

Supplemental Material S3. Effects of age at implantation and cognitive functioning with age as continuous variable: Information provided by authors for cochlear implant (CI) users and correlation coefficients, if provided, as estimates of effect size.

Authors	N	M (SD) age (yrs) at implant	M (SD) age (yrs) at test	M (SD) duration of use (yrs)	Assessment/task	M (SD) ^a	Statistical analyses	Primary finding	r ^a
					Executive function				
Kronenberger, Pisoni, Henning, et al. (2013)	53	2.9 (0.34)	14.4 (4.1)	11.5 (3.2)	STM/WM: Forward digit span Backward digit span Visual digit span Forward spatial span Backward spatial span Design memory Picture memory	6.7 (2.7) 8.9 (2.9) 8.4 (3.1) 9.8 (2.6) 10.9 (2.4) 9.7 (2.5) 8.6 (2.8)	Correlation	Age at implantation unrelated to all 17 measures. Only one (Stroop task) significantly related to longer duration of use	NR
					Fluency-speed: Coding Coding copy Visual matching Retrieval fluency Pair cancellation	9.0 (2.7) 9.8 (3.0) 91.9 (18.1) 92.1 (13.6) 98.6 (11.1)	Correlation		
					Inhibition-concentration: Trail making-switching Stroop TOVA RT variability TOVA commissions TOVA omissions	9.2 (3.2) 48.7 (11.1) 85.7 (22.6) 83.5 (23.5) 76.9 (27.5)	Correlation		
Kronenberger et al. (2014)	64	2.96 (1.63)	15.0 (4.9)	12.1 (3.9)	STM/WM: Forward digit span Backward digit span Visual digit span Forward spatial span Backward spatial span	NR	Factor analysis, correlation	None of the 11 tasks significantly related to age at implantation or duration of use	NR
					Fluency-speed: Coding Coding copy Pair cancellation	NR	Factor analysis, correlation		

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					Inhibition-concentration: TOVA RT variability TOVA commissions TOVA omissions	NR	Factor analysis, correlation		
Beer et al. (2014)	24	1.67 (.66)	4.36 (1.14)	2.73 (1.14)	BRIEF performance: attention sustained memory for digits visual-motor integration	8.95 (2.24) 9.96 (2.50) 101.54 (17.31)	Correlation	None of the scales significantly related to age at implantation, fewer planning/ organization problems related to longer duration of use	-.58 ^b
					BRIEF parent-report measure: inhibitory control working memory plan/organize	59.32 (13.26) 60.55 (12.61) 52.68 (12.06)	Correlation		
Marschark, Spencer et al. (2015), Exp. 3	32	6.9 (5.1)	College age	NR	LEAF: comprehension factual memory attention processing speed vis-spatial organization sequential processing working memory problem-solving	4.22 (2.61) 4.16 (2.57) 4.34 (2.80) 4.66 (2.84) 2.91 (2.45) 3.53 (2.16) 4.92 (3.02) 4.09 (2.66)	Correlation	None of the scales significantly related to age at implantation	-.06 .04 -.16 .09 .01 -.05 -.10 .16
					Theory of mind (ToM)				
Rommel and Peters (2009)	30	2.9 (1.4)	7.5 (2.2)	4.5 (1.9)	5-item ToM scale Hiding-finding False photograph Complement memory	3.84 (0.70) 72.25% 93.5% 93.5%	Correlation	Age at implantation unrelated to performance in all tasks, longer duration of use significantly related to better performance on 5- item ToM scale,	.03 .14 .07 -.23

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								explanation of action task	
Ketelaar et al. (2012)	72	0.5–3.25	3.12 (1.12)	1.59 (1.06)	Understanding desires: Common (same) Uncommon (different)	0.31 (0.42) 0.20 (0.36)	Correlation	Age at implantation and duration of use unrelated to performance	.15, .28 .04, .22
Marschark et al. (2019)	46	6.62 (4.84)	College-age	NR	Sarcasm Second-order false belief Double bluff	0.61 (0.32) 0.35 (0.33) 0.59 (0.35)	Multiple regression	Age at implantation and duration of use unrelated to performance on all tasks	NR
					Other cognitive processes				
Willstedt- Svensson et al. (2004)	15	4.03 (.09)	7.68 (.11)	4.09 (.11)	Novel word learning Novel word retention Working memory	0.46 (0.30) 0.28 (0.23) 0.41 (0.30)	Correlation	Later implantation associated with better novel word learning and retention, age at implantation not related to working memory	.63 .72 “NS”
Fagan et al. (2007)	26	2.5 (1.3)	9.1 (2.5)	2.3 (1.4)	Hand imitation Fingertip tapping Manual motor seq. Visuomotor precision	10.6 (2.5) 10.7 (3.0) NR 7.4 (3.4)	Correlation	Only backward digit span associated with earlier implantation, no significant associations with duration of implant use	–.52 ^b
					Visual-spatial design copying task	8.0 (3.4)			
					Forward digit span Backward digit span	6.5 (2.0) 5.0 (2.8)			
					WRMT Word Attack subtest	101.0 (14.7)			
Conway et al. (2011)	25	1.77 (0.69)	7.51 (0.82)	3.13 (1.62)	Sequence learning: Learning Recall-grammatical Recall-ungrammatical	76.19% 50.0% 52.5%	Partial correlation	Age at implantation and duration of use only marginally	–.41, .41 NR, NR NR, NR

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								related to learning scores	
Kronenberger, Pisoni, Harris, et al. (2013)	66	3.8 (1.7)	7.6 (1.4)		WISC-III: Forward digit span Backward digit span	5.8 (2.9) 7.0 (2.6)	Repeated measures mixed- effects models on recall clusters	Age at implantation unrelated to memory spans at either age	NR
			11.4 (2.2)		WISC-III: Forward digit span Backward digit span	6.5 (2.9) 7.9 (3.2)			NR
Nicastri et al. (2014)	31	0.75–3.42	8.58 (2.15)	6.31 (1.74)	MEDEA Battery: Verbal metaphors Figured metaphors	2.7 (1.3) 3.3 (2.5)	Correlation	Age at implantation associated with better performance on all tasks except Situations	-.49 -.65
					MEDEA Battery: Implicit inference Situations inference	6.2 (2.9) 5.8 (1.8)	Correlation		-.67 -.26
Mancini et al. (2015)	31	0.75–3.42	8.58 (2.15)	6.31 (1.74)	MEDEA Battery: Referential communication	NR	Correlation	Neither age at implantation nor duration of use associated with performance	-.14, -.05
AuBuchon et al. (2015)	55	3.03 (1.67)	15.3 (4.9)	12.3 (3.9)	Verbal rehearsal speed	1.9 (0.4)	Correlation	Age at implantation and duration of use unrelated to performance	.04, -.07
					Perceptual encoding speed: Digit naming Color naming	83.5 (18.3) 57.3 (12.6)	Correlation	Age at implantation and longer duration of use associated with better performance	.47 .45
Marschark, Spencer, et al. (2015) Exp. 1	51	6.4 (4.8)	College-age	NR	Visual-spatial ability: WJ-III Pair Cancellation WJ-III Spatial Relations Embedded figures	91.02 (9.52) 89.25 (8.06) 37.83 (13.18)	Correlation	Age at implantation associated only with Spatial Relations scores	-.21 -.41 -.25
Marschark, Spencer, et al. (2015) Exp. 2	33	7.2 (5.7)	College-age	NR	Corsi blocks: Highest span Total trials	6.52 (1.25) 13.39 (3.35)	Correlation	Age at implantation unrelated to test performance	-.06 .02

Authors	N	M (SD) age (yrs) at implant	M (SD) age (yrs) at test	M (SD) duration of use (yrs)	Assessment/task	M (SD) ^a	Statistical analyses	Primary finding	r ^a
Marschark, Spencer, et al. (2015) Exp. 3	32	6.9 (5.1)	College-age	NR	GAMA: Matching Analogy Sequences Construction	9.88 (2.94) 11.31 (3.13) 11.84 (2.90) 9.94 (2.85)	Correlation	Age at implantation significantly related only to Sequences scores	-.14 -.13 -.42 -.17
De Hoog et al. (2016)	39	1.75	8.0	6.17	Memory for words	3.82 (1.55)	Correlation	Age at implantation unrelated to performance on any tasks	-.01
					Memory for sentences	2.33 (1.95)			-.04
					Forward digit span	5.15 (1.86)			.01
					Backward digit span	2.85 (2.03)		.08	
					Non-word repetition test	6.57 (4.74)			-.03
Talli et al. (2018)	15	2.61 (0.85)	6.65 (1.23)	4.05 (1.18)	Digit span task	3.93 (.80)	Kendall's Tau-b	Neither age at implantation nor duration of use related to performance on any tasks	-.03, .26
					Non-word repetition task	.39 (.16)	Kendall's Tau-b		-.23, .34
					Rapid picture naming task (accuracy)	87.27 (26.89)	Kendall's Tau-b		.01, -.39
					Raven's Progressive Matrices	65.33 (22.55)	Kendall's Tau-b		.17, .04
Klein et al. (2018)	20	1.9 (0.90)	9.4 (1.5)	3.7–10.2	Simon task Serial reaction time task	NR	Growth curve analysis	Age at implantation unrelated to task performance	NR
Torkildsen et al. (2018)	34	1.47 (0.81)	10.46 (1.56)	8.99 (.13)	Implicit sequence learning	57.7 (11.6)	Partial correlation	Age at implantation unrelated to task performance	.03
Borgna et al. (2018)	33	6.03 (4.15)	19.0 (1.20)	NR	Numerical estimation	9.96 (5.34)	Multiple regression	Age at implantation unrelated to performance on any task	NR
					Real-world estimation	1.80 (1.08)			
					ACT mathematics subtest	19.0 (3.74)			

Note. NR = not reported; STM/WM = short-term memory/working memory; TOVA = Test of Variables of Attention; RT = response time; BRIEF = Behavior Rating Inventory of Executive Function; LEAF = Learning, Executive, and Attention Functioning; WRMT = Woodcock Reading Mastery Test; WISC-III = Wechsler Intelligence Scale for Children–Third Edition; MEDEA = Italian Pragmatic Language Skills test; WJ-III DRB = Woodcock-Johnson III Diagnostic Reading Battery; GAMA = General Ability Measure for Adults.

^aMultiple *M*s (*SD*s) listed correspond to the order of assessments/tasks; multiple correlation coefficients listed correspond to the order of primary findings.

^bCorrelation coefficients for significant effects only.

References

- AuBuchon, A. M., Pisoni, D. B., & Kronenberger, W. G. (2015). Short-term and working memory impairments in early-implanted, long-term cochlear implant users are independent of audibility and speech production. *Ear and Hearing, 36*(6), 733–737. <https://doi.org/10.1097/AUD.000000000000189>
- Beer, J., Kronenberger, W. G., Castellanos, I., Colson, B. G., Henning, S. C., & Pisoni, D. B. (2014). Executive functioning skills in preschool-age children with cochlear implants. *Journal of Speech, Language, and Hearing Research, 57*(4), 1521–1534. https://doi.org/10.1044/2014_JSLHR-H-13-0054
- Borgna, G., Convertino, C., Walton, D., Marschark, M., Crowe, K., & Trussell, J. (2018). Numerical and real-world estimation abilities of deaf and hearing college students. *Deafness and Education International, 20*, 59–79. <https://doi.org/10.1080/14643154.2018.1437238>
- Conway, C. M., Pisoni, D. B., Anaya, E. M., Karpicke, J., & Henning, S. C. (2011). Implicit sequence learning in deaf children with cochlear implants. *Developmental Science, 14*, 69–82. <https://doi.org/10.1111/j.1467-7687.2010.00960.x>
- De Hoog, B. E., Langereis, M. C., van Weerdenburg, M., Keuning, J., Knoors, H., & Verhoeven, L. (2016). Auditory and verbal memory predictors of spoken language skills in children with cochlear implants. *Research and Developmental Disabilities, 57*, 112–124. <https://doi.org/10.1016/j.ridd.2016.06.019>
- Fagan, M. K., Pisoni, D. B., Horn, D. L., & Dillon, C. M. (2007). Neuropsychological correlates of vocabulary, reading, and working memory in deaf children with cochlear implants. *Journal of Deaf Studies and Deaf Education, 12*, 461–471. <https://doi.org/10.1093/deafed/enm023>
- Ketelaar, L., Rieffe, C., Wiefferink, C., & Frijns, J. (2012). Does hearing lead to understanding? Theory of mind in toddlers and preschoolers with cochlear implants. *Journal of Pediatric Psychology, 37*, 1041–1050. <https://doi.org/10.1093/jpepsy/jss086>
- Klein, K. E., Walker, E. A., & Tomblin, J. B. (2018). Nonverbal visual sequential learning in children with cochlear implants: Preliminary findings. *Ear and Hearing. https://doi.org/10.1097/AUD.0000000000000564*
- Kronenberger, W. G., Beer, J., Castellanos, I., Pisoni, D. B., & Miyamoto, R. T. (2014). Neurocognitive risk in children with cochlear implants. *JAMA Otolaryngology—Head & Neck Surgery, 140*, 608–615. <https://doi.org/10.1001/jamaoto.2014.757>
- Kronenberger, W. G., Pisoni, D. B., Harris, M. S., Hoen, H. M., Xu, H., & Miyamoto, R. T. (2013). Profiles of verbal working memory growth predict speech and language development in children with cochlear implants. *Journal of Speech, Language, and Hearing Research, 56*, 805–825. [https://doi.org/10.1044/1092-4388\(2012/11-0356\)](https://doi.org/10.1044/1092-4388(2012/11-0356))
- Kronenberger, W. G., Pisoni, D. B., Henning, S. C., & Colson, B. G. (2013). Executive functioning skills in long-term users of cochlear implants: A case control study. *Journal of Pediatric Psychology, 38*, 902–914. <https://doi.org/10.1093/jpepsy/jst034>
- Mancini, P., Dincer D'Alessandro, H., Guerzoni, L., Cuda, D., Ruoppolo, G., Musacchio, A., . . . Nicastrì, M. (2015). Adequate formal language performance in unilateral cochlear implanted children: Is it indicative of complete recovery in all linguistic domains? Insights from referential communication. *International Journal of Pediatric Otorhinolaryngology, 79*, 598–604. <https://doi.org/10.1016/j.ijporl.2015.02.003>
- Marschark, M., Edwards, L., Peterson, C., Crowe, K., & Walton, D. (2019). Understanding theory of mind in deaf and hearing college students. *Journal of Deaf Studies and Deaf Education, 24*, 104–118. <https://doi.org/10.1093/deafed/eny039>
- Marschark, M., Spencer, L., Durkin, A., Borgna, G., Convertino, C., Machmer, E., Kronenberger, W. G., & Trani, A. (2015). Understanding language, hearing status, and visual–spatial skills. *Journal of Deaf Studies and Deaf Education, 20*, 310–330. <https://doi.org/10.1093/deafed/env025>
- Nicastrì, M., Filipo, R., Ruoppolo, G., Viccaro, M., Dincer, H., Guerzoni, L., . . . Mancini, P. (2014). Inferences and metaphoric comprehension in unilaterally implanted children with adequate formal oral language performance. *International Journal of Pediatric Otorhinolaryngology, 78*(5), 821–827. <https://doi.org/10.1016/j.ijporl.2014.02.022>
- Rommel, E., & Peters, K. (2009). Theory of mind and language in children with cochlear implants. *Journal of Deaf Studies and Deaf Education, 14*, 218–236. <https://doi.org/10.1093/deafed/enn036>
- Talli, I., Okalidou, A., & Tsalighopoulos, M. (2018). The relation between short-term memory and vocabulary skills in Greek children with cochlear implants: The role of hearing experience. *First Language, 38*, 359–381. <https://doi.org/10.1177/0142723717749073>

Supplemental material, Marschark et al., "Effects of Age at Cochlear Implantation on Learning and Cognition: A Critical Assessment," *AJSLP*, https://doi.org/10.1044/2019_AJSLP-18-0160

Torkildsen, J. V. K., Arciuli, J., Haukedal, C. L., & Wie, O. B. (2018). Does a lack of auditory experience affect sequential learning? *Cognition*, *170*, 123–129.

<https://doi.org/10.1016/j.cognition.2017.09.017>

Willstedt-Svensson, U., Löfqvist, A., Almqvist, B., & Sahlén, B. (2004). Is age at implant the only factor that counts? The influence of working memory on lexical and grammatical development in children with cochlear implants. *International Journal of Audiology*, *43*, 506–515.

<https://doi.org/10.1080/14992020400050065>