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Late Receipt of a Second Cochlear Implant: Better Late Than Never?

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1. Abstract

The present study explored the incremental benefits of late receipt of a second cochlear implant (CI) by examining various aspects of educational, cognitive and social-emotional functioning among college-age CI users. Secondary analyses were conducted on data from seven studies that had compared deaf students who were active CI users, deaf students who had never used CIs and hearing students; information concerning unilateral or bilateral CI use had been collected but was not analysed previously. The seven studies provided for comparisons on four dozen dimensions including executive function, world knowledge, visual-spatial ability, academic achievement and quality of life. Ages of first/only cochlear implantation did not differ significantly in any of the comparisons, nor did the groups differ significantly on most of the outcome measures across cognitive and social-emotional domains. The findings consistently indicated that while cognitive and social-emotional differences might be apparent between samples of unilateral and bilateral CI users during earlier childhood, they were not evident in this group of CI users who had reached college-age. Limitations of this study related to the nature of the participant samples indicate the need for further research on long-term benefits of bilateral implantation.

2. Keywords: Bilateral cochlear implantation; Long-term outcomes; Cognitive development; Social-emotional development

3. Introduction

With the increasing prevalence of cochlear implant (CI) use and particularly implantation during infancy, implanting both ears has become more common. In countries such as Canada and New Zealand, for example, bilateral implantation has become standard practice for children with symmetrical severe to profound hearing losses [1]. The increasing prevalence of CI use also has been associated with an increasing volume of research and related literature concerning variables that are predictive of language, cognitive and social-emotional outcomes following cochlear implantation, although evidence with regard to long-term outcomes remains limited. This study addresses one aspect of long-term CI use, the relative impact of late receipt of a second CI. In particular, it compared functioning in several cognitive and social-emotional domains in the current cohort of college students who received either unilateral or bilateral CIs as children or adolescents.

A variety of studies has examined potential benefits of

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pediatric cochlear implantation to auditory- and speech and language-related functioning (for a review, see [2]). Further, there is now broad support in the literature for bilateral implantation providing significantly greater benefit to several domains of hearing, speech and language relative to unilateral implantation. Those benefits are mostly related to sound localization (i.e. spatial hearing: [3]) and improved speech perception abilities in the presence of background noise [4,5]. Bilateral implantation is also associated with better expressive and receptive spoken language outcomes than unilateral implantation [6,7] (for a review, see [8]). The "bilateral advantage" seems to be found regardless of length of auditory deprivation, time between implants, or ages at implantation, at least among children [9,10]. However, in a review of seven studies that specifically examined the impact of inter-implant interval on various speech and language outcomes, results were conflicting; whereas three of the reviewed studies reported that a longer inter-implant interval was associated with poorer language development and speech perception in quiet, four other studies did not find such an impact on outcomes [11]. In addition, [12] concluded that there is a "critical age" after which the receipt of a second implant will not provide significant speech perception benefits. Therefore, there is a need to look at the potential benefits of a second implantation later in life, beyond the usual auditory and speech outcomes.

4. Bilateral Implant Use and Learning and Cognition

Auditory- and speech and language-related variables associated with bilateral cochlear implantation are of lesser interest for the present purposes than their ultimate impact on the higher-level functions involved in learning, cognition and behaviour. For example, the improvement potentially provided by bilateral implants to hearing, auditory localization and greater ease and diversity in social interactions would support individuals' attending to or overhearing the speech of others that might direct them to the acquisition of new knowledge and more advanced problem-solving and interpersonal functioning over time [7]. Outside of the domains of speech and language, however, research concerning possible long-term benefits of bilateral implantation is rare. This situation may be related to restricted interests, resources and funding of investigators who study pediatric cochlear implantation, but the resulting lack of information is problematic both clinically and theoretically. A review by [13], for example, concluded that the early benefits to deaf children's cognition and learning accruing from early access to spoken language via CIs like those accruing from early access to sign language from deaf parents are largely absent by high school and college age [14-16]. A review by [17] similarly found age at implantation largely unrelated to academic and cognitive outcomes of CI users. Across 167 assessments in 44 peer-reviewed articles, only about one in five analyses yielded evidence of earlier implantation providing greater benefits relative to later implantation in childhood.

Like findings with regard to hearing, speech and language following bilateral cochlear implantation, however, outcomes of pediatric cochlear implantation in other domains are quite variable. [18] examined a large number of child and family factors associated with language, academic achievement and social-emotional variables, as reported by parents of 247 children who used CIs. Sixty-five of the children (26.3% of the sample) had received sequential bilateral CIs. Multiple regression analyses using parent report data indicated that bilateral CI use was one of several variables accounting for significant portions of variance in communication skills, social functioning and social participation as well as (expected) better academic achievement and future life outcomes.

[19] specifically examined the benefits of bilateral versus unilateral CI use on academic outcomes in a study involving 44 8-year-old CI users, 34 of whom had bilateral CIs. All of the children had used their CIs for approximately seven years. Sarant et al. examined the

children's progress in mathematics and literacy as well as language development. Across all the academic areas, the CI users performed below the levels expected of hearing children, although the bilateral CI users scored significantly higher than the unilateral users in mathematics and written language.

[4] conducted a study including 30 children with bilateral CIs and 20 with unilateral CIs, together with a comparison group of 56 hearing children. Lovett et al. noted that "the average chronological age of the normally-hearing children was similar to the average length of time for which the bilaterally- and unilaterally-implanted children had used at least one implant" (p. 108). The three groups were reported to have similar mean "hearing ages" of 54.2 months, 49.6 months and 48.9 months, respectively, even though the hearing children were about 2.5 years younger than the two CI groups. The investigators found better sound localization and speech perception among the children with bilateral CIs, but bilateral and unilateral CI users did not differ significantly in parent-reported quality of life.

[20] included bilateral versus unilateral implantation as one factor in their study of psychosocial, cognitive and language abilities among 159 pediatric CI users, 120 of whom used bilateral CIs and 39 of whom used unilateral CIs. All received their first or only implants by 3.5 years of age and, if they had a second, it was received by 6 years of age. Psychosocial functioning was evaluated at 5 and 7 to 8 years of age using the Strengths and Difficulties Questionnaire, with subscales tapping emotional symptoms, conduct problems, hyperactivity, inattention, peer problems and prosocial behaviour. Cognitive abilities were evaluated using the Wechsler Nonverbal Scale of Ability. In the social domain, parent reports indicated that the CI users did not differ significantly from hearing peers in any area except prosocial behaviour. The latter finding is consistent with a number of studies indicating that young deaf children and even deaf young adults with CIs (or not) are significantly delayed in their development of theory of mind, an important foundation of prosocial behaviour [21-26]. Use of bilateral CIs, however, was associated with better psychosocial functioning, especially among children in the Sarant et al. study who received their second CI earlier. Interestingly, children with better cognitive abilities evidenced greater difficulties with regard to peer problems and prosocial behaviour, leading to the conclusion that "more intelligent eight-year-old children were at increased risk of difficulties with other children" (p. 778).

5. The Present Study

Taken together, the research findings described above concerning higher-level language and academic outcomes following bilateral cochlear implantation generally indicate significant benefits, at least in young children. The most notable characteristic of that literature, however, might be its paucity, especially regarding the impact of inter-implant interval. [7] for example, noted that there is only a limited literature on academic outcomes among children who are CI users and [20] made a similar observation with regard to studies of psychosocial functioning among those children. Several other investigators further have emphasized the lack of research concerning long-term outcomes following cochlear implantation more generally [17,27-30]. Moreover, those studies that have examined long-term outcomes tend to define "long-term" as only up to 7 years of CI use. Although several recent investigations have examined longer CI use by examining academic achievement and, to a lesser extent, social-emotional functioning among CI users of high school and college age (see below), studies of longer-term outcomes following bilateral cochlear implantation are largely absent [31].

The present study was aimed at taking a first step toward remedying this situation by re-examining data from a series of studies that were focused on college students who were CI users; although none of those studies had considered the possible added value of bilateral over unilateral CIs. The studies were drawn from a (US) government-funded research program conducted from 2012 to 2018 that investigated language, cognition and social-emotional functioning among three populations of college students: CI users, deaf students who indicated that they had never received a CI (henceforth "deaf nonusers") and hearing peers. The students were enrolled across the nine colleges of Rochester Institute of Technology (RIT), one of which is the National Technical Institute for the Deaf (NTID). Deaf and hard-of-hearing students at RIT make up approximately 9% of the student body, with about half in associate and pre-baccalaureate degree programs at NTID and the other half, with hearing peers, in baccalaureate and graduate degree programs in the other RIT colleges. That distinction was not considered in any of the studies described below, but it reflects the fact that the deaf participants were drawn from a relatively diverse population of college students with significant hearing loss (see Marschark & Rosica, 2021, for a national perspective). For the present purposes, only data from active CI users were considered.

Recruitment of students for all studies entailed advertising around the university campus and personal contacts. Although participants were drawn from the same student body over a five-year period, overlap of CI users across the various study samples was relatively rare. Considering the studies in pairs, there were never more than two participants overlapping with the exception that two studies described below that examined visual-spatial ability and quality of life largely included the same participants. That sample was part of an all first-year student cohort that was followed longitudinally for purposes not relevant here; differing sample sizes below were the result of participants' missing sessions for some experiments. Participating researchers with different areas of expertise came from several universities in five countries.

Because the focus here is on the impact of the late receipt of a second CI, results of the original studies are summarized only briefly; details concerning materials and methodologies can be obtained from the original publications and the Appendix.

6. General Methodology

Data evaluated in the present study were drawn directly from seven studies that were conducted as part of a research program investigating relations among language, cognition and social-emotional functioning among CI users and deaf nonusers as compared to each other and to hearing peers. All of the participants were college students enrolled at RIT; over 95% of all individuals in the original studies and over 95% of the CI users considered here were between 18 and 24 years of age. Consistent with recent findings involving deaf individuals from high school age through adulthood in Europe and North America [14,32,33], both CI users and deaf nonusers reported variously using sign language and spoken language, with most using both. Without any accurate way to assess the quality or the extent to which individuals used each of the modalities [34], that variable is not considered here. In order to ensure that participants understood the task demands, however, the experimenters in all the studies were certified sign language interpreters with many years' experience working with deaf students at RIT. They interacted with deaf participants using both spoken language and sign language. All tasks also included written instructions and participants were encouraged to ask questions for clarification whenever necessary.

Analyses described below aimed to evaluate possible performance differences between unilateral CI users and bilateral users who received their second CIs relatively late and with a relatively long inter-implant interval [6]. These consisted of t-tests comparing their performance on the tasks of interest in each study. Ages of their first and second implantations were compared in order to be able to control for any significant differences in that regard, but as will be evident below, such control turned out not to be necessary. Bivariate correlational analyses examined relations between participants' test performance and implant characteristics: self-reported ages of first and second implantation and time between the two implantations.

Those data frequently indicate that mean reported ages of implantation were relatively late by current standards, but they accurately represent characteristics of current cohorts of college students who are CI users in the United States. Means, standard deviations and results of group comparisons (with Cohen's *d* effect sizes) are presented in a table for each study. Because of the possibility that ages of implantation were skewed, medians for ages of implantation are provided in the text, as are any significant correlations between performance and ages at implantation.

As in most studies concerning long-term outcomes of cochlear implantation, the present study does not provide (nor had available) any data with regard to the auditory benefits received by individual participants through unilateral or bilateral CIs. Similarly, familial and other demographic information that might provide insight into participants' early language environments and CI use was not available to the investigators. Nor was information available with regard to why individual participants had received bilateral or only unilateral CIs. Such information would be particularly important with regard to studies of young children, for whom environmental factors are playing a key role in language and cognitive development before and after cochlear implantation [30]. While those factors appear less important for young adults [13], the failure to consider them along with audiological variables in studies of pediatric CI users may be problematic [20,27,35].

7. Cognitive and Academic Functioning

Vocabulary and World Knowledge

[36] examined knowledge differences among CI users, deaf nonusers and hearing peers in six domains: vocabulary, world history, geography, occupations of famous people, magnitudes of real-world animals and objects and the accuracy of non-numerical magnitude judgments.

Vocabulary was assessed using the Peabody Picture Vocabulary Test-IV (PPVT). Knowledge of USA geography and famous people involved stimulus matching (e.g., assigning famous names to professional categories). Assessment of historical knowledge required ordering historical events on an end-anchored timeline.

Knowledge of real-world magnitudes required individuals to provide estimates on various dimensions (e.g., the height of a basketball goal, the number of apples in a pound), while non-numerical magnitude judgments required estimates of objects in a laboratory setting (e.g., the circumference of a laboratory wall clock).

Hearing college students outperformed both CI users and deaf nonusers, with no significant differences between the latter two groups on any task. Age of first cochlear implantation was not significantly related to performance.

Participants and results: Participants in the present comparisons included 92 CI users, 69 of whom received unilateral CIs at a median age of 6.00 years. The 23 bilateral CI users reported receiving their first CI at a median age of 7.00 years and their second CI at a median age of 16.00 years.

The independent sample t-tests comparing the bilateral and unilateral CI users indicated no significant differences in their performance on any of the six tasks, although a large effect size was associated with the history task and a medium effect size with the geography task (Table 1).

The two groups also did not differ significantly in the ages at which they received their first/only CI. There were no significant correlations between age at implantation and performance on any of the tasks for the unilateral CI group, but ages of both first, $r(21) = .43$, $p = .042$ and second, $r(21) = .42$, $p = .047$, implantations were significantly related to the bilateral users' knowledge about the magnitudes of objects and animals in the real world. Positive coefficients counterintuitively indicated that later implantations were associated with higher scores.

A shorter period between their two implantations also was associated with higher scores on the geography task, $r(21) = -.42$, $p = .047$.

Table 1: Mean scores and standard deviations (*SD*) for CI characteristics and performance on Peabody Picture Vocabulary Test (PPVT) vocabulary and world knowledge tasks with *t*-test results and effect sizes (Cohen's *d*).

	Unilateral Users		Bilateral_Users			
	Mean	SD	Mean	SD	*t* (90)	*d*
Age of first cochlear implantation	8.31	6.18	8.22	5.62	0.06	0.02
Age of second cochlear implantation			15.59	3.19		
Time between implantations (years)			7.37	4.57		
PPVT Standard scores	81.35	20.49	82.96	23.13	0.32	-0.08
Famous people (% correct)	0.40	0.19	0.37	0.16	0.69	0.17
History timeline (% correct)	0.19	0.15	0.14	0.12	1.43	-1.27
Geography (% correct)	0.76	0.23	0.65	0.27	1.77	0.46
Real-world magnitudes (% correct)	0.08	0.08	0.10	0.08	0.99	-0.25
Laboratory estimates (% correct)	0.05	0.07	0.05	0.05	0.28	0.00

These findings indicate that the vocabulary advantages sometimes observed among young children who are bilateral CI users when compared to unilateral CI users [30] were not found in this sample of college students. Among bilateral CI users but not unilateral CI users, greater knowledge about the magnitudes of objects and animals was associated with later first and second implantations. Less time between receiving their two CIs was associated with bilateral CI users' better knowledge of USA geography.

Executive Function and Academic Achievement

[37 Experiment 1] examined eight aspects of cognitive executive function among CI users, deaf nonusers and hearing peers as part of a series of studies investigating social maturity among deaf and hearing college students [see also 38,39] The investigators also obtained college entrance scores for the deaf participants. Executive function was assessed using the Learning, Executive and Attention Functioning (LEAF) scale. Two versions of the LEAF were administered: the original self-report measure (adapted from a parent-report measure) and one with simplified, more accessible language intended for use with deaf learners. Only one of the eight scales yielded a (small but) significant difference between the two versions; and all of the data are combined here, as they were in the original study. American College Test (ACT) English, mathematics, reading comprehension and science subtest scores were available for 55 of the CI users, but were not used for analyses in the original study. Analyses of LEAF scores indicated that deaf students reported significantly more executive function difficulties than their hearing peers in several domains, but there were no differences between CI users and deaf nonusers, nor was age at implantation significantly associated with any of those scores.

Participants and results: This study included 66 CI users; 27 of them reported using bilateral CIs. The 39 unilateral CI users reported receiving their CIs at a median age of 3.00 years. The bilateral CI users reported receiving their first CI at a median age of 4.00 years and their second CI at a median age of 13.00 years.

As can be seen in Table 2, the unilateral and bilateral CI users did not differ significantly in the age of receiving their first/only CI. Comparisons of two groups' scores on the eight LEAF dimensions of executive function also failed to yield any significant differences and all effect sizes were small. However, consistent with findings of [7] with children, the 23 bilateral CI users had obtained significantly higher college entrance scores than the 32 unilateral CI users on English, reading and mathematics ACT subtests, only the last having a relatively large effect size (Table 2). Correlation analyses reflected the lack of association between executive function and age at implantation, as no significant coefficients were obtained.

Table 2: Means and standard deviations (*SD*) for CI characteristics and executive function scores on the Learning, Executive, and Attention Functioning (LEAF) scale (n = 66, df = 64) and American College Test (ACT) college entrance scores (n = 55, df = 53) with *t*-test results and effect sizes (Cohen's *d*).

	Unilateral Users		Bilateral Users			
	Mean	SD	Mean	SD	*t*	*d*
Age of first cochlear implantation	4.40	2.84	4.26	2.56	0.84	0.05
Age of second cochlear implantation			12.70	3.01		
Time between implantations (years)			8.44	2.89		
LEAF						
Comprehension/Conceptual Learning	4.59	2.17	4.78	2.42	0.33	-0.08
Factual Memory	4.03	2.71	4.44	3.07	0.58	-0.14
Attention	4.46	2.62	3.63	2.51	1.29	0.33
Processing Speed	5.62	3.42	4.52	3.20	1.31	0.34
Visual-Spatial Organization	2.87	2.77	2.30	2.23	0.90	0.23
Sustained Sequential Processing	3.56	2.27	3.04	2.58	0.88	0.22
Working Memory	4.64	2.59	4.89	3.48	0.33	-0.08
Novel Problem Solving	3.56	2.68	3.15	2.78	0.61	0.15
ACT						
English	13.69	3.34	18.00	5.23	3.73*	-1.04
Mathematics	17.72	3.44	21.04	5.41	2.78**	-0.77
Reading Comprehension	17.41	3.74	20.91	5.55	2.80**	-0.78
Science	18.87	3.47	21.04	5.04	1.89	-0.53

*p = .001, **p = .01. Note: Higher LEAF scores indicate greater executive function difficulties.

Visual-Spatial Ability

[40] empirically examined the frequent assumption that deaf individuals and especially those who use sign language have better visual-spatial abilities than hearing individuals [41]. Visual-spatial abilities in their Experiment 1 were tapped using the Spatial Relations and Pair Cancellation tasks from the Woodcock-Johnson III Tests of Cognitive abilities (WJ-III) and an embedded figures test. Contrary to expectations but consistent with findings of [31] and [42], hearing students significantly outperformed both CI users and deaf nonusers on the Spatial Relations and embedded figures tasks. Hearing students also outperformed the CI users and deaf participants, overall, on the Pair Cancellation task. Marschark, Spencer, et al. found no significant differences in performance between CI users and deaf nonusers on any of the tasks [see also, 42,43].

Participants and Results: Participants included here were 52 CI users, including 17 bilateral CI users. Among the 35 unilateral CI users, the median age at which they reported receiving their CIs was 6.00 years. The median age of receiving a first CI among the bilateral users was 4.00 years; the median age of receiving a second CI was 15.00 years.

Comparisons of unilateral and bilateral CI users indicated that bilateral users significantly outperformed the unilateral users on the WJ-III Spatial Relations task, yielding a large effect size, but the two groups did not differ in performance on the embedded figures task or Pair Cancellation task (see Table 3). Correlational analyses indicated that earlier implantation among unilateral CI users was significantly associated only with better performance on the Spatial Relations task, r (33) = -.42, p = .012.

With regard to earlier implantation being associated with better visual-spatial skills among unilateral users but not bilateral users, it is important to note that [40] found that across three experiments, visual-spatial skills were significantly associated with deaf participants' language abilities, regardless of whether they relied primarily on spoken language or sign language. That is, while better visual-spatial ability was positively linked to stronger sign language skills among signers, it also was positively linked to stronger spoken language skills among deaf participants who used spoken language (most of whom were CI users).

Table 3: Mean scores and standard deviations (*SD*) for CI characteristics and visual-spatial task scores with *t*-test results and effect sizes (Cohen's *d*).

	Unilateral Users		Bilateral Users				
	Mean	**SD**	**Mean**	**SD**	***t***	***df***	***d***
Age of first cochlear implantation	6.90	5.00	4.73	3.68	1.55	49	0.48
Age of second cochlear implantation			14.38	2.92			
Time between implantations (years)			9.64	4.29			
WJ-III Spatial relations	87.55	8.04	92.98	6.95	2.54*	50	-0.72
WJ-III Pair cancellation	37.43	13.94	38.72	11.70	0.77	50	-0.09
Embedded figures	90.39	10.36	92.39	7.49	0.81	50	-0.21

*p = .011.

Theory of Mind, Visual-Spatial Reasoning and Sequential Processing

[22] investigated theory of mind in CI users, deaf nonusers and hearing college students using tasks requiring the understanding of sarcasm and advanced false belief (second-order false belief and double bluff). Theory of mind refers to individuals' understanding that people have thoughts, wants and beliefs that influence their interpersonal behaviour, an ability that normally develops with increasing complexity across age groups, languages and cultures. Delays in theory of mind development frequently seen among deaf children and other populations have led to a conversational account of theory of mind development (and its delay) in terms of the nature and amount of social communication experienced by children directly (conversationally) and indirectly (via overhearing). Both likely would be enhanced by CI use, but bilateral CIs might be expected to be particularly facilitative insofar as auditory localization would indicate the directions of relevant speakers, thus helping to clarify intentions from context and facial expressions [19].

Given the visual-spatial and sequential cognitive processes likely to be involved in being able to perform their sarcasm and advanced belief tasks, [22] also employed tasks tapping those abilities. The former was assessed using the WJ-III Spatial Relations task. As noted earlier, visual-spatial skill typically is expected to be greater among deaf individuals than hearing individuals and among deaf sign language users than deaf spoken language users. The General Ability Measure for Adults (GAMA) Sequence's subtask was used to evaluate sequential processing ability, typically expected to be greater among hearing then deaf individuals [44]. Consistent with previous studies of theory of mind among deaf and hearing children [21,23,25], [22] found that the deaf college students scored significantly below hearing participants on all three theory of mind tasks. They also performed significantly more poorly than hearing participants on the visual-spatial [31,40,42] and sequential-processing tasks. CI users and deaf nonusers did not differ significantly from each other on any of the three theory of mind tasks, nor did they differ on the visual-spatial or sequential processing tasks.

Participants and results: Participants included 46 CI users, including 14 bilateral CI users. Among the 32 unilateral CI users, the median age at which they reported receiving their CIs was 4.00 years. The median age of receiving a first CI among the bilateral users was 7.50 years; the median age of receiving a second CI was 16.00 years.

Comparisons of the unilateral and bilateral CI users' performance on the three theory of mind tasks, the visual-spatial task and the sequential processing task, all failed to indicate significant differences (see Table 4). The two samples also did not differ in the age of their first implantation. Correlational analyses indicated that consistent with the study discussed just previously, unilateral CI users who received their CIs earlier performed better only on the Spatial Relations task, r (30) = -.41, p = .021. Among the bilateral users, there were no significant correlations with age at implantation.

Table 4: Mean scores and standard deviations (*SD*) for CI characteristics and performance on theory of mind, visual-spatial, and General Ability Measure for Adults (GAMA) sequential processing tasks with *t*-test results and effect sizes (Cohen's *d*).

	Unilateral Users		Bilateral Users			
	Mean	**SD**	**Mean**	**SD**	***t* (44)**	***d***
Age of first cochlear implantation	6.41	5.01	7.12	4.56	0.45	-0.15
Age of second cochlear implantation			14.79	2.94		
Time between implantations (years)			7.68	4.92		
Sarcasm understanding	0.60	0.32	0.62	0.34	0.23	-0.06
Double bluff understanding	0.58	0.38	0.61	0.29	0.25	-0.09
Second-order false belief understanding	0.33	0.35	0.39	0.29	0.61	-0.18
Spatial Relations score	0.75	0.13	0.74	0.14	0.11	0.08
GAMA Sequences score	0.52	0.16	0.56	0.09	0.93	-0.29

In short, although it is reasonable to expect that use of bilateral CIs would allow users to be more involved in conversations about others' mental states relative to use of unilateral CIs [19], having bilateral CIs was not found to be associated with theory of mind performance in the present study. Nor did the unilateral and bilateral CI users differ in the visual-spatial or sequential processing abilities that [22] argued were involved in performing their theory of mind tasks. As can be seen in Table 4, all effect sizes were small. Age at implantation was negatively related to Spatial Relations scores among unilateral users, but positively related to age of first implantation among bilateral users.

Interim Summary: Cognitive and Academic Functioning

Summarizing results from the several cognitive and academic dimensions evaluated above, bilateral CI users were found to have achieved higher college entrance scores than unilateral users, perhaps related to their having better speech reception abilities relative to unilateral CI users [40].

They also scored higher than unilateral CI users on the WJ-III Spatial Relations task, but no differences were obtained between the two groups in 22 other comparisons involving various cognitive domains ($p < .01$, by sign test).

The unilateral CI and bilateral CI groups did not differ in the mean ages at which they received their only/first CI in any of the studies.

Taken together, these results suggest that if cognitive differences existed between these unilateral and bilateral CI users as children, they were largely absent by the time they reached college age.

8. Social Emotional Functioning

Personality Traits

A study in the social-emotional domain, conducted by [32], used the HEXACO-60 to examine six dimensions of personality and the Generalized-Efficacy (GSE) scale to examine perceived self-efficacy among CI users, deaf nonusers and hearing students. Hearing students scored higher on the HEXACO-60 Conscientiousness scale (i.e., reported being more conscientious) than either CI users or deaf nonusers and higher on the Openness to Experience scale than CI users.

They also scored higher on self-efficacy compared to deaf nonusers. CI users and nonusers did not differ significantly from each other on any of the dimensions examined.

Participants and results: Participants completing the HEXACO-60 included 104 CI users, 64 of whom had received their unilateral CIs at a median age of 4.00 years. The 40 individuals who reported being bilateral CI users received their first CIs at a median age of 6.00 and their second CIs at a median age of 15.00 years. A convenience subsample of 47 of the CI users, including 26 unilateral users (median age at implantation = 4.00 years) and 21 bilateral users (median age at first implantation = 6.00; median age at second implantation = 15.00), also completed the GSE.

As can be seen in Table 5, comparisons of the unilateral and bilateral CI users indicated that they did not differ significantly in the age at which they received their only/first CI.

Comparisons of the two samples also indicated no significant differences on any of the six HEXACO-60 personality dimensions or on the GSE.

A correlational analysis indicated that among both unilateral and bilateral CI users, earlier implantation was associated with greater Emotionality (i.e., experiencing more stress and more emotional dependence), r (62) = -.29, p = .02 and r (38) = -.33, p = .04, respectively.

Among bilateral CI users, a longer time between their two implantations also was associated with greater Emotionality, r (38) = .36, p = .02 and receiving their second CI later was associated with greater Conscientiousness, r (38) = .48, p = .002.

Although receiving a second CI later was associated with greater Conscientiousness, there was no overall difference between the unilateral and bilateral CI groups on that dimension or any other.

The present results thus indicated little difference in personality between the unilateral and bilateral CI users, at least on the several dimensions examined here.

As can be seen in Table 5, all of the effect sizes were small and half of the differences favoured the unilateral CI users.

Table 5: Means and standard deviations (*SD*) for CI characteristics and scores on HEXACO-60 (n = 104, df = 102) and GSE (n = 47, df = 45) personality assessments with *t*-test results and effect sizes (Cohen's *d*).

	Unilateral Users		Bilateral_Users			
	Mean	SD	Mean	SD	*t*	*d*
Age of first cochlear implantation	6.51	5.23	6.69	4.48	0.17	-0.04
Age of second cochlear implantation			14.48	3.71		
Time between implantations (years)			7.70	4.24		
HEXACO-60						
Honesty-humility	33.86	5.01	32.18	5.41	1.21	0.33
Emotionality	31.86	5.79	30.98	6.09	0.74	0.15
Extroversion	33.22	5.66	34.00	5.71	0.68	-0.14
Agreeableness	33.59	4.57	32.98	5.05	0.64	0.13
Conscientiousness	32.80	4.59	33.98	5.49	1.18	-0.24
Openness to experience	33.08	5.09	32.50	4.86	0.57	0.12
Self-efficacy (GSE)	2.96	0.43	3.09	0.42	0.86	-0.31

Acculturation and Social Dominance

[45] investigated social dominance orientations (SDO) among CI users and deaf nonusers and the extent to which they saw themselves as having deaf or hearing

cultural identities. The SDO_7 was used to examine attitudes toward social dominance and egalitarianism and the Deaf Acculturation Scale (DAS) was used to assess deaf and hearing cultural affiliations. Analysis of SDO_7 scores indicated that when language orientation (sign language versus spoken language) was controlled, there were no differences in social dominance or egalitarian orientations among groups of CI users, deaf nonusers and their hearing peers. Not surprisingly, deaf individuals scored higher on a deaf identity scale than hearing individuals and hearing individuals scored higher than deaf individuals on a hearing identity scale, but the CI users and deaf nonusers did not differ significantly on either dimension.

Participants and results: This study included 61 CI users, 19 of whom used bilateral CIs. The 42 unilateral CI users reported receiving their CIs at a median age of 4.25 years. The bilateral CI users reported receiving their first CIs at a median age of 5.00 years and their second CIs at a median age of 15.00 years. The unilateral and bilateral CI users did not differ significantly on either of the SDO_7 scales (social dominance or egalitarianism) or on either of the DAS scales (deaf identity, hearing identity) (Table 6).

Table 6: Mean scores and standard deviations (*SD*) for CI characteristics and scores on Social Dominance Orientation (SDO) scores and Deaf Acculturation Scale (DAS) scores with *t*-test results and effect sizes (Cohen's *d*).

	Unilateral Users		Bilateral Users			
	Mean	SD	Mean	SD	*t* (59)	*d*
Age of first cochlear implantation	6.81	5.64	5.68	3.41	0.80	0.23
Age of second cochlear implantation			14.10	4.23		
Time between implantations (years)			8.42	4.14		
SDO – social dominance	3.50	0.80	3.53	0.47	0.10	-0.04
SDO – egalitarianism	3.10	0.85	3.29	0.51	0.90	-0.25
DAS Deaf acculturation	3.32	0.79	3.03	0.64	1.43	0.40
DAS Hearing acculturation	3.58	0.52	3.41	0.54	1.21	0.33

Among both unilateral and bilateral CI users, there were no significant correlations between age at implantation and any of the DAS or SDO_7 scales. In short, use of unilateral versus bilateral CIs by college students in this study was not associated with distinctions of cultural identity or social dominance orientations. This conclusion is reflected by the lack of statistically significant differences between the two groups and the small effect sizes seen in Table 6.

Quality of Life

[46] examined quality of life among CI users, deaf nonusers and hearing college students over their first year of university using the Youth Quality of Life – Deaf and Hard-of-Hearing (YQoL-DHH) inventory and deaf and hearing acculturation, using the DAS. The YQoL-DHH is a self-report measure consisting of three subscales relating to perceived stigmatization with regard to hearing loss, social participation and self-acceptance/advocacy. Consistent with the results of [45] described earlier, DAS scores in [46] indicated that deaf nonusers had greater senses of deaf identity than CI users, but the two groups did not differ in their degree of hearing identity. With regard to quality of life, consistent with previous studies by the developers of the YQoL-DHH [47-49], [46] found that scores on the three YQoL-DHH subscales did not differ significantly between CI users and nonusers.

Participants and Results: Participants in the present study included 51 CI users, 16 of whom were bilateral CI users. The 35 unilateral CI users had a median reported age at which they received their CIs of 6.00 years. The bilateral users reported a median age of receiving their first CI at 4.00 years and a median age of receiving a second CI at 15.00 years.

Table 7 reflects the finding that, consistent with findings of [4] in their study of quality of life among deaf children with unilateral and bilateral CIs, there were no significant differences between the college-age unilateral and the bilateral CI users here on any of the three YQoL-DHH subscales. In contrast to findings from analysing the data of [45] above, however, unilateral CI users scored significantly higher in deaf identity than bilateral users, yielding a large effect size.

Correlational analyses yielded no significant coefficients between any CI characteristics and YQoL-DHH subscales for either unilateral or bilateral CI users. Similar analyses involving DAS scores indicated that among the bilateral users, earlier implantation of their first CIs was associated with greater hearing identity, r (14) = -.54, p = .037. There were no significant correlations between deaf and hearing identity scores and age at implantation among the unilateral CI users.

Table 7: Mean scores and standard deviations (*SD*) for CI characteristics and Youth Quality of Life – Deaf and Hard-of-Hearing (YQoL-DHH) scores and Deaf Acculturation Scale (DAS) scores with *t*-test results and effect sizes (Cohen's *d*).

	Unilateral Users		Bilateral_Users				
	Mean	SD	Mean	SD	*t*	*df*	*d*
Age of first cochlear implantation	6.90	5.00	5.39	4.49	1.76	49	0.32
Age of second cochlear implantation			14.47	2.85			
Time between implantations (years)			9.08	4.77			
YQoL-DHH Stigmatization	111.23	15.37	114.88	12.82	0.85	49	-0.26
YQoL-DHH Social participation	28.51	18.08	26.82	14.57	0.34	49	0.10
YQoL-DHH Self-acceptance/advocacy	51.97	18.32	48.76	19.59	0.58	49	0.18
DAS Deaf acculturation	3.19	0.73	2.64	0.62	2.55*	45	0.81
DAS Hearing acculturation	3.46	0.55	3.77	0.51	1.88	46	-0.59

*p = .011.

The above results extend previous findings in suggesting that not only does the YQoL-DHH fail to distinguish CI users and deaf nonusers on dimensions frequently described as important for quality of life among deaf individuals (e.g., mainstream versus schools for the deaf, use of sign language; [47,48]), but its quality-of-life subscales also are unrelated to unilateral versus bilateral CI use or age at implantation among deaf college students.

Interim Summary: Social-Emotional Functioning

Taken together, these and other findings described earlier suggest that while self-reports and parental reports of children who have received CIs indicate greater quality of life after implantation, any such effects appear to be diminished or eliminated by college age in this late-implanted with large inter-implant interval population. More narrowly, any advantages gained from bilateral CI use that affect quality of life among pediatric CI users also appear absent by early adulthood, at least among these college students. Across the 16 dimensions on which college-age unilateral and bilateral CI users were compared, above, only one yielded a significant difference (p <.01, by sign test).

9. Discussion

The present study sought to examine the possible added value in several cognitive and social-emotional domains of bilateral CIs among college students who had received their second implants after relatively long inter-implant intervals. The investigation was motivated in part by increasing awareness that auditory deprivation (i.e., hearing loss) and auditory restoration (e.g., through cochlear implantation) and have widespread effects on brain development, with cascading effects in a variety of neuropsychological domains [50-52].

This study used previously unanalysed data drawn from seven published investigations involving deaf college students who were CI users to examine possible differences between unilateral and bilateral CI use as well as ages of implantation and length of time between implantations for the bilateral CI users. College student CI users' cognitive/academic performance was examined on assessments of vocabulary and real-world knowledge, magnitude estimation ability, executive function, academic achievement, visual-spatial and sequential processing and advanced theory of mind understanding. Social-emotional domains examined included dimensions of personality, social dominance orientation, acculturation and quality of life. Taken together, the results of these outcome studies indicated that within this population:

1. Age at first (or only) implantation was not associated with significantly better outcomes on most assessments. Calculation of a weighted, mean effect size (Cohen's *d*) across the seven studies yielded only a "small" effect of 0.12.
2. Bilateral implantation yielded few significant benefits when compared with unilateral implantation on these tasks. The similar calculation of a weighted, mean effect size (Cohen's *d*) across the seven studies yielded a "small" effect of -0.12.

These findings were obtained against the backdrop of some recently published evidence regarding the impact of longer inter-implant intervals and the late receipt of a second CI (CI2) on speech perception skills and on the continued use of CI2 later in life. [12] found that none of the 9 children who received their second CI after the age of 15 had "satisfactory" speech perception scores. [53] found higher rates of CI2 non-use with the lengthening of inter-implant interval in 56 bilaterally implanted young adults (mean age at first CI was 5.8 years and mean age at second CI was 14.7 years). Similarly, to the Low and colleagues' study, the participants in the present study received both CIs at relatively late ages. Rather than being seen only as a limitation, the investigation of this cohort provides new information of clinical and theoretical interest. The bilateral CI users who participated in these studies are, to date, among the oldest deaf "children" whose outcomes have been examined in the literature. It may be that, at least by the time they reach their adolescent and young adult years, other factors are more important in predicting their outcomes than age at CI or whether they are using one or two CIs. In addition to the myriad of individual and demographic factors likely to affect various aspects of development after cochlear implantation (e.g., family socioeconomic status, exposure to linguistic and social diversity, educational programming; [13,19,17,27]), the environments, expectations and skills of older CI users (and nonusers) are far more complex than those among younger children. This situation may be a primary reason for early academic/cognitive benefits found among pediatric CI users largely disappearing by high school and college age [14-16,46]. In that context, it is interesting that [37] failed to find significant differences in college entrance examinations between CI users and deaf nonusers and yet the analyses described above indicated that within their sample of CI users, bilateral users scored significantly higher on three out of four ACT subtests, including English and Reading Comprehension. Given the expectations of parents and professionals with regard to academic outcomes for both unilateral and bilateral CI users, this issue is well worthy of further study.

Beyond the greater linguistic, cognitive and environmental demands on deaf youth as they move from the primary school years to the secondary school years, a further possible explanation for the lack of significant age at implantation effects in the present study and others involving language and cognitive abilities among high school and college students is that cochlear implantation may have occurred too late to confer significant benefits for either unilateral or bilateral users. In the terms of [51], late implantation and concomitant auditory deprivation alters connectivity within brain centers serving higher-order neurocognitive functions; [54]) emphasized the decreasing cortical plasticity with longer periods of auditory deprivation. Yet, the typically confounded effects of language deprivation and duration of CI use remain to be distinguished. It is also likely that a relatively low level of benefit, in terms of access to auditory information, could be expected from CI use in such a late-implanted population. Similarly, earlier-implanted children who receive more benefit from their devices (and/or language exposure) and have better neural auditory pathways, might experience better quality of life as a function of improved "downstream" language, cognitive and social-emotional functioning. While the late implantation among participants in the studies described here are a limitation on the present investigation, it is the reality for many CI users and the present findings thus are of clinical as well as theoretical significance.

If the first CI a child receives does not provide a great deal of benefit to speech perception and language development for the reasons given above, giving a late, second device to teenagers likely would provide only a relatively low level of benefit to audition rather than true binaural listening and the listening benefits in noise conferred by it. Unfortunately, we do not know about the speech perception abilities of the participants of the present studies, a frequent limitation of studies involving older CI users. If it is the case that many of these individuals did not receive significant listening benefits from either of their CIs and do not therefore receive the benefits of binaural hearing, we would not expect to see significant differences in outcomes between the unilateral and bilateral users, particularly given that some of the areas assessed in these studies may be more highly influenced by other factors than hearing (e.g., intelligence, reading ability, maternal sensitivity).

As mentioned previously, there is considerable evidence that early bilateral cochlear implantation can facilitate very good speech perception abilities in most children with severe to profound hearing losses and can also support positive language, academic and other outcomes. It also should be noted that for many of the studies reporting such positive outcomes, the children often had highly supportive and well-educated families who used spoken communication. While the significant and positive impact of these factors on speech and language outcomes has been well-documented [7,19,39], research into their longer-term impact in cognitive, social-emotional and academic domains is just beginning.

In addition to many of the students in the current study being implanted late by current standards, factors such as device usage, speech perception benefit, family characteristics, the presence of additional disabilities, mode of communication and interventions received were unknown. Information on initial adjustment and device use has been shown to be predictive of later success and outcomes (see [15,55]), but is rarely considered in studies of functioning in other domains, even in children. Given what is known clinically about the difficulties experienced by many older children in accepting and using their CIs, it also may be the case that some of the students in the current study were not consistent users of their devices as children, even if they are as college students. These unknown factors and other as yet unidentified factors that may apply to older CI users and not to younger ones could have contributed to the outcomes reported here. It is therefore not possible to determine the extent to which the outcomes reported in this study were affected by relatively late implantation. Nevertheless, the lack of significant correlations between first and second ages of implantation and performance in the various domains assessed here suggest that age at implantation is unlikely to be a unitary, dominant predictor of psychological functioning by young adulthood. Despite the above limitations, this study is one of the first to examine the effects of bilateral cochlear implantation in teenagers and young adults regarding cognitive, academic and social-emotional functioning.

10. Summary and Conclusion

The findings of this study highlight the many questions that remain unanswered with regard to what will facilitate the best possible outcomes for children with

CIs. The current, scant published evidence, together with the results of this investigation, suggest that we do not know the extent to which the factors that promote better outcomes for younger children are relevant to adolescents and young adults, particularly given the enormous differences in their environments, skills and what is expected of older students in terms of their linguistic, social-emotional and academic competence. The significant reduction in professional educational support services given to secondary and older students compared with younger students appears to be in response to the belief that if early-implanted children with CIs are professionally supported in their early intervention and elementary school years and they achieve age-appropriate language, they are then equipped to learn for themselves in their later educational years. However, much of the evidence for these older students' poorer academic outcomes than their hearing peers suggests otherwise [37,16,56].

The question of the extent to which bilateral CIs facilitate significantly better outcomes for older children, adolescents and young adults currently remains unanswered. There is an urgent need for further long-term (and longer-term) empirical studies that follow children from implantation throughout the school years in order to answer not only this question, but also to identify other factors that can assist these children to develop their full potential. In the meantime, a continued high level of educational support for older children with CIs appears to be strongly recommended.

Notes

1. There also is a notable lack of research concerning language outcomes following unilateral or bilateral cochlear implantation among adolescents and young adults, presumably because of the number of factors affecting that domain beyond those operative during childhood.
2. Because the initial studies were aimed at comparing CI users and deaf nonusers, no efforts had been made to equate the numbers of unilateral and bilateral CI users. Several studies in the larger project that included fewer than 14 bilateral CI users are not discussed here.
3. [37] collected social maturity data from a subset of the original participants in a second, follow-up experiment. Smaller samples in the follow-up experiment and missing data combined to result in samples too small to be included for the present purposes, but the bilateral and unilateral CI groups did not differ in the frequency with which they reported engaging in positive and negative behaviours.

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References

1. Canadian Cochlear Implant Centers Group. Journal of Otolaryngology-Head & Neck Surgery. 2010; 39: 479-485.
2. JZ Sarant. Cochlear implants in children: A review. In S Naz (Ed.) Hearing loss. 2012; 331-382.
3. SM Godar, RY Litovsky. Experience with bilateral cochlear implants improves sound localization acuity in children. Otology and Neurotology. 2010; 31: 1287-1292.
4. RES Lovett, PT Kitterick, CE Hewitt, AQ Summerfield. Bilateral or unilateral cochlear implantation for deaf children: An observational study. Archives of Disease in Childhood. 2010; 95: 107-112.
5. C Vincent, JP Bébéar, E Radafy, FM Vaneecloo, I Ruzza, S Lautissier, et al. Bilateral cochlear implantation in children: localization and hearing in noise benefits. International Journal of Pediatric Otorhinolaryngology. 2012; 76: 858-864.
6. T Boons, JP Brokx, T Dhooge, JH Frijns, L Peeraer, A Vermeulen, et al. Predictors of spoken language development following pediatric cochlear implantation. Ear and Hearing. 2012; 44: 617-639.
7. JZ Sarant, DC Harris, LA Bennet, S Bant. Bilateral versus unilateral cochlear implants in children: A study of spoken language outcomes. Ear and Hearing. 2014; 35: 396-409.
8. JC Johnston, A Durieux-Smith, D Angus, A O'Connor, EM Fitzpatrick. Bilateral padiatric cochlear implants: A critical review. International Journal of

Audiology. 2009; 48: 601-617.

9. YE Smulders, AB Rinia, MM Rovers, GA van Zanten, W Grolman. What is the effect of time between sequential cochlear implantations on hearing in adults and children? A systematic review of the literature. The Laryngoscope. 2011; 121: 1942-1949.

10. DM Zeitler, MA Kessler, V Terushkin, JT Roland, MA Svirsky, AK Lalwani, et al. Speech perception benefits of sequential bilateral cochlear implantation in children and adults: A retrospective analysis. Otology and Neurotology. 2008; 29: 314-325.

11. MJ Lammers, RP Venekamp, W Grolman, GJ van der Heijden. Bilateral cochlear implantation in children and the impact of the inter-implant interval. The Laryngoscope. 2014; 124 : 993-999.

12. J Graham, D Vickers, J Eyles, J Brinton, GA Malky, W Aleksy, E Midgley. Bilateral sequential cochlear implantation in the congenitally deaf child: evidence to support the concept of a ‘critical age ‘after which the second ear is less likely to provide an adequate level of speech perception on its own. Cochlear Implants Int. 2009; 10: 119-141.

13. M Marschark, H Knoors. Sleuthing the 93% solution in deaf education. In H Knoors and M Marschark (Eds.), Evidence-based practice in deaf education. New York, NY: Oxford University Press. 2019; 1-32.

14. K Crowe, M Marschark, J Dammeyer, C Lehane. Achievement, language and technology use among college-bound deaf learners. J Deaf Stud Deaf Edu. 2017; 22: 393-401.

15. A Geers, E Tobey, J Moog, C Brenner. Long-term outcomes of cochlear implantation in the preschool years: From elementary grades to high school. Int J Audiol. 2008; 47: 21-30.

16. M Marschark, DM Shaver, K Nagle, L Newman. Predicting the academic achievement of deaf and hard-of-hearing students from individual, household, communication and educational factors. Except Child. 2015; 81: 350-369.

17. M Marschark, L Duchesne, D Pisoni. Effects of age of cochlear implantation on learning and cognition: A critical assessment. Am J Speech Lang Pathol. 2019; 28: 1318-1334.

18. M Hyde, R Punch, P Grimbeek. Factors predicting functional outcomes of cochlear implants in children. Cochlear Implants Int. 2011; 12: 94-104.

19. JZ Sarant, DC Harris, LA Bennet. Academic outcomes for school-aged children with severe–profound hearing loss and early unilateral and bilateral cochlear implants. J Speech Lang Hear Res. 2015; 58: 1017-1032.

20. JZ Sarant, DC Harris, KL Galvin, LA Bennet, M Canagasabey, PA Busby. Social development in children with early cochlear implants: normative comparisons and predictive factors, including bilateral implantation. Ear Hear. 2018; 39: 770-782.

21. AL Jackson. Language facility and theory of mind development in deaf children. J Deaf Stud Deaf Edu. 2001; 6: 161-176.

22. M Marschark, L Edwards, C Peterson, K Crowe, D Watson. Understanding theory of mind in deaf and hearing college students. J Deaf Stud Deaf Edu. 2019; 24: 104-118.

23. M Meristo, K Strid, E Hjelmquist. Early conversational environment enables spontaneous belief attribution in deaf children. Cognition. 2016; 157: 139-145.

24. T Most, C Aviner. Auditory, visual and auditory-visual perception of emotions by individuals with cochlear implants, hearing aids and normal hearing. J Deaf Stud Deaf Edu. 2009; 14: 449-464.

25. A Sundqvist, B Lyxell, R Jönsson, M Heimann. Understanding minds: Early cochlear implantation and the development of theory of mind in children with profound hearing impairment. Int J Pediatr Otorhinolaryngol. 2014; 78: 538-544.

26. G Szagun, B Stumper. Age or experience? The influence of age at implantation and social and linguistic environment on language development in children with cochlear implants. J Speech Lang Hear Res. 2012; 55: 1640-1654.

27. L Duchesne, M Marschark. Effects of age at cochlear implantation on vocabulary and grammar: A review of the evidence. Am J Speech Lang Pathol. 2019; 28: 1673-1691.

28. KL Galvin, JF Holland, KC Hughes. Longer-term functional outcomes and everyday listening performance for young children through to young adults using bilateral implants. Ear Hear. 2014; 35: 171-182.

29. WG Kronenberger, BG Colson, SC Henning, DB Pisoni. Executive functioning and speech-language skills following long-term use of cochlear implants. J Deaf Stud Deaf Edu. 2014; 19: 456-470.

30. M Sparreboom, MC Langereis, AF Snik, EA Mylanus. Long-term outcomes on spatial hearing, speech recognition and receptive vocabulary after sequential bilateral cochlear implantation in children. Res Dev Disabil. 2015; 36: 328-337.

31. G Blatto-Vallee, RR Kelly, MG Gaustad, J Porter, J Fonzi. Visual-Spatial Representation in Mathematical Problem Solving by Deaf and Hearing Students. J Deaf Stud Deaf Edu. 2007; 12: 432-448.

32. J Dammeyer, C Lehane, M Marschark. Use of technological aids and interpretation services among children and adults with hearing loss. Int J Audiol. 2017; 56: 740-748.

33. J Dammeyer, M Marschark, I Zettler. Personality traits, self-efficacy and cochlear implant use among deaf and hard-of-hearing young adults. J Deaf Stud Deaf Edu. 2018; 23: 351-359.

34. LJ Spencer, M Marschark, E Machmer, A Durkin, G Borgna, C Convertino. Communication skills of deaf and hard-of-hearing college students: Objective measures and self-assessment. J Commun Disord. 2018; 75: 13-24.

35. CL Haukedal, OB Wie. Early literacy skills in children with simultaneous bilateral cochlear implantation between 5 and 18 months. Presentation to the 13th International Conference on Cochlear Implants and Other Implantable Auditory Technologies. Munich, Germany. 2014.

36. C Convertino, G Borgna, M Marschark, A Durkin. Word and world knowledge among deaf learners with and without cochlear implants. J Deaf Stud Deaf Edu. 2014; 19 : 471-483.

37. M Marschark, WG Kronenberger, M Rosica, G Borgna, C Convertino, A Durkin, et al. Social maturity and executive function among deaf learners. J Deaf Stud Deaf Edu. 2017; 22: 22-34.

38. M Marschark, D Walton, K Crowe, G Borgna, W Kronenberger. Relations of social maturity, executive function and self-efficacy among deaf university students. Deaf Edu Int. 2018; 20: 100-120.

39. T Boons, JP Brokx, JHM Frijns, Louis Peeraer, Birgit Philips, Anneke Vermeulen, et al. Effect of pediatric bilateral cochlear implantation on language development. Arch Pediatr Adolesc Med. 2012; 166: 28-34.

40. M Marschark, L Spencer, A Durkin, G Borgna, C Convertino, E Machmer, et al. Understanding language, hearing status and visual-spatial skills. J Deaf Stud Deaf Edu. 2015; 20: 310-330.

41. H Lane, RC Pillard, U Hedberg. People of the eye: Deaf ethnicity and ancestry. New York, NY: Oxford University Press. 2011.

42. M Marschark, C Morrison, J Lukomski, G Borgna, C Convertino. Are deaf students' visual learners? Learn Individ Differ. 2013; 25: 156-162.

43. M Marschark, A Paivio, LJ Spencer, A Durkin, G Borgna, V Convertino, et al. Don't assume deaf students are visual learners. J Phys Dev Disabil. 2017; 29: 153-171.

44. J Todman, E Seedhouse. Visual-action code processing by deaf and hearing children. Language Cognitive Processes. 1994; 9: 129-141.

45. M Marschark, I Zettler, J Dammeyer. Social dominance orientation, language orientation and deaf identity. J Deaf Stud Deaf Edu. 2017; 22: 269-277.

46. M Marschark, E Machmer, L Spencer, G Borgna, A Durkin, C Convertino. Language and psychosocial functioning among deaf learners with and without cochlear implants. J Deaf Stud Deaf Edu. 2018;

23: 28-40.

47. P Kushalnagar, TD Topolski, B Schick, TC Edwards, AM Skalicky, DL Patrick. Mode of communication, perceived level of understanding and perceived quality of life in youth who are deaf or hard of hearing. J Deaf Stud Deaf Edu. 2011; 16: 512-523.

48. B Schick, A Skalicky, T Edwards, P Kushalnagar, T Topolski, D Patrick. School placement and perceived quality of life in youth who are deaf or hard of hearing. J Deaf Stud Deaf Edu. 2013; 18: 47-61.

49. A Sharma, MF Dorman, AJ Spahr. A sensitive period for the development of the central auditory system in children with cochlear implants: implications for age of implantation. Ear Hear. 2002; 23: 532-539.

50. CM Conway, J Karpicke, EM Anaya, SC Henning, WG Kronenberger, DB Pisoni. Nonverbal cognition in deaf children following cochlear implantation: Motor sequencing disturbances mediate language delays. Dev Neuropsych. 2011; 36: 237-254.

51. A Kral, WG Kronenberger, DB Pisoni, GM O'Donoghue. Neurocognitive factors in sensory restoration of early deafness: a connectome model. Lancet Neurol. 2016; 15: 610-621.

52. S Nittrouer, A Caldwell-Tarr, JH Lowenstein. Working memory in children with cochlear implants: Problems are in storage, not processing. Int J Pediatr Otorhinolaryngol. 2013; 77: 1886-1898.

53. D Low, D Shipp, K Gordon, L Smith, K Smilsky, T Le, et al. Sequential bilateral pediatric cochlear implantation--Long-term usage of the second implant and factors predictive for its use. J Hear Sci. 2018; 8 : 109-109.

54. A Kral, A Sharma. Developmental neuroplasticity after cochlear implantation. Trends Neurosci. 2012; 35: 111-122.

55. KL Galvin, KC Hughes. Adapting to bilateral cochlear implants: Early post-operative device use by children receiving sequential or simultaneous implants at or before 3.5 years. Cochlear Implants Int. 2012; 13: 105-112.

56. M Marschark, M Rosica. Reading abilities of deaf college students: Has Elvis already left the building? In S. Easterbrooks & H. Dostal (Eds.), The Oxford handbook of deaf studies in literacy. New York, NY: Oxford University Press. 2020.

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