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ORIGINAL ARTICLE

A Pilot Study on Balance and Cognitive Functions of Cochlear Implant Recipients in Universiti Kebangsaan Malaysia

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ABSTRACT

Implantasi koklea (CI) telah terbukti berkesan dalam merawat kehilangan pendengaran sensorineural yang teruk pada pesakit kanak-kanak dan dewasa. Selain memulihkan pendengaran pada individu pekak, semakin banyak bukti terbaru yang menunjukkan bahawa CI mungkin dikaitkan dengan peningkatan dalam fungsi kognitif dan keseimbangan. Kajian ini menyiasat keseimbangan dan fungsi kognitif dalam kalangan penerima CI di Universiti Kebangsaan Malaysia (UKM). Kajian ini merupakan kajian rintis berbentuk keratan rentas. Seramai 13 pesakit telah direkrut melalui program implan koklea UKM. Pesakit yang sesuai menjalani ujian pra-operasi sebagai garis dasar, diikuti dengan pengulangan keseimbangan dan penilaian kognitif selepas sekurang-kurangnya 3 bulan selepas implantasi koklea. Ujian keseimbangan yang digunakan ialah "Modified Clinical Test of Sensory Interaction and Balance" atau "Paediatric Clinical Test of Sensory Interaction and Balance". Ujian kognitif yang bersesuaian dengan umur yang digunakan ialah "Wechsler Preschool and Primary Scale of Intelligence - 4th Edition (WIPPSI-IV), Wechsler Intelligence Scale for Children – 5th Edition (WISC-V) dan Wechsler Adult Intelligence Scale - 4th Edition". Analisis statistik menunjukkan peningkatan dalam skor subujian kognitif selepas CI, iaitu "Similarities" dan "Digit Span". Tiada perubahan ketara dilihat dalam fungsi imbangan. Terdapat korelasi negatif yang dilihat antara subujian fungsi kognitif "Picture Span" dan fungsi imbangan (mata tertutup, keadaan permukaan buih). Kajian ini mencadangkan bahawa CI boleh meningkatkan domain tertentu fungsi kognitif. Selain itu, terdapat korelasi antara implantasi koklea dengan keseimbangan dan prestasi kognitif.

Kata kunci: *Implan koklea; keseimbangan postur; kognitif; kehilangan pendengaran; sensorineural*

ABSTRACT

Cochlear implantation (CI) has proven to be effective in treating severe-profound sensorineural hearing loss in paediatric and adult patients. Besides hearing restoration in the deaf, there has been growing evidence suggesting that CI may be associated with improvement in cognitive and balance functions. This study investigated the balance and cognitive functions among Universiti Kebangsaan Malaysia (UKM) CI recipients. It was a pilot, cross-sectional study. A total of 13 patients were recruited via the UKM cochlear implant program. Suitable patients underwent pre-operative testing as a baseline followed by a repeat of balance and cognitive assessments after at least 3 months post-cochlear implantation. Balance tests used were Modified Clinical Test of Sensory Interaction and Balance or Paediatric Clinical Test of Sensory Interaction and Balance). Age-appropriate cognitive tests used were Wechsler Preschool and Primary Scale of Intelligence - 4th Edition, Wechsler Intelligence Scale for Children – 5th Edition and Wechsler Adult Intelligence Scale - 4th Edition. The statistical analysis showed an increase in cognitive subtest scores post-CI: Similarities and Digit Span. No significant changes were seen in balance function. There was a negative correlation seen between cognitive function subtest Picture Span and balance function (eyes closed, foam surface condition). This study suggests that cochlear implantation may enhance certain domains of cognitive function. There also appears to be a correlation between cochlear implantation, balance and cognitive performance.

Keywords: Cochlear implants; cognition; hearing loss; postural balance; sensorineural

INTRODUCTION

Humans possess five basic human senses; one of which is hearing. The ability to hear properly plays an essential role in our daily functioning and when impaired will have significant individual and societal impacts. In babies, toddler and young children, it has been said that severe bilateral hearing loss is a "neurodevelopmental emergency" which includes impaired development of speech and language in children and cognitive ability to name a few. Furthermore, unaddressed hearing impairment imposes an economic burden that costs over $980 billion (World Health Organisation 2021). These exuberant costs are related to medical care, education, work productivity losses and societal costs.

Globally more than 1.5 billion people suffer from some degree of hearing loss. Nearly one third (430 million people) have hearing loss of at least moderate severity in the better ear. According to the World Health Organisation (WHO), the majority of people affected (109.4 million) are from the Southeast Asia region. By 2050, 25% of the population are projected to have some form of hearing loss. According to a survey conducted by the Institute of Public Health in 2006, the prevalence of hearing loss in Malaysia is 21.57% or one fifth of the populations. Thus, it would be reasonable to expect an increase in the number of hearing loss patients locally.

There are several management options available to deal with hearing loss. However, there has been an increasing interest and usage of a sophisticated, high-tech device known as a cochlear implant (CI) which has been used in both pediatric and adult groups for more than 30 years. CIs are an effective surgical treatment for those with severe, profound, or moderate sloping to profound sensorineural hearing loss. In Malaysia, the first CI was performed in 1995 at Hospital Universiti Kebangsaan Malaysia (HUKM), then followed by Universiti Sains Malaysia and Universiti Malaya. In 2006, the Ministry of Health (MOH) launched the National Cochlear Implant Programme which has continued to make this option available to more patients in need.

As with any operation, there are always possible risks. One of the possible complications is vestibular dysfunction due to trauma caused by electrode insertion (Ibrahim et al. 2017). In such cases, patients would suffer from symptoms such as dizziness, vertigo and imbalance post-operatively (Piker et al. 2020). However, it is worth noting that there are many more cases, in which after undergoing cochlear implantation, there appears to be no impairment of balance function. Interestingly, there have been several studies with results suggesting an improvement in balance function believed to be associated with having underwent cochlear implantation. A study found that unilateral CI patients experienced significant improvements in postural stability according to objective tools of measurements called computerised dynamic platform posturography (CDP) (Buchman et al. 2004). Another study found that patients with CI stimulation had a more prominent positive impact on their postural and balance control (Ardıç et al. 2024). A cross-sectional study observed that children with early CI implantation (4 years old and younger) demonstrated significantly greater ability to balance for longer periods according to Paediatric Clinical Test of Sensory Interaction for Balance (p-CTSIB) in the Eyes Closed Foam Surface (ECFoamS) condition (Mujdeci et al. in 2021).

There have been several possible explanations proposed for this pattern of findings, such as increased auditory information, which aids in sound localisation and postural alignment. Another possibility is that the additional auditory input plays a role in central compensation for reduced vestibular function. Another postulation is that the presence of CI may activate an underlying vestibular deficit which then triggers enhanced central compensation. Another consideration is the impact of CI on the patient's cognitive function. Patients with hearing impairment are more likely to have reduced cognition when compared to those with normal hearing (Buchman et al. 2020). Specifically, it has been associated with poorer performance on global cognitive assessments, memory measures, executive function and processing speed. Thus, it has been suggested that cochlear implantation may improve cognitive function by restoring hearing (Almomani et al. 2021). Further research is necessary to understand better the association between the presence of CI with cognitive and balance functions. The objectives of this study were to study the balance and cognitive functions among Universiti Kebangsaan Malaysia (UKM) CI recipients.

MATERIALS AND METHODS

Ethics Approval

Approval was obtained from the UKM Research Ethics Committee (Ethics approval reference: JEP-2022-513).

Study Design

This was a single cohort study, which studied the effect of cochlear implantation on their balance and cognitive function. The study was conducted at the Otorhinolaryngology (ORL) clinic, Hospital Canselor Tuanku Mukhriz (HCTM); Hospital Tunku Ampuan Besar Tuanku Aishah Rohani (TABTAR), Hospital Pakar Kanak-kanak UKM (HPKK); Centre for Rehabilitation & Special Needs Studies, Faculty of Health Sciences, UKM; and Centre for Community Health (ReaCH), Faculty of Health Sciences, UKM.

Sampling Population

All patients were recruited via the UKM CI program according to inclusion and exclusion criteria. A total of 20 patients comprising a mixture of paediatric and adult patients with either single-sided or bilateral profound sensorineural hearing loss which underwent cochlear implantation were initially considered. Several patients (n = 7) were excluded from recruitment as they met one or more of the predefined exclusion criteria or were unable to commit to subsequent follow-up assessments as they resided in out-of-town locations. In the end, a total of 13 patients that fitted the inclusion criteria were successfully recruited.

Sample Size

A priori sample size was calculated using G*Power, version 3.1.9.7 (Heinrich Heine University Düsseldorf, Düsseldorf, Germany). software for paired t test with given alpha = 0.05, power = 80% and calculated effect size of 0.454. The sample size calculated was 32. With an expected dropout rate of approximately 20%, a sample size of 38 would be required. The sample size was based on parameters from a similar previous study (Almomani et al. 2021). However, due to feasibility constraints related to participant availability and study logistics, recruitment was limited, and 13 participants were ultimately enrolled. As such, the present study was conducted as a pilot, exploratory study with the primary aim of assessing feasibility, estimating effect sizes, and generating preliminary data to inform the design and sample size calculation of a future adequately powered confirmatory study.

Inclusion Criteria

The inclusion criteria for this study were all patients undergoing CI aged 2.5-90 years old, patients and/or parents agreeable for pre- and post-operative balance and cognitive function tests, patients undergoing a second CI.

Exclusion Criteria

The exclusion criteria were patients who were unable to tolerate balance assessment and patients who had underlying medical conditions, such as history of head trauma, severe visual impairment, injury to spinal cord, central causes of vertigo, learning disabilities, neurological disorders and psychiatric disorders.

Intervention

Most patients were implanted with CI devices from Cochlear Corp. (Lane Cove, New South Wales, Australia) and a few were implanted with MED-EL (MED-EL Medical Electronics, Innsbruck, Austria) and Advance Bionic (Advanced Bionics AG, Stäefa, Switzerland). The CI was activated after 2 weeks, once the wound healed. Patients were required to meet the audiologist for mapping and rehabilitation post-CI.

Research Tools

There were a total of four research tools used in this study, one to assess the patients' balance function and three to assess the patients' cognitive function (according to their respective age groups). Suitable patients underwent pre-operative testing as a baseline followed by a repeat of balance and cognitive assessments after at least 3 months post-cochlear implantation. The cognitive assessments were carried out by the researcher who had undergone supervised training by a certified, clinical psychologist who regularly performed these assessments in his own clinical practice.

Balance Research Tools

(i) Modified Clinical Test of Sensory Interaction and Balance or Paediatric Clinical Test of Sensory Interaction and Balance

This is a simple, clinical, bedside test which is able to rapidly check for the patient's dependence on various inputs for balancing. The patient was assessed for 30 seconds in a total of four conditions i.e eyes open and closed on firm surface, eyes open and closed on foam. Each trial was measured using a stopwatch. The trial was considered over when the patient opened his/her eyes in an eyes closed condition, raised arms from sides or lost balance and required manual assistance to prevent a fall. Only one trial was administered if the patient was able to complete the trial without loss of balance for at least 30 seconds. If the patient experienced loss of balance before 30 seconds duration, then a total of three trials was given and average time calculated. For younger children, the assessment would still be attempted in all four conditions if possible, with the use of engagement tools like handheld devices playing videos for eye open conditions.

Cognitive Research Tools

(i) Wechsler Preschool and Primary Scale of Intelligence - 4th Edition

Wechsler Preschool and Primary Scale of Intelligence - 4th Edition (WIPPSI-IV) is an objective tool used to assess the cognitive functions for children ages 2 years 6 months to 7 years 7 months old. It is made up of a total of five index scales with 10 primary subsets. Each index scale is made of two subtests. Each subtest has a total of 10 points. The five indexes are: Verbal Comprehension Index (VCI), Visual Spatial Index (VSI), Fluid Reasoning Index (FRI), Working Memory Index (WMI) and the Processing Speed Index (PSI). In this study, we tested three index scales and each of their respective subtests. The VCI included the Receptive Vocabulary and Information (IN) subtests for children aged 2 years 6 months to 3 years 11 months and the Vocabulary (VC) and IN subtests for children aged 4 years to 7 years and 7 months. The VSI comprised the Block Design and Object Assembly subtests, while the WMI comprised the Picture Memory and Zoo Locations subtest.

(ii) Wechsler Intelligence Scale for Children – 5th Edition

Wechsler Intelligence Scale for Children – 5th Edition (WISC-V) is an objective tool used to assess the cognitive functions for children ages 6-16 years old. It is made up of a total of five index scales with 10 primary subsets. Each index scale is made of two subtests. Each subtest has a total of 10 points. The five indexes are VCI, VSI, FRI, WMI and the PSI. In this study, we tested three index scales and each of their respective subtests. The VCI subtests included the Similarities (SI), VC subtests, the VSI included the Block Design and Visual Puzzle subtests and the WMI included the Digit Span (DS) and Picture Span subtests.

(iii) Wechsler Adult Intelligence Scale - 4th Edition

Wechsler Adult Intelligence Scale - 4th Edition (WAIS-IV) is an objective tool used to assess the cognitive functions for subjects ages 16-90 years old. It is made up of a total of four index scales with 10 primary subsets. Each index scale is made of two subtests. Each subtest has a total of 10 points. The four indexes are VCI, Perceptual Reasoning Index (PRI), WMI and the PSI. In this study, we tested three index scales and each of their respective subtests: The VCI comprised the SI and VC subtests, the PRI comprised the Block Design and Visual Puzzle subtests and the WMI comprised the DS and Arithmetic subtests.

Statistical Analysis

Data were cleaned and analysed using SPSS version 26.0 (IBM Corp., Armonk, NY, USA) and STATA, version 14.0 (StataCorp LLC, College Station, TX, USA). The distribution of continuous variables was checked using Shapiro Wilk test. Continuous variables were presented as mean and standard deviation if they were found to be normally distributed. Otherwise, non-continuous variables would be presented as median (25th percentile, 75th percentile). Categorical variables were presented as frequency and percentage. The changes in cognitive and balance performance pre- and post-CI were tested using paired sample t-test and Wilcoxon signed-rank test. The association between patients' clinical information with cognitive and balance performance were explored using Mann-Whitney U test and Spearman correlation test. Spearman correlation test were further performed to explore the correlation between change in balance performance scores with change in cognitive performance scores. All the tests were two-sided and statistical significance were denoted by $p < 0.05$. The study was conducted over a 38-month period, from January 2022 to March 2025.

TABLE 1: Patients' demographics and clinical information

Characteristics		**Frequency (%)**
Pre or post lingual, n (%)	Pre-lingual	4 (44.4)
	Post-lingual	9 (69.2)
1st or 2nd CI, n (%)	1st CI	11 (84.6)
	2nd CI	2 (15.4)
Operation side, n (%)	Left	6 (46.2)
	Right	5 (38.5)
	Bilateral	2 (15.4)
Non-operated ear	BTE HA	10 (76.9)
	CI	2 (15.4)
	NA	1 (7.7)
Past medical history, n (%)	No	6 (46.2)
	Yes	7 (53.8)
Ethnicity, n (%)	Malay	3 (23.1)
	Chinese	9 (69.2)
	Indian	1 (7.7)
Population, n (%)	Paediatric	8 (61.5)
	Adults	5 (38.5)
Months post-CI tests repeated, mean ± SD		6.85 ± 2.88
Age of 1st CI implanted, mean ± SD		18.25 ± 14.81
- Age of 1st CI implanted (pre-lingual), mean ± SD		4.50 ± 1.58
- Age of 1st CI implanted (post-lingual), mean ± SD		27.75 ± 12.00
Age of 2nd CI implanted, mean ± SD		16.00 ± 0.11

BTE HA: Behind-the-ear hearing aid; CI: Cochlear implant; NA: Not Applicable; SD: Standard deviation

RESULTS

Patients' Demographics and Clinical Information

The patients' demographic details and clinical information were described in Table 1. A total of 13 patients were analysed in this study. Four (44.4%) of them were pre-lingual and almost all of them had their first CI (84.6%). Six (46.2%) operated on the left side and the main management for non-operated ear was behind-the-ear hearing aid (BTE HA) (76.9%). There were seven (53.8%) reported past medical history, which include Goldenhaar syndrome, dilated vestibular aqueduct and incomplete partition type II and H syndrome. The mean duration post-CI tests repeated was approximately 7 months (SD: 2.88).

Pre- and Post-cochlear Implantation Cognitive Function

The patients underwent several, age-appropriate, cognitive subtests before and after cochlear implantation. Each subtest had their respective "subtest scaled score" and when combined produce their respective "composite scores" also known as "index scores". Each of these index scores represented cognitive domains assessed by the Wechsler intelligence scales. The patients' cognitive results were summed up in Tables 2, 3 and 4.

The only significant increase seen in Table 2 was the SI subtest scaled score (mean ± SD pre vs post: 5.11 ± 3.52 vs 7.78 ± 3.11; p = 0.003). The effect size (Cohen's d = 1.38) was large which suggested a substantial clinical improvement. Improving trends for VC (p = 0.778), IN (p = 0.215) and VCI composite score (p = 0.105) were

TABLE 2: Pre- and post-CI cognitive performance (VCI)

Tests	Pre-CI Scores (Mean ± SD)	Post-CI Scores (Mean ± SD)	Score Difference (Mean ± SD)	p-value	Effect Size (CI)
Subtest Scaled Scores					
Vocabulary	4.15 ± 2.85	4.38 ± 3.12	0.23 ± 2.89	0.778	0.08 (-0.70, 0.84)
Similarities	5.11 ± 3.52	7.78 ± 3.11	2.67 1.94	*0.003	1.38 (0.29, 2.33)
Information	3.25 ± 1.71	2.50 ± 1.73	-0.75 0.96	0.215	-0.78 (-2.10, 0.75)
Composite Scores	69.45 ± 14.90	76.18 ± 18.93	6.73 12.52	0.105	0.54 (-0.33, 1.37)

Paired sample t-test; CI: Cochlear implant; SD: Standard deviation; VCI: Verbal Comprehension Index

TABLE 3: Pre- and post-CI cognitive performance (VSI/PRI)

Tests	Pre-CI Scores (Mean ± SD)	Post-CI Scores (Mean ± SD)	Score Difference (Mean ± SD)	p-value	Effect Size (CI)
Subtest Scaled Scores					
Block Design	8.77 ± 1.96	9.31 ± 2.84	0.54 ± 1.56	0.237	0.35 (-0.44, 1.11)
Visual Puzzle	7.78 ± 2.86	7.56 ± 2.24	-0.22 ± 1.39	0.645	-0.16 (-1.08, 0.77)
Object Assembly	8.00 ± 2.94	8.00 ± 3.27	0.00 ± 0.82	0.999	0.00 (-1.39, 1.39)
Composite Scores	90.08 ± 11.08	91.15 ± 11.49	1.08 ± 4.23	0.377	0.25 (-0.53, 1.02)

Paired sample t-test; CI: Cochlear implant; SD: Standard deviation; VSI/PRI: Visual Spatial Index/Perceptual Reasoning Index

TABLE 4: Pre- and post-CI cognitive performance (WMI)

Tests	Pre-CI Scores (Mean ± SD)	Post-CI Scores (Mean ± SD)	Score Difference (Mean ± SD)	p-value	Effect Size (CI)
Subtest Scaled Scores					
Digit Span	9.00 ± 2.92	10.44 ± 2.70	1.44 ± 1.24	*0.008	1.16 (0.11, 2.10)
Picture Span	10.33 ± 2.52	11.67 ± 5.51	1.33 ± 3.51	0.578	0.38 (-1.30, 1.91)
Picture Memory	6.50 ± 1.73	6.00 ± 1.63	-0.50 ± 3.11	0.769	0.16 (-1.53, 1.25)
Zoo Location	8.25 ± 1.71	8.75 ± 2.87	0.50 ± 2.08	0.664	0.24 (-1.18,1.60)
Composite Scores	89.17 ± 12.61	93.42 ± 16.55	4.25 ± 8.35	0.105	0.51 (-0.32, 1.30)

Paired sample t-test; CI: Cochlear implant; SD: Standard deviation; WMI: Working Memory Index

observed but did not reach statistical significance.

Table 4 explored the changes in WMI pre- and post-CI. The DS subtest score was the only score that increased significantly (mean ± SD pre vs post: 9.00 ± 2.92 vs 10.44 ± 2.70; p = 0.008). The observed effect size (Cohen's d = 1.16) was substantially large. Improving trends for Picture Span (p = 0.578), Zoo Location (p = 0.664) and WMI composite score (p = 0.105) were observed but did not reach statistical significance.

TABLE 5: Pre- and post-CI balance performance

Tests	Pre-CI Scores (Median, (IQR)	Mean ± SD (Range)	Post-CI Scores (Median, (IQR)	Mean ± SD (Range)	Score Difference (Median, (IQR)	p-value	Effect Size (CI)	Range (Difference Between Pre-CI and Post-CI)
pCTSIB/mCTSIB								
Eyes Open Firm Surface	30 (30, 30)	30 (0)	30 (30, 30)	30 (0)	0 (0, 0)	0.999	0 (-0.84, 0.84)	0 to 0
Eyes Closed Firm Surface	30 (30, 30)	29.2 (8.3)	30 (30, 30)	30 (0)	0 (0, 0)	0.080	-0.55 (-1.38, 0.32)	0 to 8.3
Eyes Open Foam Surface	30 (30, 30)	29.5 (6)	30 (30, 30)	30 (0)	0 (0, 0)	0.317	-0.32 (-1.15, 0.53)	0 to 6
Eyes Closed Foam Surface	26 (4, 30)	18.2 (27.4)	30 (10, 30)	22.8 (26.2)	0 (0, 7)	0.080	-0.55 (-1.38, 0.32)	-0.6 to 16
Comments/		NA		NA	NA	NA	NA	NA
Observations, n (%)	1(7.7)		0 (0.0)					
Fell backwards	2(15.4)		1 (7.7)					
Fell to left	0 (0.0)		1 (7.7)					
Fell to right	2(15.4)		0 (0.0)					
Swaying both sides	1(7.7)		0 (0.0)					
Swaying to left	1(7.7)		0 (0.0)					
Swaying to right	2(15.4)		3(23.1)					
Minimal Swaying	3(23.1)		3(23.1)					
Not attempted								

Wilcoxon signed-rank test; CI: Cochlear implant; IQR: Interquartile range; NA: Not applicable; pCTSIB/mCTSIB: Paediatric clinical test of sensory interaction for balance / Modified clinical test of sensory interaction for balance

Pre- and Post-cochlear Implantation Balance Function

The patients' balance function results were summed up in Table 5. The balance function was tested pre- and post-CI, and no significant changes were reported. However, the proportion of patients who fell decreased from 23.1% pre-CI to 15.4% post CI and there were no patients reported swaying post-CI compared to four (30.8%) pre-CI. Patients with minimal swaying increased from 15.4% pre-CI to 23.1% post CI. This was in keeping with the general trend of increase in mean time patients were able to balance under Eye Closed Firm Surface and Eyes Closed Foam Surface conditions when comparing pre- and post-CI although these scores did not reach statistical significance.

Correlations Between Cochlear Implantation, Cognitive and Balance Functions

The presence of any correlations between the various aspects of the patients' cognitive function with balance function before and after cochlear implantation were explored (Table 6). The correlation between the change in cognitive performance with change in balance performance were explored in Table 6. The only significant correlation was change in Picture Span scaled scores with change in the Eyes Closed Foam Surface time in which there was a negative correlation seen. For example, if the patient had greater change in Picture Span score (pre to post-CI), there will be less change in the ECFoamS balance subtest. The result which showed significant correlation was represented in scatter plots (Figure 1).

DISCUSSION

This study aimed to evaluate the effect of cochlear implantation on balance and cognitive functions. Furthermore, analysis was performed to determine the presence of any correlation between CI, balance and cognitive functions.

Cochlear Implant Patients' Cognitive Function (pre- and post-operatively)

Evaluating the effects of cochlear implantation on cognitive function in adults is important, given increasing evidence that sensorineural hearing loss represents one of the most significant modifiable risk factors for dementia development in middle age and later life (Moberly et al. 2019). In line with this, a prospective case-control study conducted in Australia compared 16 adult CI recipients to 23 adult CI candidates awaiting surgery and found significantly better neurocognitive performance among the implanted group (Jayakody et al. 2017). At the 6-month follow-up, CI recipients demonstrated superior scores in cognitive domains, such as attention, processing speed and working memory. By 12 months post-implantation, further improvements were observed in working memory, general memory and executive function. In a separate, large prospective study on post-CI cognitive function conducted on 55 individuals in total found at the 6-month mark improvements in attention, inhibitory control, and both short-term and working memory (Völter et al. 2018). By 12 months, additional enhancements were observed in attention, as well as in short-term, working and long-term memory. The benefits of cochlear implantation in those who are deaf clearly whether children or adult clearly extend beyond merely hearing.

In the past decade, there have been an increasing number of studies looking at the impact of CI on cognitive development and performance. To the best of our knowledge, almost all of the studies focused either on CI in paediatric or adult patients as evidenced by two systematic reviews (Miller et al. 2015). However, in our study, we recruited patients from both age groups (range from 3 years to 42 years) and analysed their cognitive and balance functions together with the use of age-appropriate research tools. There are various cognitive function assessment tools widely available. According to a systematic review, out of the 46 different cognitive tests/subtest used to assess respective

TABLE 6: Correlation between change in cognitive performance with change in balance performance

Tests	EOFS		ECFS		EOFoamS		ECFoamS	
	r (95% CI)	p-value	r (95% CI)	p-value	r (95% CI)	p-value	r (95% CI)	p-value
VCI	NA	NA	0.27 (-0.16, 0.71)	0.216	0.27 (-0.18, 0.73)	0.238	0.05 (-0.60, 0.71)	0.869
Vocabulary	NA	NA	0.18 (-0.19, 0.55)	0.350	0.20 (-0.15, 0.56)	0.260	-0.49 (-1.04, 0.05)	0.075
Similarities	NA	NA	0.07 (-0.38, 0.52)	0.761	0.07 (-0.42, 0.56)	0.780	0.09 (-0.68, 0.87)	0.815
Information	NA	NA	NA	NA	NA	NA	NA	NA
VSI	NA	NA	-0.06 (-0.52, 0.40)	0.804	-0.10 (-0.49, 0.29)	0.617	-0.49 (-1.16, 0.19)	0.159
Block Design	NA	NA	-0.06 (-0.47, 0.35)	0.776	-0.10 (-0.47, 0.26)	0.582	-0.16 (-0.86, 0.54)	0.654
Picture Puzzle	NA	NA	-0.07 (-0.52, 0.37)	0.747	-0.07 (-0.49, 0.35)	0.735	-0.16 (-0.97, 0.66)	0.709
Object Assembly	NA	NA	-	-	-	-	-	-
WMI	NA	NA	0.07 (-0.41, 0.55)	0.777	0.12 (-0.28, 0.51)	0.565	-0.13 (-0.91, 0.66)	0.752
Digit Span	NA	NA	0.28 (-0.12, 0.69)	0.166	0.28 (-0.11, 0.68)	0.152	-0.41 (-1.00, 0.18)	0.177
Picture Span	NA	NA	NA	NA	NA	NA	-0.87 (-1.04, -0.69)	*0.001
Picture Memory	NA	NA	NA	NA	NA	NA	NA	NA
Zoo Location	NA	NA	NA	NA	NA	NA	NA	NA

Spearman correlation; CI: Cochlear implant; EOFS: Eyes open, firm surface ; ECFS: Eyes closed, firm surface; EOFoamS: Eyes opened, foam surface ; ECFoamS: Eyes closed, foam surface; NA: Not applicable (due to either insufficient samples or constant score reported in the variable); VCI; Verbal Comprehension Index; VSI: Visual Spatial Index; WMI: Working Memory Index

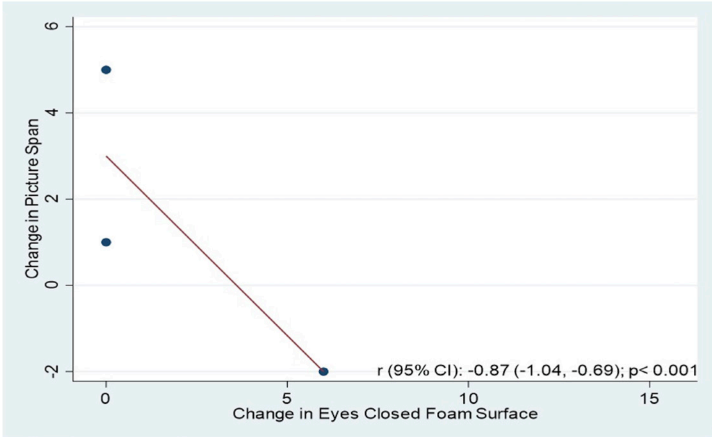

FIGURE 1: Correlation between change in picture span and change in eyes closed foam surface

cognitive domains, the WISC-V was by far the most commonly used test (47.6%), followed by NEuro (neuropsychology) and PSY (psychology) (28.6%) and Leiter International Performance Scale-Revised (LIPS-R) (19%) (Lima et al. 2023). The LIPS-R test has several advantages making it a strong alternative choice by offering a completely non-verbal measure of intelligence which is ideal for those who are hearing and/or speech impaired and may not speak English as their first language; also it can cater to subjects ages 3 years to 75 years old. However, in our study, we selected the Wechsler Intelligence Scales (i.e. WIPPSI-IV, WISC-V, WAIS-IV) which collectively was able to cater to subjects ages 2 years 6 months to 90 years old. Another advantage is the comprehensive assessment of both verbal and nonverbal cognitive domains, its widespread clinical use, and the availability of normative data.

This was important in our study, because approximately 69% (n = 9/13) of our study patients were post-lingual and had developed spoken language skills which could be meaningfully assessed with the appropriate subtests. Each patient underwent a total of six subtests which produced three composite scores, each of which represented a specific cognitive subdomain. It is worth nothing that each subtest requires multiple cognitive processes to complete the task and that the required process may differ throughout the subtest. In Table 2, the index scores for VCI and constituent subtest scaled scores are summarised. *"This ability to construct designs requires visual spatial reasoning, integration and synthesis of part-whole relationships, attentiveness to visual detail, and visual-motor integration".* Someone with a high VCI find it is easier to verbalise their feelings and resolve conflicts maturely instead of acting out. The VCI showed a non-significant improvement from "very low" or "low" to "borderline". All the subtests under this index score require auditory-verbal input from the patient. In our study, one of the VCI-subtest that showed statistically significant improvement post-CI was SI subtest. Whereas, VC and IN subtests did not meet statistical significance. An SI > VC implies that post-CI, patients developed a relatively strong abstract reasoning and cognitive flexibility compared with lexical knowledge. These aspects of cognition are closely related to executive functioning which can be strengthened even with limited vocabulary through general auditory exposure. The early auditory experiences provide temporal patterns to the developing brain which become one of the important foundational building blocks for executive functions (EFs) (De Giacomo et al. 2021).

In Table 3, the index scores for VSI and PRI and constituent subtest scaled scores are summarised.

VSI is a measurement of the patient's ability to evaluate visual details and to understand visual spatial relationships to construct geometric designs from a model "es" (Wechsler 2012). In real-life scenarios, this kind of cognitive ability might refer to the ability of subjects to easily assemble a model or perform a task which requires referring to visual diagrams or using a map. In our study, PRI scores where compared to VSI scores as they represent the same cognitive subdomains for their respective age groups and comprise of the same subtests i.e. Block Design and Visual Puzzles (Wechsler 2008). One possible explanation for no improvement in VSI/PRI scores and subtest scores could due to cross-modal plasticity. This process of neurocognitive reorganisation refers to functional repurposing of certain cortical regions that would normally be receiving sensory modality input (eg. auditory, visual) but is missing to support other intact modalities (Ewall et al. 2021). With CI, once switched on, the modality of hearing has been restored which will now cause the auditory and language-related cortices to adapt and become more optimised. It is postulated that over time with the auditory "territory" being reclaimed this might affect the visual/tactile cortical-related areas. Another possibility, is that the short post-CI interval may not capture the improvement since the visual-spatial functions are less directly influenced by auditory restoration and may need more time to show significant improvement (Bell et al. 2019). Consistent with that reasoning, a prospective study reported statistically significant improvements in non-verbal cognitive functions at 5 and 10 years post-cochlear implantation when assessed with the Griffiths Mental Developmental Scale (GMDS) and LIPS-R (Colletti et al. 2011). But the improvements in cognitive subdomains of visual/spatial attention and fluid reasoning was seen at the 10-year point when undergoing the LIPS-R (Bell et al. 2019). Other than that, another factor could be that visual-spatial skills are not part of post-CI rehabilitation programmes.

In Table 4, the index scores for WMI and constituent subtest scaled scores are summarised. WMI is a measurement of the patient's ability to temporarily retain information in memory, perform some mental operation on, or manipulation, that information to produce a result. "Working memory involves attention, concentration, mental control and reasoning" (Wechsler 2014). A real-world implication with better WMI would look like being able to follow multi-step, more complicated instructions or be able to participate and follow multiple speakers' points in a group conversation instead of losing track mid-discussion. A study involving 70 post-CI patients revealed statistically significant increase in WMI composite score at 12-months post operatively (Knopke et al. 2021). It is noteworthy that, in the present study, the average interval between cochlear implantation and post-operative cognitive reassessment was approximately 6.8 months. It is plausible that with a longer follow-up duration, improvements in the WMI composite scores may have reached statistical significance. In our study, the WMI-subtest showed statistically significant improvement post-CI was DS whereas the other WMI-subtests and WMI composite score did not reach statistical significance. The task in DS requires storage and retrieval of information through immediate auditory recall. Interestingly, this could be that since hearing has been restored post-CI the patient is beginning to use their working memory to solve problems best in response to information presented verbally compared to visual. As expected, pre-CI average PS scores were better than average DS scores due to underlying profound hearing loss. A possible explanation of only the DS score being significantly improved could be that with the CI, there is enhanced auditory access to verbal input which is essential for short-term memory encoding. Also, the task is simpler and more "input dependent" and does not require multiple, complicated mental processes or executive cognitive functions. According to the Wechsler Intelligence Scales - Technical and Interpretive Manual, theoretically WMI skills are also necessary to facilitate complex problem solving abilities, which are represented by other cognitive subdomains like VCI and VSI/PRI. So the improvement of WMI may also indirectly boost the other cognitive subdomains' performances.

Cochlear Implant Patients' Balance Function (pre- and post-operatively)

It is well-known that one of the potential complications arising from CI surgery is injury to the vestibular labyrinth which may result in long-term vestibular dysfunction. When this occurs, depending on the severity of the iatrogenic injury it may lead to patients experiencing vertigo and/or imbalance. We define "balance" as the body's ability to maintain it's line of gravity within its base of support when at rest. According to one prospective cohort study, the observed rate of labyrinthine injury was small and comparable to other risks of CI (Melvin et al. 2009). However, the true incidence of vestibular dysfunction following CI surgery may be masked by central compensation, a form of neural adaptation in which the brain learns to depend on other sensory inputs (e.g. visual, somatosensory, auditory) for any presence of balance deficits. On the other hand, a study found that unilateral CI patients experienced significant improvements in postural stability according to objective tools of measurements called computerised dynamic platform posturography (CDP) (Buchman et al. 2004). One possible explanation behind this could be that having a CI stimulated a preexisting uncompensated vestibular deficit potentially leading to increased central vestibular compensation. Another possibility could be that the additional electrical input provided by the CI could also potentially stimulate the patient's vestibular apparatus. Studies that help us to understand these speculated underlying mechanisms between CI and balance function are necessary.

There were no statistically significant changes in balance functions when comparing between pre- and post-CI (Table 5). Further analysis of the mean balance test scores taken during the first three conditions, i.e. Eyes Open Firm Surface, Eyes Closed Firm Surface and Eyes Open Foam Surface, indicated that patients had no problems maintaining their balance. However, there is a considerable reduction seen in the ability to maintain balance in the final condition i.e. Eyes Closed Foam Surface denoted by the drop in the mean balance test scores. In the final condition, the vestibular system is specifically tested as patients will be required to maintain balance control without visual and somatosensory inputs. Hence, these results may indicate the presence of impaired vestibular function. It is worth noting that this reduction is seen both pre- and post-CI with mean balance test scores of 18.2s and 22.8s, respectively. This implies that even prior to undergoing surgery, there may have been vestibular dysfunction to a certain degree. Interestingly, the mean balance subtest score post-CI is better than pre-CI which indicate that patients did no experience worsening of pre-existing balance deficits. In fact, the overall data suggests a non-significant improving trend seen in 4 out of 13 (30.8%) of these patients. It is possible that central compensation has a pivotal role here as the brain integrates additional auditory input made available from cochlear implantation to aid impaired vestibular signalling (Wu et al. 2024). Another important factor to consider are the ages of the patients and the maturity of their balance systems. Adolescents starting from the age of 12 years old and above begin to have more mature balance functions which are near-adult postural control (Micarelli et al. 2020). However, above the age of 60 years old our balance systems begin to decline as it enters a degeneration phase (Granacher et al. 2011). In our study, 38% of patients (n = 5) were under the age of 12 years old but those that were too young to follow instructions for the p-CTSIB test could not complete their test. As a result, their data were excluded, and did not influence the overall balance test outcomes. There were no elderly patients recruited into our study.

Based on the comments/observations made during balance function testing, the proportion of patients who fell decreased from 23.1% pre-CI to 15.4% post-CI. Furthermore, there were no patients reported to have significant swaying post-CI (n = 0 [0.0 %] compared to pre-CI (n =

4 [30.8%]). The results may possibly indicate that the presence of cochlear implantation is associated with improved balance. A study found that patients with CI stimulation had a more prominent positive impact on their postural and balance control (Ardıç et al. 2024). This pattern was observed from individual data, which revealed that the patients' m-CTSIB composite score, which was defective in 42% of patients (CI switched off), reduced to 36% (CI switched on without music) and 24% (CI switched on with music). According to one cross-sectional study, children with early CI implantation (4 years old and younger) demonstrated significantly the ability to balance for longer periods in p-CTSIB in ECFoamS condition (Mujdeci et al. 2021). It has been hypothesised that this finding may be explained by increased auditory information which aids in sound localisation and postural alignment (much like how vestibular input functions). Further research is necessary to understand better the effect of CI surgery age on patients' balance functions.

Establishing a clear role of central and vestibular compensation in patients that have underwent CI surgery would enable a more tailored approach in management especially when addressing their balance functions. For example, a study emphasised the importance of early and active vestibular rehabilitation during the critical period where neuroplastic reorganisation is taking place (Lacour et al. 2016). Being aware of this opportunity window will enable clinicians to maximise balance outcomes. Also, rehabilitation exercises which particularly stimulate central compensation such as gaze stabilisation, postural control exercises and dynamic balance training could be emphasised. In our study, there appears to be a positive trend seen when comparing pre- and post-CI balance test scores, but further analysis is required to confirm its reliability as this result did not reach statistical significance. It is obvious that greater understanding of the role of the central nervous system's neuro-adaptability in vestibular rehabilitation will further highlight the importance of a multi-disciplinary approach (involving vestibular therapists, neurologists, audiologists, otologists) in managing patients going for CI. It will also justify measures taken to improve overall effectiveness of vestibular rehabilitation by utilising the role of central compensation.

Correlations between Cochlear Implant, Balance and Cognitive Functions

The human brain is a complex organ with the ability to process various sensory information and integrates auditory, vestibular and cognitive inputs to support coordinated function in everyday tasks such as walking, conversing and decision-making. The primary effect of cochlear implantation is to restore hearing, however it appears to also play a role in broader neurocognitive and central vestibular compensatory effects. There is growing evidence demonstrating these intercorrelations. A study done in children with CI reported findings that suggested balance performance being a significant predictor for the cognitive subdomain working memory (Janky et al. 2022). It was also found that vestibular function gain measured by video head impulse test was a significant predictor for cognitive executive function. Another study revealed that balance is significantly associated with working memory ($P < 0.05$) irrespective of the level of cognitive impairment (Volkers et al. 2014). This suggests further links between vestibular and balance with cognitive functions that warrant further exploration.

In our study, we explored possible correlations between CI, balance and cognitive functions. None of the cognitive subtests (spanning three cognitive subdomains) and their change of scores were found to have any correlation with the balance test and their change of scores in the conditions 'eyes closed, firm surface (ECFS)' and 'eyes opened, foam surface (EOFoams)' (Table 6). However, we report a strong negative correlation in change of Picture Span scaled scores with change in the Eyes Closed Foam Surface time. In this final condition of the balance test, the vestibular system is specifically targeted during testing. It is interesting to observe that in our patients, a greater change in Picture

Span score (pre to post-CI) was associated with there will be smaller change in the ECFoamS balance subtest. A possible explanation for why an increase in one of the parameters of working memory function is associated with a reduced increase in vestibular performance could be related to the concept of "dual-task interference" (Dingle et al. 2024). Multi-tasking is a normal part of our everyday lives especially among busy individuals, however dual-task interference refers to when there is decline in performance in one of the two tasks being performed together as a result of interference between the processes controlling the two tasks and/or drawing from shared attentional resources (Woollacott et al. 2002). Specifically, in our study it may be that working memory and and balance control both rely on overlapping cognitive resources, particularly in executive attention and central processing capacity. As cochlear implantation improves access to auditory input, it will facilitate the recruitment of cognitive resources which may transiently draw cognitive capacity away from balance-related processing. In the ECFoamS condition of the balance test, visual and somatosensory cues are minimised thereby increasing reliance on vestibular input. This could explain why although there is still central vestibular adaptation occurring as evidenced by the increase in this specific balance subtest score (it is a reduced increase). At the very least, it appears that in post-CI patients, their brains are prioritising auditory-cognitive integration and neuroplastic resource allocation more than auditory-balance adaptation.

Study Limitations and Recommendations

The main limitation of this study was the small sample size. In addition to that, the post-CI cognitive and balance tests were not successfully repeated at the same interval for all patients with average interval 6.8 months due to logistical challenges. It is likely that central vestibular compensation may be incomplete at earlier time points and will continue to mature with longer follow-ups. Furthermore, the cognitive assessment tool utilised was designed based on normative data collected from children residing in the United Kingdom with English as primary language. Several study participants spoke Bahasa Malaysia (Malay) or Mandarin Chinese as their mother tongue. Effort was made to standardise the translated Malay and Mandarin words used during testing. However semantic equivalence, cultural context and difficulty of vocabulary does not necessarily translate across languages. The cognitive function assessments were also lengthy. Future studies are recommended to use the official, translated version of Wechsler Intelligence Scales (Chinese) and professional translator for Malay language if feasible. For balance assessment with pCTSIB/mCTSIB tools, usage of instrumented platforms may be considered to obtain more accurate, quantitative parameters for degree of swaying. This was not used in our study due to its lack of portability. While positive improvements in particular cognitive subdomains and balance were observed, the modest sample size and relatively short post-operative interval limits the generalisability of the results. Future research with larger cohorts and extended follow-up durations will be essential.

CONCLUSION

In summary, this pilot study provides preliminary insights into the complex interplay between cochlear implantation, cognitive function and balance performance. We report significant improvement of several cognitive subtest scaled scores post-CI namely in SI and DS which represent partially the Verbal Comprehension and Working Memory cognitive subdomains respectively. There was no significant change in balance test scores post-CI. However, a non-statistically significant, positive trend was observed post-CI for Eyes Closed Foam Test score and a reduction in the percentage of patients reported to fall and sway. Furthermore, there was a negative correlation between the change in one of the cognitive subtests (i.e. Picture Span) and change in one of the conditions of the balance function test (i.e ECFoamS). There appears to be a correlation between cochlear implantation, balance and cognitive performances.

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