COGNITIVE PROCESSING IN CHILDREN USING COCHLEAR IMPLANTS: THE RELATIONSHIP BETWEEN VISUAL MEMORY, ATTENTION, AND EXECUTIVE FUNCTIONS AND DEVELOPING LANGUAGE SKILLS

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We performed this study to determine whether children using a cochlear implant performed differently from age- and gender-matched hearing aid users on 8 neuropsychological measures of visual memory, attention, and executive functioning. The study also examined whether differences in cognitive skills could account for some of the observed variance in speech perception, vocabulary, and language abilities of hearing-impaired children. In contrast to previous studies, our results revealed no significant cognitive differences between children who use a cochlear implant and children who use hearing aids. Partial correlation analysis indicated that the children's visual memory skills, ie, their recognition memory, delayed recall, and paired associative learning memory skills, correlated significantly with their language skills. When examined at a significance level of .01, attention and executive functioning skills did not relate to the children's developing speech perception, vocabulary, or language skills. The results suggested that differences in visual memory skills may account for some of the variance seen in the language abilities of children using implants and children using hearing aids.

KEY WORDS — attention, child, cochlear implant, cognition, hearing aid, language, memory, speech perception, vocabulary.

INTRODUCTION

Although many children who use a cochlear implant develop substantial improvements in their speech perception, word recognition, and language skills,¹⁻³ there is still great variation in the performance levels achieved. Factors such as implant experience and school setting are known to contribute to this variation; however, much of the variation remains unaccounted for.²⁻⁵ Recently, it has been proposed that the integrity of cognitive functions such as attention, memory, and executive functions may influence language acquisition after implantation.⁶

To date, most studies of nonlanguage functions in children using cochlear implants have investigated attentional functions. This focus relates to observed behavioral similarities between profoundly hearing-impaired children and children with disorders characterized by impulsiveness (eg, attention deficit hyperactivity disorder) and hyperactivity.⁷⁻¹⁰ Attentional functions are necessary for joint attention and turn-taking skills, which are two basic stages of language development. Attentional functions are also related to profoundly hearing-impaired children's reading

skills, conceptual thinking, and classroom performance.¹¹ The data to date suggest that children with a cochlear implant have superior attentional abilities as compared to profoundly hearing-impaired children who use either hearing aids or vibrotactile aids, although this difference may be moderated by maturation.^{12,13} For example, between the ages of 6 and 8 years, profoundly hearing-impaired children with and without cochlear implants performed the same on continuous performance tasks (CPTs), and both groups performed significantly worse than age-matched hearing controls.¹² However, the performance of another group of children with implants between 9 and 13 years of age was similar to that of normally hearing controls and was superior to that of profoundly hearing-impaired children without implants.¹² Similarly, although CPT performance improves with increasing age in all hearing-impaired children, the magnitude of the developmental trajectory in attentional performance was greatest in children 7 to 9 years of age who had implants.¹³ These studies included children who participated in either an oral or a total communication education program. Profoundly hearing-impaired children may develop a distribution of atten-

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tional processes different from that of normally hearing children, so that the visual system takes on dual roles: that of the ears, in attending to the surrounding environment for changes, as well as the usual one of the eyes, in focusing attention on a specific task.¹³ Children provided with additional auditory information via an implant may, in conjunction with developing attention skills, develop a more evenly distributed attention system that allows them to perform similarly to normally hearing children on visually assessed attention tasks.¹³ Observed differences between young versus older children with implants could be attributed to developing attentional processes that develop most rapidly between the ages of 5 and 7 years.¹⁴

Although these findings suggest that attention skills may differ in hearing-impaired children in relation to their access to auditory information, recent claims regarding the absence of a sound neuroscientific framework renders CPTs a poor model of attentional function.¹⁵ Furthermore, as Mitchell and Quittner¹⁶ noted, performance impairments on CPTs could arise from dysfunction of cognitive abilities other than attention. In addition to attending to the stimuli, CPTs also require that children remember which stimuli are targets and which are not, inhibit responses to nontargets, and select appropriate movement sequences at the appearance of the target. Impairments in any of these functions could give rise to poor performance on CPTs even if attentional processes were normal. Neuropsychological models consider movement sequencing, the inhibition of responses, and working memory as executive functions, all of which could also give rise to poor performance on CPTs even if attentional processes were normal.¹⁷ Therefore, although these studies suggest that attention skills may differ in children using a cochlear implant versus profoundly hearing-impaired children, a broader investigation of different cognitive processes is warranted. This investigation should use neuropsychological tests that are based on a sound neuroscientific framework, that have a demonstrated sensitivity to the effects of maturation, and that can be used to study cognition in children with limited linguistic skills because of their young age, profound hearing loss, or both. The current study compared a range of visual attentional, executive, and memory abilities between implant users and hearing aid users with a battery of nonverbal computer-administered neuropsychological tasks, relating their performance to their developing speech perception, vocabulary, and language skills.

METHOD

Subjects. The participants were drawn from an on-

going longitudinal language study and are described in detail elsewhere.¹ The sample consisted of 24 Nucleus cochlear implant users and 24 hearing aid users selected so that the two device groups would be matched overall for age and gender. Their ages ranged between 6.0 and 14.5 years, with an average of 9.39 years (SD, 2.26 years) for the entire sample. All participants attended an oral-aural educational setting, and all had prelingual hearing loss. No subjects were color-blind. To obtain suitable age and gender matches for the cochlear implant group as a whole, we included hearing aid users with various degrees of hearing loss; this group consisted of 11 children with a profound loss, 8 children with a severe loss, and 5 children with a moderate to severe loss.

Measures of Cognitive Abilities. The participants' developing attention, executive functions, and visual memory skills were assessed with the Cambridge Neuropsychological Test Automated Battery (CANTAB),¹⁸ a computed nonverbal battery of visually presented neuropsychological tests. The tests were administered on a touch-sensitive computer screen and were completed by the children within 4 months of their annual language assessment. The CANTAB battery consisted of 9 subtests. The Motor Reaction Time task was administered initially to all subjects, purely to allow them to gain familiarity with using a touch screen. The remaining 8 tests were divided under 2 group headings: 4 visual memory subtests and 4 tests of attention and executive functioning. The presentation order of these 2 subtest groupings was balanced across subjects, as was the ordering of the tests within the groupings. The majority of subjects completed the 8 subtests in 2 hour-long sessions conducted either at school or at home in a quiet room. Each subtest was demonstrated up to a set point with simple verbal instructions accompanied by some basic gestures, then restarted for the subject. The subjects were provided with feedback from the computer program and were given verbal encouragement by the experimenter as needed. All subjects were rewarded with stickers for their involvement. Each subtest will be described briefly. The reader is referred to the reports of Morris et al,¹⁹ Roberts and Sahakian,²⁰ and Luciana and Nelson²¹ for detailed explanations of each subtest.

Visual Memory Subtests. The Pattern and Spatial Recognition test assessed recognition memory skills for recently presented, nonverbal patterned and spatial stimuli from 2 items: 1 matching the target, the other a distractor. Percentage correct scores were calculated out of 24 items for pattern recognition and out of 20 for spatial recognition. The Delayed Matching to Sample (DMTS) test examined delayed matching of complex, nonverbal patterns from among 4

response choices. One response item matched the target, 2 matched either the colors or patterns of the target stimulus, and the remaining option acted as a distractor. The task included 3 delay conditions — 0-, 4-, and 12-second delays — as well as a simultaneous option, during which the target stimuli remained on the screen while the 4 response options were shown. Each condition was assessed 10 times. From this, total percentage correct scores were calculated for each condition. The Paired Associates (PA) test assessed the subject's ability to quickly learn associations between various patterns and their presentation location on the touch screen. The task increased in complexity from 1-pattern location to recall, to 2-, then 3-, 6-, and 8-pattern locations to retain and recall. The program recorded the number of trials required by the subject to place each pattern in its correct location, in addition to the overall number of completed levels and errors made.

Attention and Executive Functions Subtests. The Intradimensional/Extradimensional Set-Shifting Task (ID/ED) measured discrimination and reversal learning while the subject shifted his or her attention to changing visual stimuli. This task contained 9 stages of increasing difficulty. At each stage, the child was presented with 2 stimuli. By touching 1 stimulus, the subject received feedback from the computer as to whether they had selected the "correct" response. Once the child had identified the correct item, they were encouraged to continue selecting that item until, at an unspecified time, the rule changed. The task complexity increased, requiring the subject to apply a previously learned rule to new stimuli and finally to a previously ignored aspect of the stimulus. The program recorded the number of responses made by the subject to ascertain and complete each of the task levels and also the number of errors. The Spatial Span test measured memory for a figural sequence. White boxes presented randomly on the touch screen changed color in a particular sequence, which the subject was to repeat after a brief delay. This task increased in complexity, beginning with a 2-box sequence and continuing until the subject was unable to repeat the sequence correctly. The highest number of boxes correctly touched in sequence was recorded. The Spatial Working Memory (SWM) test measured working memory for spatial stimuli and required the use of mnemonic information to search effectively. The subject searched through boxes to locate hidden tokens. Each box contained only 1 token at some period during the trial. Throughout the test, the number of boxes to search through increased from 2 to 3, 4, 6, and finally 8 boxes; each task level had 4 trials. The subject's efficiency in searching for and recalling the location of previously obtained to-

kens was recorded, providing specific information on his or her strategy skills. The Tower of London test measures spatial planning and behavioral inhibition. The subjects were presented with 2 images of 3 colored balls arranged in "pockets." The "bottom" ball arrangement was slightly different from the "top" image arrangement. Using as few ball moves as possible, the subject was to match the bottom image to the top image. The task complexity increased from 2-move trials to 3-, 4-, and 5-move trials. The average number of moves required by the subject to complete each task level was recorded.

Language, Vocabulary, and Speech Perception Assessments. The data were obtained from the subject's annual language assessment performed for the ongoing language study. The reader is referred to Blamey et al¹ for detailed test descriptions and administration procedures. In brief, the children's open-set speech perception skills were assessed with the Bamford-Kowal-Bench (BKB) sentences list²² and the Consonant-Nucleus-Consonant (CNC) word lists,²³ which were administered twice in the auditory-alone condition. The calculated average number of key words repeated correctly from the 2 BKB assessments and the average number of words and average number of phonemes repeated from the CNC testing were included in the current analysis. The Northwestern University Children's Perception of Speech (NU-CHIPS)²⁴ closed-set consonant perception test was administered in the auditory-alone condition, and the percentage of items correctly identified was noted. Vocabulary was measured with the Peabody Picture Vocabulary Test-Revised (PPVT-R),²⁵ and the raw score was calculated. Depending on the subject's language age, they completed either the Clinical Evaluation of Language Fundamentals (CELF)-Preschool test, which contained 6 subtests,²⁶ or the CELF-3 test, which included 9 subtests.²⁷ In the current sample, 16 subjects with implants (mean age [$\pm$ SD], 8.76 $\pm$ 2.13 years) and 11 hearing aid users (8.28 $\pm$ 1.87 years) completed the CELF-Preschool test, and 8 children with implants (10.12 $\pm$ 1.8 years) and 13 hearing aid users (10.98 $\pm$ 1.94 years) completed the CELF-3 test. The CELF-3 subtests were selected on the basis of the subject's chronological age.

RESULTS

The following variables required transformation by methods suggested by Tabachnick and Fidell²⁸: CANTAB variables, DMTS 12-second delay condition, ID/ED Simple Discrimination and Compound Discrimination Reversal, Tower of London 2- and 3-move trials, SWM Total Number of Double Errors-Language Variables, NU-CHIPS, and the CELF

TABLE 1. AVERAGE CANTAB SUBTEST SCORES BY GROUP

	Subjects With Cochlear Implants			Subjects With Hearing Aids		
	Mean	SD	N	Mean	SD	N
Pattern Recognition (total % correct)	80.79	9.54	23	78.12	13.36	24
Spatial Recognition (total % correct)	65.65	13.84	23	69.37	12.54	24
Delayed Matching to Sample						
Simultaneous % correct	90.00	13.19	24	91.67	10.07	24
Average % correct on 0-s, 4-s, and 12-s trials	60.97	10.47	24	63.19	18.66	24
Paired Associates						
Total No. of levels completed	8.00	0.00	24	8.00	0.00	24
Total No. of levels completed on first trial	18.87	3.31	24	19.29	4.33	24
Total No. of errors across all trials	11.29	8.54	24	11.79	10.20	24
ID/ED						
No. of levels completed	8.00	1.84	24	8.33	1.37	24
No. of errors across all trials	17.22	9.73	18	16.95	6.87	19
Spatial Working Memory						
Total between-search errors	49.58	8.76	24	42.83	13.77	24
Total within-search errors	1.29	1.60	24	1.04	1.43	24
Total double-search errors	2.83	5.71	24	1.54	2.65	24
Strategy Score	39.33	2.41	24	38.25	3.11	24
Spatial Span	5.08	1.53	24	5.00	1.21	24
Tower of London (average No. of moves)						
2-move trial	2.08	0.28	24	2.00	0.00	24
3-move trial	3.85	0.83	24	4.06	1.40	24
4-move trial	6.35	0.96	24	6.06	1.15	24
5-move trial	7.98	1.39	22	8.34	1.84	23
Block 1	3.96	0.68	24	3.95	0.80	24
Block 2	7.59	0.96	23	7.56	1.10	23

CANTAB — Cambridge Neuropsychological Test Automated Battery, ID/ED — Intradimensional/Extradimensional Set-Shifting Task.

subtests Word Classes, Sentence Structure, Word Structure, and Basic Concepts.

Before the subjects' speech perception, vocabulary, and language scores were compared to their performance on the cognitive tests, independent sample *t*-tests were calculated to determine whether the two device groups differed on their cognitive performance. The results revealed equivalent performances by both groups on all measures of visual memory, attention, and executive functioning as assessed by the CANTAB. Table 1 presents the average scores achieved by each device group on the tests of cognition with untransformed values. Because previous research has identified cognitive differences based on the degree of hearing loss, the independent-samples *t*-tests were again calculated for all of the cognitive variables, including only matched profoundly hearing-impaired hearing aid users ($N = 9$) and subjects with implants ($N = 9$). The individual CANTAB results for the 18 children are reported in Table 2. Despite the small sample size, the results again revealed no significant differences between the two device groups. Because the two main device groups did not differ on any cognitive measure, the group results

will be collapsed for the remaining analyses.

Bivariate correlational analysis revealed numerous weak (.3) to strong (.7) relationships between the cognitive subtests and the various speech perception, vocabulary and language measures at significance levels from .05 to .001. Weak significant relationships at the level of .05 were identified between the NU-CHIPS, BKB, and CNC speech perception measures and some trials from various cognitive subtests; however, the speech perception tests did not correlate with any of the major cognitive measures and therefore will not be examined further.

Because cognitive performance increases with age,²¹ partial correlations were calculated between the identified significant bivariate correlations, with age at testing held as a constant. This analysis removed many significant correlations. Table 3 presents the significant partial correlations between the major cognitive measures and the remaining vocabulary and language tests. Significant bivariate correlation values that did not alter when age at testing was held constant are also included in Table 3. Because of the small sample size, correlations significant at

TABLE 2. AVERAGE CANTAB RESULTS FOR MATCHED SUBGROUPS OF CHILDREN USING COCHLEAR IMPLANT OR HEARING AIDS

	CI1	CI2	CI3	CI4	CI5	CI6	CI7	CI8	CI9	HA1	HA2	HA3	HA4	HA5	HA6	HA7	HA8	HA9
Pattern Recognition (total % correct)	100	75	87.5	83.3	79.2	75	100	70.8	83.3	54.2	75	75	87.5	75	79.2	58.3	95.8	100
Spatial Recognition (total % correct)	70	70	75	75	55	65	60	80	60	55	50	50	70	75	90	50	90	80
Delayed Matching to Sample																		
Simultaneous % correct	100	100	90	100	100	90	80	100	100	70	70	90	90	90	100	100	100	100
Average % correct on 0-s, 4-s, and 12-s trials	76.7	83.3	56.7	56.7	60	70	60	66.7	66.7	16.7	66.7	43.3	66.7	83.3	66.7	76.7	76.7	73.3
Paired Associates																		
Total No. of levels completed	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
Total No. of levels completed on first trial	6	6	6	5	3	6	5	7	6	5	5	5	7	5	6	5	6	7
Total No. of errors across all trials	7	5	21	7	26	6	8	2	9	25	19	9	7	26	8	5	4	3
ID/ED																		
No. of levels completed	9	9	9	9	4	9	9	9	9	7	9	9	9	9	9	9	5	9
No. of errors across all trials	6	25	10	11	28	8	24	18	17	36	19	25	29	32	10	12	31	9
Spatial Working Memory																		
Total between-search errors	51	45	53	56	60	48	57	58	42	56	45	57	49	32	40	38	49	42
Total within-search errors	0	0	1	0	5	0	0	5	0	2	2	2	0	0	0	2	0	0
Total double-search errors	0	0	1	1	28	2	0	5	0	2	2	4	3	0	5	0	1	0
Strategy Score	40	37	37	38	41	36	41	40	37	39	38	40	39	35	31	35	41	38
Spatial Span	8	5	4	5	3	5	4	8	4	3	5	5	5	4	5	5	8	6
Tower of London (average No. of moves)																		
2-move trial	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
3-move trial	3.5	3	5	3.5	3.5	4	3.5	4	4.5	3	7	4.5	5	3	3	4.5	3	3
4-move trial	5	7.75	7.75	5	6.5	5.75	5.5	5.5	7	6.5	6.5	7.25	7.25	4.5	6.5	5.75	4.5	5.5
5-move trial	8.5	7.25	7.75	F	8	7.25	7.5	5	9.75	8.75	8.75	12	7.5	6.75	6	8.5	8	8.5
Block 1	3.83	4.5	4.5	3.5	3.17	3.67	3.83	3.33	4.67	3.83	5	5.17	4.5	3.33	3	3.83	3	3.83
Block 2	7	7.17	8.17	F	8.33	7	6.67	5.67	8.67	8	8.17	9.4	8	5.83	7	7.83	7	7.17

F — failed to complete trials required to calculate score.

the .05 level are reported in the Table; however, because of the large number of correlations, only those with a significance value of .01 or less will be interpreted.²⁸ All correlations with vocabulary were significant only at the level of .05. When age at testing was held constant, no significant correlations remained between CELF and measures of attention and executive functioning. Significant partial correlations were found between the visual memory subtests and 6 of the CELF-3 subtests and 1 CELF-Preschool language test at the significance level of .01. Visual memory measures of recognition memory (Pattern Recognition), retention and delayed recall of complex information (DMTS), and paired associative learning (PA) related to the children's ability to respond to several of the CELF subtests. Calculated coefficients of determination values revealed that between 26% and 59% of the variance in the CELF language mea-

asures and CANTAB scores was shared.

DISCUSSION

This study differs from previous research in that only orally educated children were included in the sample, hearing aid users with various degrees of loss participated, and a wide range of neuropsychological tests were included, each based on sound neuroscientific theories. Comparison of children who used either a cochlear implant or hearing aids on various measures of attention, visual memory, and executive functioning revealed no significant differences, even when only profoundly hearing-impaired subjects were compared to matched implant users. The two device groups performed similarly on all tests of cognition — a finding suggesting that the cognitive skills of children with implants were not aided

TABLE 3. PARTIAL CORRELATION VALUES BETWEEN CANTAB SUBTESTS AND MEASURES OF VOCABULARY AND LANGUAGE SKILLS

	PPVT-R	C-3 WC ^a	C-3 FS	C-3 RS	C-3 SA	C-3 SR	C-3 SS ^a	C-3 WS ^a	C-3 C&D	C-3 WA	Pre LC	Pre RSC	Pre BC ^a	Pre FL
Pattern Recognition (% correct)			.60 ^d (17)		.65 ^{b,d} (16)	.57 ^d (18)	-.53 ^c (14)	-.49 ^c (15)		.67 ^{b,d} (12)				
Spatial Recognition (% correct)		-.43 ^c (20)	.49 ^c (17)		.50 ^c (15)		-.55 ^{b,c} (15)					.46 ^c (25)		
Delayed Matching to Sample														
Simultaneous (%)	.33 ^c (45)											.41 ^c (25)		
0-s delay (%)									.55 ^{b,d} (22)					
4-s delay (%)							-.52 ^c (15)							
12-s delay (%) ^a		-.57 ^d (21)	.47 ^c (18)					-.48 ^c (16)	.42 ^c (21)					
Total % correct		-.55 ^d (21)	.50 ^c (18)					-.52 ^c (16)	.71 ^c (21)					
Paired Associates														
6-pattern trial 1	.29 ^c (45)												-.51 ^{b,d} (26)	.39 ^c (25)
6-pattern trial 3													.57 ^d (25)	-.41 ^c (25)
8-pattern trial 2			.49 ^c (18)							.77 ^d (10)				
8-pattern trial 3		.54 ^d (21)	-.56 ^{b,d} (19)	-.54 ^{b,c} (19)										
Total No. first trial all correct		-.41 ^{b,c} (22)												
ID/ED Compound Discrimination— Revised (<i>t</i>) ^a											-.40 ^c (24)			
Spatial Working Memory														
Total within-search errors											-.42 ^c (24)			
Tower of London														
3-move trial (<i>t</i>) ^a											-.42 ^c (24)			
4-move trial (<i>t</i>)	-.32 ^c (45)									.61 ^c (10)				

Data are correlation values, with number of participants in correlation in parentheses.

PPVT-R — vocabulary, C-3 — CELF-3, WC — Word Classes, FS — Formulated Sentences, RS — Recalling Sentences, SA — Sentence Assembly, SR — Semantic Relationships, SS — Sentence Structure, WS — Word Structure, C&D — Concepts and Directions, WA — Word Associations, pre — CELF-Preschool, LC — Linguistic Concepts, RSC — Recalling Sentences in Context, BC — Basic Concepts, FL — Formulating Labels.

^aTransformed variable.

^bDenotes bivariate correlation value, as partial correlation value did not differ.

^c*p* < .05.

^d*p* < .01.

^e*p* < .001.

by the additional auditory information provided by the implant. In the current sample of orally educated children, no differences were identified between the two device groups in their performance on any attention measures, including their abilities to discriminate targets from nontargets (ID/ED) and to attend to detail (ID/ED and DMTS simultaneous condition).

Partial correlation analysis indicated that when age

at testing was held constant, attention and executive functioning did not relate to the children's speech perception, vocabulary, or language skills. Even after age at testing was held constant, visual memory skills were found to correlate significantly with the CELF. The creators of the CELF-3 recognize that memory skills are important for the subtests Concepts and Directions, Recalling Sentences, and Word Associations.²⁷ The current study demonstrates that

6 of the 9 CELF-3 subtests require memory skills to various extents. The ability to recognize previously presented patterned information, the retention of complex information for various durations, and the ability to make associations between patterns and locations correlated at a level between .51 and .77 at the significance level of .01 with the identified CELF-3 subtests and the CELF-Preschool measure.

Although it is clear that certain cognitive skills are present at the time that language is first acquired, the relationship and interplay between developing cognitive and language abilities is unknown. It may be that children with good visual memory skills are able to remember, attend to, and process language information better than children with poor cognitive skills. Alternatively, despite the nonverbal design of the cognitive subtests, performance on some tasks

may be aided by the use of verbal mnemonic strategies such as labeling abstract stimuli or acknowledging aloud a stimulus location. Children with better language skills may apply verbal strategies that effectively assist them to obtain higher scores on the CANTAB. Either way, confirmation of these findings with a larger sample could identify future directions for habilitation and educational programs.

The relationships identified in this study between language and cognition are important considerations in interpreting tests that assess the speech perception, vocabulary, and language abilities of children with implants and other hearing-impaired children. In particular, the relationships between visual memory skills and language should be examined further as a possible source of the unexplained variation in overall language performance.

REFERENCES

1. Blamey PJ, Sarant JZ, Paatsch LE, et al. Relationships among speech perception, production, language, hearing loss, and age in children with impaired hearing. *J Speech Lang Hear Res* 2001;44:264-85.
2. Fryauf-Bertschy H, Tyler RS, Kelsay DMR, Gantz BJ, Woodworth GG. Cochlear implant use by prelingually deafened children: the influences of age at implant and length of device use. *J Speech Lang Hear Res* 1997;40:183-99.
3. Svirsky MA, Robbins AM, Kirk KI, Pisoni DB, Miyamoto RT. Language development in profoundly deaf children with cochlear implants. *Psychol Sci* 2000;11:153-8.
4. Dowell RC, Blamey PJ, Clark GM. Potential and limitations of cochlear implants in children. *Ann Otol Rhinol Laryngol Suppl* 1995;104(suppl 166):324-7.
5. Sarant JZ, Blamey PJ, Dowell RC, Clark GM, Gibson WPR. Variation in speech perception scores among children with cochlear implants. *Ear Hear* 2001;22:18-28.
6. Pisoni DB. Cognitive factors and cochlear implants: some thoughts on perception, learning, and memory in speech perception. *Ear Hear* 2000;21:70-8.
7. Altshuler KZ, Deming WE, Vollenweider J, Rainer JD, Tendler R. Impulsivity and profound early deafness: a cross cultural inquiry. *Am Ann Deaf* 1976;121:331-45.
8. Harris MMH. Learning to look in the right place: a comparison of attentional behavior in deaf children with deaf and hearing mothers. *J Deaf Stud Deaf Educ* 1997;2:95-103.
9. Kelly DP, Kelly BJ, Jones ML, Moulton NJ, Verhulst SJ, Bell SA. Attention deficits in children and adolescents with hearing loss. A survey. *Am J Dis Child* 1993;147:737-41.
10. Paul PV, Jackson DW. Toward a psychology of deafness: theoretical and empirical perspectives. 1st ed. Needham Heights, Mass: Allyn and Bacon, 1993.
11. Quittner AL, Glueckauf RL, Jackson DN. Chronic parenting stress: moderating versus mediating effects of social support. *J Pers Soc Psychol* 1990;59:1266-78.
12. Quittner AL, Smith LB, Osberger MJ, Mitchell TV, Katz DB. The impact of audition on the development of visual attention. *Psychol Sci* 1994;5:347-53.
13. Smith LB, Quittner AL, Osberger MJ, Miyamoto R. Audition and visual attention: the developmental trajectory in deaf and hearing populations. *Dev Psychol* 1998;34:840-50.
14. Aslin RN, Smith LB. Perceptual development. *Annu Rev Psychol* 1988;39:435-73.
15. Maruff P, Pantelis C. Attention and neuropsychiatric disorders. *Curr Opin Neuropsychiatry* 1991;12:339-44.
16. Mitchell TV, Quittner AL. Multimethod study of attention and behavior problems in hearing-impaired children. *J Clin Child Psychol* 1996;25:83-96.
17. Diamond A. Guidelines for the study of brain-behavior relationships during development. In: Levin HS, Eisenberg HM, Benton AL, eds. *Frontal lobe function and dysfunction*. New York, NY: Oxford University Press, 1991:339-78.
18. Fray PJ, Robbins TW, Sahakian BJ. Neuropsychiatric applications of CANTAB. *Int J Geriatr Psychiatry* 1996;11:329-36.
19. Morris RG, Evenden JL, Sahakian BJ, Robbins TW. Computer-aided assessments of dementia: comparative studies of neuropsychological deficits in Alzheimer-type dementia and Parkinson's disease. In: Stahl SM, Iversen SD, Goodman EC, eds. *Cognitive neurochemistry*. Oxford, England: Oxford University Press, 1986:21-36.
20. Roberts AC, Sahakian BJ. Comparable tests of cognitive functions in monkey and man. In: Sahgal A, ed. *Behavioural neuroscience: a practical approach*. Oxford, England: IRL Press, 1993:165-84.
21. Luciana M, Nelson CA. The functional emergence of prefrontally-guided working memory systems in four- to eight-year-old children. *Neuropsychologia* 1998;36:273-93.
22. Bench RJ, Bamford J. Speech hearing tests and the spoken language of hearing-impaired children. London, England: Academic Press, 1979.
23. Peterson GE, Lehiste I. Revised CNC lists for auditory tests. *J Speech Hear Disord* 1962;27:62-70.
24. Elliot LL, Katz DR. Northwestern University Children's Perception of Speech (NU-CHIPS). St Louis, Mo: Auditec, 1980.

25. Dunn LM, Dunn LM. Peabody Picture Vocabulary Test—Revised. Circle Pines, Minn: American Guidance Service, 1981.
26. Semel E, Wiig EH, Secord WA. Clinical Evaluation of Language Fundamentals—Preschool. San Antonio, Tex: The Psychological Corp, 1992.
27. Semel E, Wiig EH, Secord WA. CELF-3: Clinical Evaluation of Language Fundamentals. 3rd ed. San Antonio, Tex: The Psychological Corp, 1995.
28. Tabachnick BG, Fidell LS. Using multivariate statistics. 3rd ed. New York, NY: Harper Collins, 1996.

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Title:

Cognitive processing in children using cochlear implants: the relationship between visual memory, attention, and executive functions and developing language skills

Date:

2002

Citation:

Surowiecki, V. N., Sarant, J., Maruff, P., Blamey, P. J., Busby, P. A., & Clark, G. M. (2002). Cognitive processing in children using cochlear implants: the relationship between visual memory, attention, and executive functions and developing language skills. *Annals of Otology, Rhinology and Laryngology*, 111(Suppl. 189), 119-126.

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