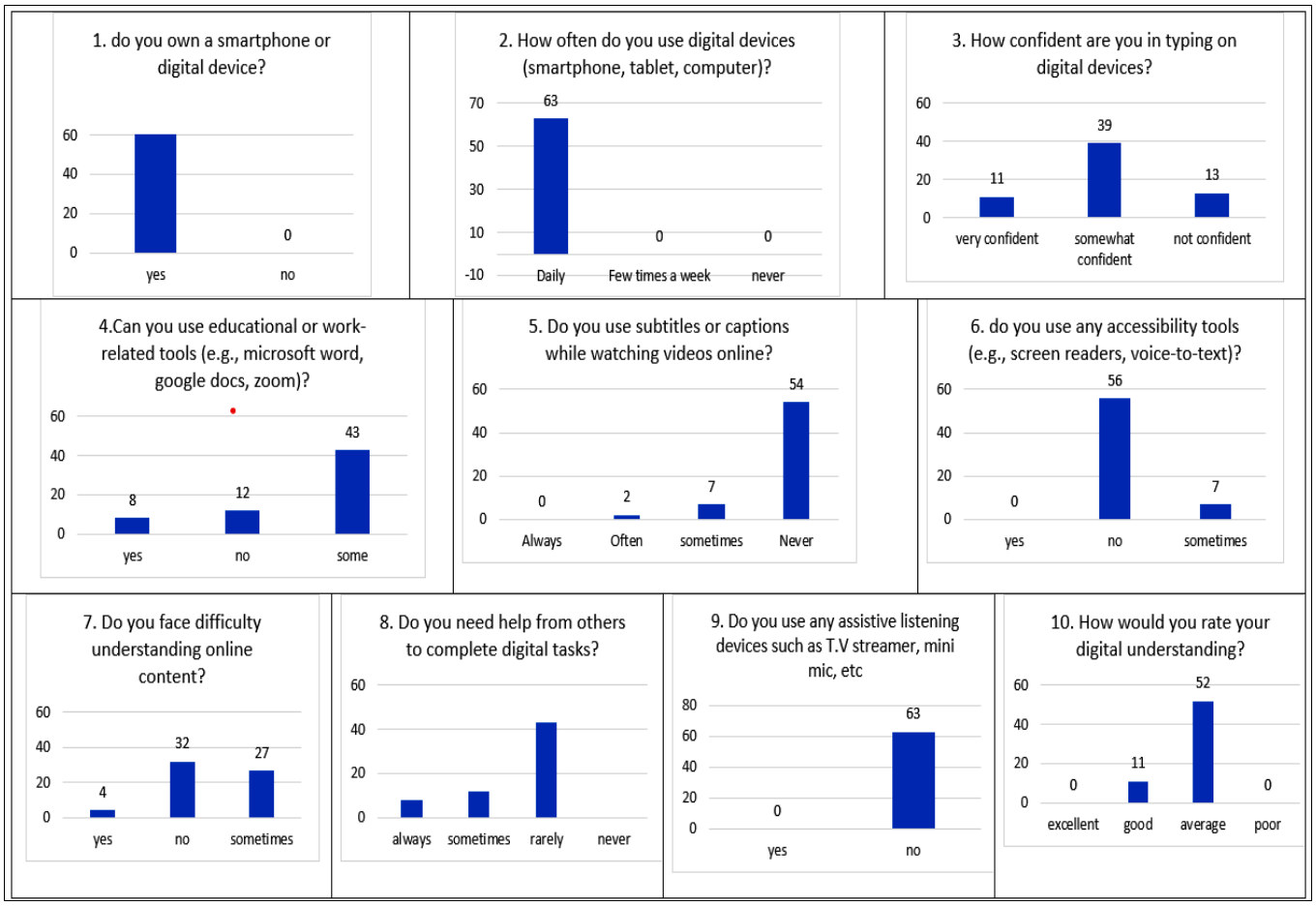


**Fig 6:** Average responses for question 1 to 10 of domain 3 (digital literacy skills) of the literacy survey questionnaire.

### 4.5. Assessment of listening fatigue

The VFS-A-10 scale was administered on all the participants to evaluate their listening fatigue levels. The average VBFS-A-10 score graph (Figure 7) represents the individual average scores of 63 participants on the VFS-A-10 scale. Findings revealed that most of the scores falls between 20 and 30 indicating moderate to high fatigue levels (Table, which suggests that Listening fatigue likely interferes with communication or quality of life. The findings also highlight that for most of the prelingual adults with cochlear implants have effortful listening and their listening demands are mentally and physically draining.

Findings from a smaller group of participants (participant 4, 8. 11. 17, 36, 44, 54 and 60) with average scores less than 20 suggests mild to moderate level of listening fatigue, which further suggests that fatigue is noticeable but may not severely impact daily life. But only few of the participants under this category compared to those with higher scores.

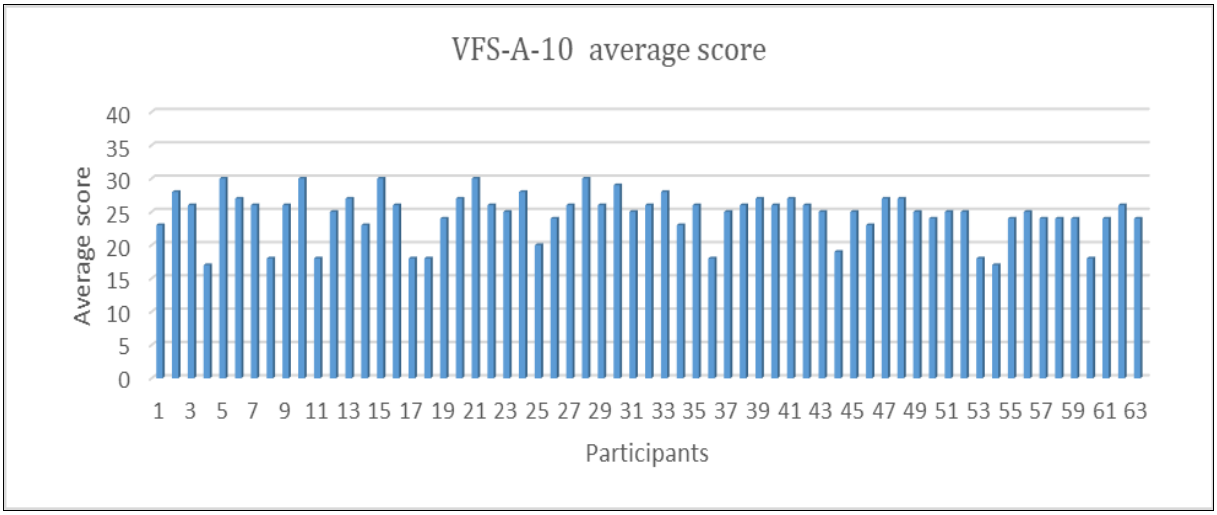


**Fig 7:** The individual average scores of 63 participants on the VFS-A-10 scale.

**Table 5:** Interpretation of The Vanderbilt fatigue scale-Adult version-10 (VFS-A-10)

| Total Score (0-40) | Fatigue Level | Interpretation |
|---|---|---|
| 0-10 | Low fatigue | Minimal perceived listening fatigue. Likely no clinical concern. |
| 11-20 | Mild to moderate fatigue | Fatigue is noticeable but may not severely impact daily life. Monitor or reassess. |
| 21-30 | Moderate to high fatigue | Listening fatigue likely interferes with communication or quality of life. |
| 31-40 | Severe fatigue | Clinically significant fatigue. Consider intervention or further assessment. |

## 5 Discussion

### 5.1 Participant demographics, educational background, and communication modes

The findings from the present study showed that the prelingual adults with cochlear implants showed inadequate literacy development. Similar findings were reported by Nelson & Crumpton (2015) [26], where they evaluated the literacy skills of 43 children with hearing impairment, and found that the participants performed significantly poor in comparison to age matched typically developing children. There are many studies (Leigh *et al*., 2016; Traxler, C. B., 2000) [19, 36] which shows that the language learning trajectories of children with severe to profound hearing loss improves after cochlear implant surgery in contrast to impaired reading comprehension in comparison to typically developing children (Wang *et al*., 2021) [38]. Similar findings have been reported for emergent learners (Nittrouer *et al*., 2001) [27], senior school going children (Geers, 2003; Nittrouer *et al*., 2014; Weisi *et al*., 2013) [9, 28, 39], and also in adolescents (Geers & Hayes, 2010; Harris & Terlektsi, 2011) [10, 13]. In terms of academic achievements, a study carried by Sarant *et al*. (2015) [32] reported that bilateral cochlear implants at the younger age predicted the better academic outcomes. According to the authors children using bilateral Cochlear achieved significantly higher scores for oral language, math, and written language than children using unilateral CIs. Research indicates that children with unilateral CIs may face challenges in language comprehension and production, which are critical for literacy development (Harris *et al*. 2016) [12].

The finding from the present study showed that all the participants were unilateral cochlear implant users and majority of them were not using hearing aid in the contralateral ear and left the ear unaided post implantation. There are various factors which could be the reason for the unilateral cochlear implant users to discontinue using hearing aids in the contralateral ear such as superior sound quality with cochlear implant compared with the hearing aid, no perceived benefit from the hearing aid and degraded acoustic signal with combined acoustical and electrical hearing (Fitzpatrick & Leblanc, 2011) [7]. Bilateral and bimodal stimulation is reported to be better in the literature (Ching *et al*., 2009) compared to unilateral stimulation where the individuals report issues with understanding in the presence of noise, localization of sound signal and music perception. All these skills are important developmental skills required to attain adequate academic development. Present study showed there the prelingual adults with cochlear implants have deficit in reading, writing and digital literacy skills, which might be due to unilateral usage of cochlear implant. These findings are is consistent with the previous research where the authors also observed that bimodal stimulation (CI + HA) is underutilized in adults (Ching *et al*., 2009) [4]. Also, the authors reported that bimodal users often demonstrate better speech recognition in noise, sound localization, and music perception (Ching *et al*., 2004; Zhang *et al*., 2020) [5, 42] useful for adequate literacy development.

The present study showed that majority of participants (39 out of 63) have completed 12$^{th}$ grade, indicating successful completion of higher secondary education. These findings bring into line partially with previous research findings suggesting that educational outcomes of cochlear implant users are comparative better than those without cochlear implants, especially when the intervention has occurred early in life and is followed with consistent rehabilitation and educational support. 10 participants of the present study did not purse education beyond 10$^{th}$ grade, indicating the impact of hearing loss and inadequate support from unilateral cochlear implant. Punch and Hyde (2011) [30] reported that while many CI users attend mainstream schools and perform adequately, a significant group of CI users still face challenges such as language processing, fatigue, social integration, and limited academic accommodations, indicating the reason for limited literacy development not beyond secondary education.

During the case history analysis, it was found that the majority of the participants from the present study opted open schooling (thorough National institute for open schooling-NIOS) from regular mainstream school by the time they reached higher grades. The educational programs offered by open schooling offers a flexible learning framework, which may helpful for students with hearing impairment and also to those using cochlear implant, who may face various challenges and barriers in acquiring education in traditional classroom setups. Open schooling may allow students with hearing impairment with self-paced learning, personalized schedules and reduced dependency on auditory information specially in the presence of background noise and special modification opted by teachers to be used with students with hearing impairment. All these concerns are frequency reported as challenges by cochlear implant users. Findings from the present study of students opting for open schooling is in concurrence with the findings of Knoors and Marschark (2014) [18], where they emphasize that students with hearing impairments often struggle with the pace and auditory demands of mainstream classrooms, particularly when adequate arrangements such as captioning, FM systems, trained interpreters are lacking. Open schooling can therefore serve as an adaptive strategy to ensure continued educational progress while minimizing stress and fatigue. Previous researches (Punch & Hyde, 2011; Stinson & Antia, 1999) [30, 34] listed out the common aspect of why students with hearing impairment have transition from mainstream schools to open schooling. The authors have listed the barriers in mainstream schools such as lack of knowledge among teachers to deal with cochlear implant device, classroom seating modifications, lack of knowledge among teachers to modify teaching methods while teaching a student with hearing impairment, social isolation or bullying faced by students in mainstream schools. These challenges faced by the participants of the present study explains the early withdrawal from mainstream schooling and opting for open schooling after grade 9.

The communication modes used by participants in the present study during their academic development (as illustrated in Figure 3) shows the majority (39 out of 63 participants) of them rely on a dual communication approach using both verbal and sign language. Another set of participants (22) used only verbal communication, while only 2 participants depended exclusively on sign language. The predominant use of dual mode of communication (both verbal and sign language) among the participants suggests that using both verbal communication and sign language can be a highly adaptive strategy use by prelingually cochlear implant users. These findings are supportive with various literature reviews such as Marschark *et al*. (2012) [23] stated that combining both sign language and verbal communication supports better comprehension and academic performance among students who have varied auditory processing abilities. They also reported that sign language provides a reliable backup support for communication in situation where speech perception is limited or inconsistent. Visual communication helps students with cochlear implants even if they have developed strong spoken language skills in linguistically demanding contexts (Geers *et al*., 2017) [8].

The 22 participants from the present study who reported to rely only on the verbal communication while attaining literacy, likely represent those CI recipients with better speech perception outcomes, due to early cochlear implantation, received consistent rehabilitation inputs and good family support and enriched communication environment to spoken language. The communication mode used by the participants in this study suggests that no single mode suits all cochlear implant users and flexibility to use both verbal and sign modalities may offer the greatest benefit, particularly in academic settings where comprehension and interaction are essential.

### 5.2. Reading, writing and digital literacy skills

The present study showed the positive reading habits especially for the digital reading along with dominant use of digital writing tools over traditional handwriting among the prelingual adults with cochlear implants. The findings are in concurrence with the global trend where the young adults bare showing increased interest for digital media and digital literacy (Katzir *et al*., 2018) [17]. In cases of individuals with cochlear implants where the cognitive load increases with digital reading due to visual strain and multitasking demands. The authors reported these findings as a reason why a large group of individuals still rely of printed material for deep reading. Students with hearing loss face linguistic deprivation in early life, which affects the literacy development (Mayberry *et al*., 2011) [24]. The limited exposure the language rich environment during the critical period of auditory and language development leads reduced vocabulary, syntactic knowledge important for reading fluency. Moreover, the participants showed distractions and lack of focus which highlight the increased listening effort with use of unilateral cochlear implant. Similar findings were reported by Hicks & Tharpe (2002) [14].

Perfetti and Hart and Marschark *et al*. (2006) [22], reported that individuals with hearing impairment often shows weaker syntactic processing and require more cognitive resources for reading and writing tasks. These findings are similar to the findings from the present study. The participants from the present study also shows low confidence level when asked to read aloud. Geers & Nicholas (2013) [11], stated that the low confidence in reading aloud in cochlear implant reflects anxiety or self-consciousness regarding pronunciation, fluency, or speech clarity. These features are more prominent in those who received late rehabilitation services. Additionally, Low confidence is also seen in spelling writing (reported by 42 participants) and grammatical sentence formation (63 participants), which further indicates weak foundational literacy skills. Spelling and grammar require phonological awareness and syntactic understanding, both of which are areas of difficulty for individuals with early auditory deprivation (Marschark & Spencer, 2006) [22]. A study carried out by Wolbers *et al*. (2012) [40], showed students with hearing impairment using cochlear implants often lag behind the age matched typically developing students in speckling accuracy and syntactic writing structures.

Multiple challenges and barriers were reported by the participants of the present study in respect to reading and written literacy development. According to Antia *et al*. (2009) [2], deaf students often require explicit instruction in written language structure, including syntax, vocabulary, and composition strategies. The absence of this instruction, as reported by participants, suggests that mainstream educational environments frequently fail to provide targeted

writing support for students with hearing impairments (Luckner & Carter, 2001) [20]. Additionally, Chandramouli *et al*. (2017) [3] reported that India lacks inclusive educational policies and services tailored for students with cochlear implants, especially in higher education. In India there is lack of teacher training programs, peer awareness education, and reading support tools for cochlear implant users as they face systemic barriers that inhibit literacy growth (Punch & Hyde, 2011) [30]. These findings align with the present study where none of the participant received literacy support from the academic institution.

Findings from the present study suggest that 49 participants experienced fatigue during prolonged reading and 43 participants avoided writing tasks due to fatigue. These findings suggests that sustained involvement in literacy activities places a heavy cognitive load on individuals with cochlear implants. These findings are in parallel to the study carried out by Paul (2009) [29], who reported that deaf individuals often require more cognitive effort to process language, whether written or spoken, due to reduced incidental language exposure in early childhood. He also added the cochlear implant users may have limited or inconsistent auditory-verbal feedback, which further increases the cognitive demands when decoding the written text or composing grammatically correct sentences.

The access to digital tools is high among prelingual adults using cochlear implants and exhibit baseline digital literacy and independence. However, there are clear skill gaps in typing, tool proficiency, and especially in the use of accessibility features, largely due to a lack of formal training, supportive environments, and awareness. The participants reported that most of them don't use associability and assistive listening tools, which suggests a major awareness or training gap among this population. Despite the fact that subtitles can significantly improve comprehension for individuals with hearing loss (Zhou *et al*., 2019) [43], many participants either don't know how to use them, find them cognitively taxing, or perceive them as unnecessary or ineffective. The gap is also noticed in functional use of productive tools as majority of the participants (43 participants) reported basic familiarity with tools like Microsoft Word, Google Docs, or video conferencing platforms. However, many of them indicated difficulty with more advanced features, such as collaborative functions or cloud-based file management. Wooten *et al*. (2014) [41] showed the similar findings that individuals with hearing impairments often develop basic digital competencies, but lack access to training that promotes higher-order digital literacy. This limitation related to use of digital productive tool showed by individuals with cochlear implants, has critical implication for employability and academic progression, particularly in a scenario where digital dependency is increasing such as document formatting, online collaboration, and virtual meetings are standard expectations.

### 5.3. Listening fatigue and literacy

The administration of the Vanderbilt Fatigue Scale - Auditory (VFS-A-10) in the study revealed that the majority of participants scored between 20 and 30, indicating moderate to high levels of listening fatigue. This range of scores aligns with previous research suggesting that individuals with hearing loss, especially those using cochlear implant, are at higher risk for mental and physical fatigue due to effortful listening (Hornsby *et al*., 2016; Bess & Hornsby, 2023) [16, 15]. Bess and Hornsby (2023) [15], reported that children and adults with hearing loss experience more listening-related fatigue, particularly in noisy environment or in complex listening situations. Similar findings were reported by Hornsby *et al*. (2016), where they stated that fatigue in individuals with hearing loss often manifests as reduced concentration, irritability, and a tendency to withdraw from communication-based activities.

Participants from the present study with high scores (>20) on the VFS-A-10 likely experience greater cognitive load during listening, which may lead to faster mental overtiredness. As a result, these individuals often rely more heavily on working memory, visual cues, and context-based inference, making listening more demanding even in quiet environments (McGarrigle *et al*., 2014) [25].

## 6. Conclusion

The present study comprehensively tried to explore the literacy skills (reading and writing), digital literacy skills, and listening fatigue experienced by prelingual adults with cochlear implants in India. Findings highlight persistent gaps in academic and literacy development, especially in reading and writing, despite the use of cochlear implants. The overwhelming reliance on unilateral cochlear implants and lack of consistent use of bimodal stimulation (CI + HA) emerged as a key factor influencing poor literacy and cognitive outcomes. While digital literacy levels are comparatively better with many participants demonstrating basic to moderate competence in using digital tools, challenges remain in higher-order digital functions and the adoption of accessibility features and assistive listening devices. A majority of participants faced significant fatigue while engaging in both reading and writing tasks, underlining the cognitive demands of processing language without early, rich auditory exposure.

The findings from VFS-A-10 further confirmed that listening fatigue is common and makes it harder for individuals to improve their reading and writing skills. It can also make it difficult for them to continue learning or working over a long period of time. Additionally, the absence of institutional support and tailored interventions across educational stages has left many cochlear implant users underprepared for the linguistic and academic demands of mainstream environments. The shift toward open schooling, dual communication modalities, and the avoidance of reading aloud or formal writing tasks reveal adaptive strategies and coping mechanisms employed by this population in the absence of adequate systemic support.

Together, these results underline the urgent need for:

- Early and consistent auditory-verbal rehabilitation.
- Promotion of bimodal hearing strategies to support better auditory outcomes.
- Implementation of structured literacy interventions, including explicit instruction in reading, writing, and grammar.
- Expanded access to digital literacy training, with emphasis on assistive technologies.
- Teacher training and inclusive education policies tailored to the needs of CI users.

Future research should explore longitudinal outcomes of bimodal users, effectiveness of digital literacy interventions,

and the role of inclusive education in enhancing literacy for individuals with cochlear implants. The findings emphasize that improving educational and cognitive outcomes for this population requires a holistic, sustained, and multi-faceted approach.

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