

Executive Function and Language in Deaf Children

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The relationship between language and executive function (EF) and their development in children have been the focus of recent debate and are of theoretical and clinical importance. Exploration of these functions in children with a peripheral hearing loss has the potential to be informative from both perspectives. This study compared the EF and language skills of 8- to 12-year-old children with cochlear implants ($n = 22$) and nonimplanted deaf children ($n = 25$) with those of age-matched hearing controls ($n = 22$). Implanted and nonimplanted deaf children performed below the level of hearing children on tests assessing oral receptive language, as well as on a number of EF tests, but no significant differences emerged between the implanted and nonimplanted deaf groups. Language ability was significantly positively associated with EF in both hearing and deaf children. Possible interpretations of these findings are suggested and the theoretical and clinical implications considered.

Deafness, Cochlear Implants, and Language Development

Spoken language development in severely or profoundly deaf children of hearing parents is typically delayed compared with their hearing counterparts. Cochlear implantation in young children has been as-

sociated with faster rates of language development postimplant compared with preimplant (e.g., Bollard, Chute, Popp, & Parisier, 1999; Dawson, Blamey, Dettman, Barker, & Clark, 1995; McDonald-Connor, Hieber, Arts, & Zwolan, 2000), as well as with faster rates of language development amongst cochlear implanted (CI) children than amongst those using conventional hearing aids (Svirsky, Robbins, Kirk, Pisoni, & Miyamoto, 2000). Cross-sectional research also suggests an advantage for CI children over those with hearing aids, in terms of the perception of auditory stimuli in real-life situations, speech intelligibility, and language skill (e.g., Geers & Moog, 1994; Lejeune & Demanez, 2006; Nicholas, 1994; Tomblin, Spencer, Flock, Tyler, & Gantz, 1999; Van Lierde, Vinck, Baudonck, De Vel, & Dhooge 2005). However, not all studies contrasting CI with hearing-aided (HA) children's language skills have established that CI children perform better than age-matched hearing aid users (e.g., Blamey et al., 2001; Eisenberg, Kirk, Martinez, Ying, & Miyamoto 2004; Peterson, 2004). There are a number of possible reasons for this, including difficulties in achieving good matching of cases between groups, and the impact of changes in cochlear implant and hearing aid technology over recent years, which makes it difficult to compare studies across time. In addition, there are great individual variations in language outcomes following cochlear implantation, associated with differences in nonverbal cognitive abilities, etiology of deafness, age at onset of deafness, age at

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implantation, and length of implant experience (Fryauf, Tyler, Kelsay, & Gantz, 1997; Harrison et al., 2001; Manrique, Cervera-Paz, Huarte, & Molina, 2004).

Deafness, Language, and Executive Function

The construct of executive function (EF) encompasses the organizational and self-regulatory skills required for goal-directed, nonautomatic behavior. It has been variously described as including planning, initiating, monitoring, and flexibly correcting actions according to feedback; sustaining as well as shifting attention; controlling impulses and inhibiting prepotent but maladaptive responses; selecting goals and performing actions that may not lead to an immediate reward, with a view to reaching a longer term objective; holding information in mind whilst performing a task (working memory); and creatively reacting to novel situations with nonhabitual responses (Hughes & Graham, 2002; Norman & Shallice, 1986; Shallice & Burgess, 1991b; Welsh & Pennington, 1988).

Recent theoretical conceptualizations of EF suggest that it is not a unitary function, but encompasses a range of dissociable skills, such that it is possible for an individual to fail on some executive tasks whilst succeeding on others (Baddeley, 1998; Burgess, 1997; Garavan, Ross, Murphy, Roche, & Stein, 2002; Miyake et al., 2000). Different EF skills may follow independent developmental pathways, some of which may be more strongly associated with language (and thus more affected by the consequences of deafness) than others.

This issue has been examined in high-functioning autistic children, where impairments in both language and EF are characteristic of the condition. In this population, not all EF components appear to be compromised (although inconsistent findings in the literature make it difficult to draw firm conclusions). There is some evidence that children with autism perform worse on EF tasks that encourage verbal encoding of rules, suggesting that language does play an important role in at least some of the EFs (Russell, Saltmarsh, & Hill 1999). Landa and Goldberg (2005) comment that the language/EF relationship could be bidirectional, with impaired EF also having a negative impact on the development of language. However, their comparison of high-functioning autistic children

and matched controls suggested no reliable relationship between EF and language impairments (including figurative language comprehension and complex sentence formation) or verbal IQ. These authors thus conclude that language and EF may be dissociable. Unfortunately, the use of a sample from a clinical population where deficits in both domains are essentially diagnostic markers makes it difficult to interpret the findings. In addition, using language tasks known to tap into functional deficits does not shed light on the relationship between language and EF generally. The language deficits in deaf children, which typically reflect delayed rather than disordered functioning, are potentially useful in clarifying the relationship between language and EF because these children's difficulties are secondary to a peripheral cause.

Electroencephalogram evidence (Wolff, Kammerer, Gradner, & Thatcher, 1989; Wolff & Thatcher, 1990) has shown differences in the neural organization of the bilateral frontal cortex (closely linked to EF abilities) and the left temporofrontal area (involved in expressive language) of deaf and hearing children. A weaker development of these cortical areas might be reflected in both poorer language and poorer EF in deaf children. No studies have examined EF comprehensively in deaf children, although a number have included tests that assess some EF components as part of wider investigations. There is some evidence for impaired attention in deaf children compared with their hearing peers (e.g. Khan, Edwards, & Langdon, 2005; Mitchell & Quittner, 1996), although Tharpe, Ashmead, and Rothpletz (2002) found no differences in *visual* attention skills. Planning and problem solving have also been found to be poorer in deaf children compared with hearing children (Das & Ojile, 1995; Marschark & Everhart, 1999). Finally, CI children's performance on both verbal and visual working memory tasks remained below normally hearing (NH) children's performance in a study by Cleary, Pisoni, and Geers (2001). In addition, Pisoni and Geers (2000) found a positive correlation between working memory (as measured by forward and backward auditory digit span) and language ability in CI children. The same results were obtained by Pisoni and Cleary (2003) using a working memory task involving visual rather than auditory stimuli.

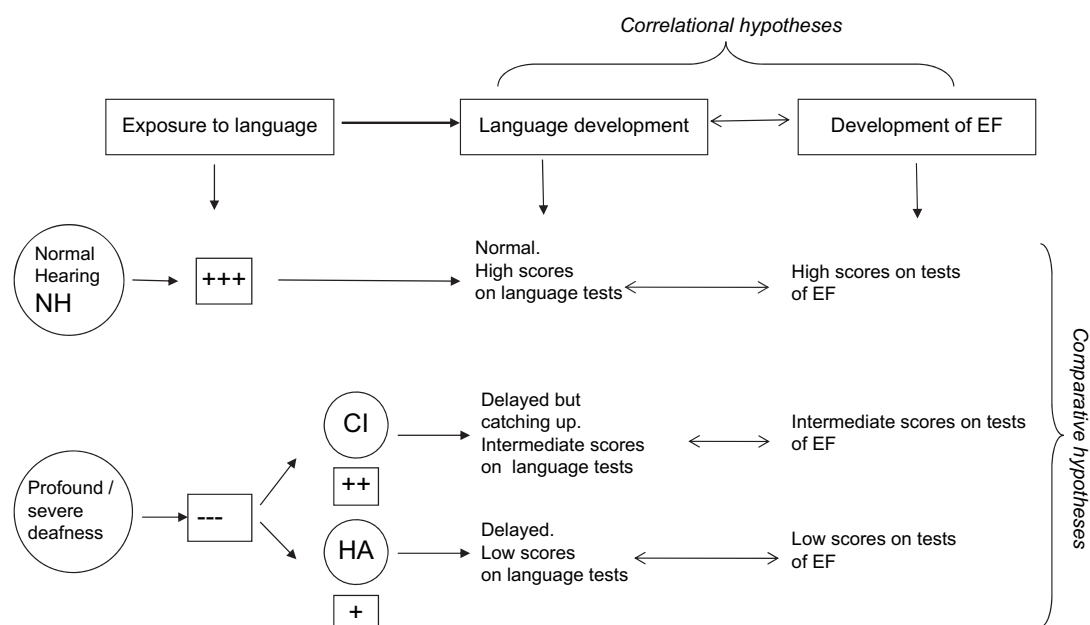


Figure 1 Relationships between hearing and cognition: hypothesized differential performance on tests of language and EF across groups of normally hearing, implanted and nonimplanted deaf children.

If the development of some EF skills is related to language ability, and if cochlear implants positively impact on the language acquisition of deaf children, then CI children's performance on at least some EF tasks should be superior to that of nonimplanted deaf children. Exploring this issue, Surowiecki et al. (2002) compared memory, EF, and language skills of CI and HA children. They found significant correlations between language and EF ability (which disappeared after controlling for age), but found no significant differences in EF performance between the HA and CI groups. Unfortunately, their research did not include a control group of NH children, so it remains to be ascertained how the HA and CI groups would have performed on EF tasks relative to age-matched NH children.

We consider the development of language and that of EF to closely interact. Given the wealth of research examining the impact of deafness on the language acquisition of deaf children, and the effects of cochlear implants on their language development, it is surprising that limited research has been carried out on implanted and nonimplanted deaf children's EF, and that there are such few studies explicitly examining the relationship between language skills and EF in deaf

children. Many of the existing studies have examined deaf children's performance on only a few of the EF subcomponents, and none of these studies have included CI, HA, and NH children. The aims of our study were thus twofold: firstly, to compare the EF and language skills of implanted and nonimplanted prelingually deaf children born to hearing parents with that of age-matched NH children. Secondly, to explore the association between language and EF in these groups. The following questions were addressed: is deafness associated with deficits in some EF skills and, if so, which ones? Are any EF deficits identified linked to delayed language development, or are they independent of language attainments? It was hypothesized that NH children would perform better than deaf children in tests of language and in some tests of EF, particularly on those assessing EF skills more closely linked to language. CI children were expected to outperform HA children on those same EF and language tests. It was also hypothesized that EF and language skills would be correlated. A model depicting these relationships is given in Figure 1. The model is necessarily simplistic and does not attempt to portray the relationship between outcomes and factors such as age at implantation or previous hearing levels.

Methods

Design

A descriptive, between-groups comparative design (Meltzoff, 2001), where performance scores across different groups are compared to test for potential group differences, was used to contrast EF and language performance across the CI, HA, and NH children. The role of language in EF performance was explored by controlling for language achievement in the between-groups analyses. The correlations between language and EF task performance were examined in a relationship design (Meltzoff, 2001), where the strength of the association between pairs of variables is analyzed.

Participants

Sixty-nine children were assessed: 22 deaf children with cochlear implants (CI group; mean age = 9.8 years, $SD = 1.6$), 25 deaf children who used conventional hearing aids (HA group; mean age = 10.8 years, $SD = 1.5$), and 22 NH children (NH group; mean age = 10.2 years, $SD = 1.3$). All but three children completed all the tests in the neuropsychological battery.

CI children were recruited through the Cochlear Implant Programme in a London teaching hospital; NH and HA children were recruited through schools within southern England. To reduce between-group variability, HA and NH children were recruited from the schools attended by the CI children. All children were aged between 8 and 12 years, and the mean length of implant use was 6.4 years ($SD = 2.0$). Children with learning disabilities or significant developmental delays (as identified by local educational services or on the basis of testing by the implant team clinical psychologist) were excluded. Children in the deaf groups were born to hearing parents and were prelingually deaf (hearing loss either congenital or acquired before 2.5 years of age). Table 1 provides details on the etiology of deafness for the CI and HA children.

Deaf children had a sensorineural loss in the moderate (41–70 dB), severe (71–95 dB), or profound (95+ dB) ranges (British Society of Audiology, 1988). Table 2 provides data on the number of chil-

Table 1 Etiologies of deafness

Etiology	CI	HA
Congenital, unknown cause	10	13
Connexin 26	4	0
Genetic, nonsyndromic	4	1
Waardenburg syndrome	1	2
Pendred syndrome	0	1
Sticklers syndrome	0	1
Acquired, unknown cause	1	0
Acquired, head injury	0	1
Premature birth/birth asphyxia	0	4
Meningitis	2	1
Unspecified	0	1

dren within each of these categories (there are three and four missing data points for the CI and HA groups, respectively), and the mean and standard deviation of hearing loss levels for the two deaf groups. The hearing loss figures represent the unaided pure tone average threshold in dB hearing loss in the better ear, taken from the most recent available audiograms, averaged over the frequencies of 500, 1000, 2000, and 4000 Hz.

Eighty-six percent of the CI children and 56% of the HA children were orally educated; the remaining children used Total Communication (a combination of spoken English and key signs, using English rather than British Sign Language [BSL] grammatical structures), with the exception of one HA child who predominantly used BSL. All children were judged able to understand simple, orally presented test instructions.

Table 3 compares the demographic and medical characteristics of the three groups. ANOVA, chi-square, and *t*-tests were employed as appropriate to the type of data.

Table 2 Number of children in each category of unaided hearing loss, and unaided pure tone average loss in better ear

Group	<i>n</i>	Number of children			PTA in better ear	
		Mod. HL	Sev. HL	Prof. HL	<i>M</i>	<i>SD</i>
CI	19	0	0	19	114.8	6.7
HA	21	4	10	7	83.6	18.7

Note. PTA, pure tone average loss; Mod. HL, moderate hearing loss (41–70 dB); Sev. HL, severe hearing loss (71–95 dB); Prof. HL, profound hearing loss (95+ dB).

Table 3 Comparison of demographic variables between groups

Variable	Groups	Test statistic (<i>df</i>)	<i>p</i>
Age	CI, HA, NH	$F(2, 66) = 2.37$	$p = .10$
Gender	CI, HA, NH	$\chi^2(2) = 1.07$	$p = .59$
Socioeconomic status	CI, HA, NH	$\chi^2(2) = 2.07$	$p = .36$
Older siblings ^a	CI, HA, NH	$\chi^2(2) = 0.87$	$p = .65$
Handedness	CI, HA, NH	$\chi^2(2) = 4.78$	$p = .09$
Ethnicity ^b	CI, HA, NH	$\chi^2(2) = 2.76$	$p = .25$
Etiology ^c	CI, HA	$\chi^2(1) = 1.29$	$p = .43$
Age at diagnosis	CI, HA	$t(40) = -0.86$	$p = .39$
Average hearing loss (unaided)	CI, HA	$t(25.6) = 7.15$	$p < .001$
Years with current device	CI, HA	$t(43) = -3.94$	$p < .001$
Age when fitted with device	CI, HA	$t(43) = 3.01$	$p = .004$

Note. Unless otherwise stated, *p* is two tailed.

^aThis variable was classed into two groups, distinguishing between children who had one or more older siblings and those who had no older siblings.

^bEthnicity was collapsed into two main categories (white vs. nonwhite) in order to avoid having cells with expected counts smaller than five.

^cAlthough etiology was collapsed into two main categories (acquired vs. congenital), there were still some cells with expected counts smaller than five. Fisher's exact significance test was therefore used.

Notably, the CI and HA groups were not matched on average level of unaided hearing loss (CI: $M = 114.8$, $SD = 6.7$; HA: $M = 83.6$, $SD = 18.7$); on the number of years during which children had been wearing their current device (CI: $M = 6.4$, $SD = 2.0$; HA: $M = 8.7$, $SD = 2.0$), or the age at which they were fitted with the device (CI: $M = 3.5$, $SD = 1.3$; HA: $M = 2.0$; $SD = 1.9$). The implications of these differences are explored in the Discussion section.

Measures

The measures employed were chosen to assess a variety of EFs, because they required minimal spoken instructions and typically nonverbal responses, and allowed for sufficient practice trials to ensure understanding of task requirements.

Measures of EF. As the construct of EF encompasses a range of skills that may be functionally independent, several tests were used to assess different EFs, including tests of EF skills that are more linked to language (planning, set shifting, working memory, impulse regulation), and tests of EF skills that are less dependent on language (visual attention).

Tower from the NEPSY battery. The child is required to move three colored balls to target positions on three sticks in a prescribed number of moves, fol-

lowing a set of rules (two balls cannot be moved at once, a ball cannot be moved from underneath another ball), within given time constraints (Korkman, Kirk, & Kemp, 1998b). The Tower test assesses planning, problem solving and self-monitoring (deciding on a strategy to complete the task within the required number of steps; keeping track of the number of executed moves and adjusting movement plans to suit test constraints), working memory (holding in mind the test rules and the devised overall strategy), impulse regulation (withholding the impulse to violate the rules), and inhibition (inhibiting intuitive moves in order to perform moves in the counter-intuitive direction relative to the end-state goal) (Bull, Epsy, & Senn, 2004; Lezak, Howieson, Loring, Hannay, & Fischer, 2004; Welsh, Satterlee-Cartmell, & Stine, 1999). The "Tower" score comprises the number of occasions in which the child reaches the goal state in the required number of moves, within the given time constraints. The second dependent variable used in this test is the number of rule violations (e.g., how many times a child tries to move two balls at once).

Visual attention from the NEPSY battery. The child is required to scan two arrays of pictures and locate targets (cats in the first set of pictures and two specific faces in the second set) from among distractors (other objects and animals in the first set; similar looking faces in the second set) (Korkman et al.,

1998b). This test is scored by combining the child's accuracy (number of targets correctly identified minus number of errors) and the total time taken. Poor performance may be related to difficulties with sustained or with selective visual attention (Korkman, Kirk, & Kemp 1998a).

Design fluency from the NEPSY battery. In this test (Korkman et al., 1998b), a series of small squares containing identical sets of dots are presented (structured arrays of dots in the first set and unstructured arrays in the second set). The child is required to generate as many different drawings as possible, in 1 min, by connecting the dots in each square. The number of unique designs is scored as a measure of creativity; the number of identical designs measures the child's inability to avoid repetitions.

Knock and tap from the NEPSY battery. This test (Korkman et al., 1998b) assesses self-regulation and the ability to inhibit immediate impulses evoked by visual stimuli when such impulses conflict with test instructions: the child initially learns a pattern of motor responses (the opposite action to that carried out by the experimenter) and must inhibit the impulse to imitate the experimenter (if the experimenter knocks on the table, the child is to tap with his or her hand flat on the table and vice versa). After learning the first response set, the child must switch to a different response set (e.g., if the experimenter knocks on the table, the child should place the side of his or her fist on the table; if the experimenter taps, the child should do nothing) and must maintain the new rules in working memory, still inhibiting the tendency to copy the experimenter. The number of correct responses is scored as a measure of inhibition.

Day–Night and One–Two tasks. These two tests (based on Diamond & Taylor, 1996 and Diamond, Kirkham, & Amso, 2002) assess inhibition skills. In the Day–Night test, children are presented with a card containing sun and moon pictures. They must say “day” in response to sun pictures and “night” in response to moon pictures. The rules are then inverted, and children are required to hold the new set of rules in mind while inhibiting the tendency to name the

pictures in the congruent way. The One–Two test is similar, but with the numbers 1 and 2 presented visually in random order. The Day–Night and One–Two test scores were amalgamated to yield two overall measures: the time (in seconds) elapsed for completion of both tasks and the aggregated number of errors.

Card Sorting test from the D-KEFS battery. Children were presented with two sets of six randomly mixed cards displaying a stimulus word (from a very basic vocabulary) and various perceptual features (Delis, Kaplan, & Kramer, 2001). They were asked to sort the cards in each set into two three-card groups according to as many categorization rules as possible. The cards within each set could be grouped into a maximum of eight target sorts: three sorts based on verbal semantic information from the words on the cards (e.g., items of clothing/parts of the body) and five sorts based on visual–spatial features or patterns on the cards (e.g., cursive writing/printed font). The D-KEFS Card Sorting test measures concept formation skills, creativity and the ability to initiate problem solving (generating different sorting rules), cognitive flexibility (switching between the verbal and perceptual domains, switching between different sorting concepts within each of the domains), and perseveration (avoiding repetition of previously used sorting strategies). The number of correct sorts, the number of repeated sorts, and the number of attempted (whether correct or incorrect) sorts are scored.

Measures of language.

The British Picture Vocabulary Scale (BPVS), Long Form. The BPVS (Dunn, Dunn, Whetton, & Pintilie 1982) measures receptive vocabulary and has been previously used with deaf children (e.g., Blamey & Sarant, 2002; Hughes, 1998; Surowiecki et al., 2002). Because poor hearing may interfere with phonological processing, participants in the current study were asked to repeat each word prior to pointing to a response. When children did not hear a word, it was pronounced again, always making lipreading as easy as possible.

The Test for Reception of Grammar—version 2. The Test for Reception of Grammar—version 2 (TROG-2) (Bishop, 2003) is a measure of receptive grammar. It

consists of 80 items with a multiple-choice format: each item comprises four pictures, one of which corresponds to the short sentence spoken by the examiner, whereas the rest are lexical and/or grammatical foils.

Procedure

Written parental consent and oral consent from the children were obtained prior to data collection. Children were all tested by the first author. Four CI children were seen at Great Ormond Street Hospital as it was possible to fit testing times around their scheduled audiology review. The remaining children were tested at school. Testing lasted for approximately 1.5 hr, during which children were offered a break and a drink of water. Only two children asked for a short break; all others were happy to carry through testing with no interruptions. Children were given stickers of stars and smiley faces to reward their efforts and sustain motivation. The same number of stickers was offered to each child, across the three groups.

Standardized test instructions were used for all tests except for the BPVS (see above). Care was taken to give instructions with maximum clarity, making sure that children could see the tester's lip movements, and that their attention was appropriately focused. The same instructions were given to all participants. Tests were always administered in the same order, to ensure that potential test-order effects would be constant across groups.

Results

Treatment of Data

Scores on all variables were examined for normality of distribution. Square root transformations and other methods suggested by Tabachnick and Fidell (1996) converted to normality three variables found to be positively skewed and two negatively skewed variables (the means and standard deviations of the original, nontransformed variables are reported). Two variables (raw number of rule violations in the Tower test and raw number of repetitions in the D-KEFS Card Sorting test) remained positively skewed.

Performance across the three groups was compared for each of the EF and language tests. First,

a series of separate one-way, between-subjects analyses of covariance (ANCOVAs) (or Kruskal–Wallis analyses where assumptions of normality were not met) were carried out for each language and EF variable as the tests are thought to measure different (although linked) abilities. Group (CI, HA, or NH) was the independent factor. In this first set of ANCOVAs, age was entered as a covariate because of the strong relationship between age and test performance, especially during childhood and adolescence.

Where a main effect of group emerged in one of the analyses comparing the three groups of children, this was followed up with post hoc comparisons to identify between which groups the differences lay. Three sets of ANCOVAs were run for variables where a significant group effect had emerged, whilst Kruskal–Wallis analyses were followed up by Mann–Whitney analyses. Planned comparisons were not carried out because we wanted to test for differences in all the possible pair combinations. To minimize the chances of Type I errors, Bonferroni corrections were applied to the post hoc analyses, giving a new significance level of .017 (0.05/3). Finally, where significant differences emerged in the three-group ANCOVAs, the analyses were performed again, this time covarying language attainment as well as age.

Intergroup Comparisons of Children's Performance on Language Tests

Table 4 provides the descriptive statistics for each group of children on the two language tests. As hypothesized, a significant effect of group emerged on children's raw score on the BPVS ($F(2, 65) = 29.89$, $p < .001$) and the TROG-2 ($F(2, 65) = 32.74$, $p < .001$). Follow-up ANCOVAs with Bonferroni corrections revealed that, as expected, NH children scored significantly higher than CI children ($F(1, 41) = 50.93$, $p < .001$) and also significantly higher than HA children ($F(1, 44) = 49.79$, $p < .001$) on the BPVS. The same was true for the TROG-2 where again NH children scored significantly higher than CI children ($F(1, 41) = 73.76$, $p < .001$) and significantly higher than HA children ($F(1, 44) = 51.47$, $p < .001$). Contrary to expectations, there were no differences between the implanted and nonimplanted deaf groups on the

Table 4 Children's performance on the BPVS and TROG-2

Group	<i>n</i>	BPVS raw scores		BPVS standard scores		TROG-2 raw scores		TROG-2 standard scores	
		<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
CI	22	54.1	17.4	67.0	16.8	7.9	4.0	66.7	15.7
HA	25	56.0	24.0	62.3	18.5	9.0	4.8	70.2	16.9
NH	22	90.9	17.8	98.1	13.0	16.2	2.0	100.7	8.5

Note. Standard scores based on a population $M = 100$, $SD = 15$.

BPVS ($F(1, 44) = 0.21$, $p = .65$) or the TROG-2 ($F(1, 44) = 0.17$, $p = .68$).

Intergroup Comparisons of Children's Performance on Tests of EF

Table 5 provides the descriptive statistics for each group of children on each of the EF variables, as well as the results of the one-way, between-subjects ANCOVAs (with age entered as a covariate) and Kruskal–Wallis analyses.

The hypothesis that children's EF test performance would differ across groups held true for some, but not all, of the EF tests. A Kruskal–Wallis analysis on the number of rule violations in the Tower test revealed significant intergroup differences on this variable. With age as the only covariate, the ANCOVAs also revealed significant differences on children's performance on the Day–Night/One–Two task combined (both in terms of the time taken to complete the tasks and in terms of the total number of errors) and on the Knock and Tap task. Intergroup differences likewise emerged in the number of total

attempted sorts and the number of correct sorts on the Card Sorting test. No significant intergroup differences emerged on the Design Fluency test raw score or on the number of design repetitions. In addition, no differences were apparent on the number of repeated sorts on the Card Sorting test, the raw number of correct items on the Tower test, or on the Visual Attention test.

Follow-up analyses for the three pairs of groups were carried out to compare children's performance on those EF tests where a significant intergroup difference had emerged on the three-group comparisons. Results of these follow-up analyses are provided in Table 6. Because Bonferroni corrections were applied to these follow-up analyses, only those results with a $p < .017$ were considered significant.

After applying Bonferroni corrections, the CI and NH groups differed significantly on the number of rule violations in the Tower test, on the Day–Night/One–Two task, and on the number of correct sorts and number of attempted sorts in the D-KEFS Card Sorting test. As predicted, CI children performed

Table 5 Children's performance on the EF tests: descriptive statistics and results of comparison analyses

Variable	CI		HA		NH		<i>F</i> value (<i>df</i>) or Kruskal–Wallis χ^2 (<i>df</i>)	<i>p</i>
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>		
Tower	12.5	2.7	12.8	2.6	13.9	1.6	$F(2, 65) = 2.10$	$p = .13$
Tower rule violations	2.3	2.4	1.7	2.6	0.2	0.5	$\chi^2(2) = 15.93$	$p < .001$
Visual Attention	19.9	5.0	18.5	5.9	19.8	4.7	$F(2, 65) = 1.64$	$p = .24$
Design Fluency	22.2	7.8	25.7	9.8	26.8	8.2	$F(2, 65) = 1.49$	$p = .23$
Design Fluency repetitions	1.6	2.8	1.5	1.6	1.4	2.2	$F(2, 65) = 0.69$	$p = .51$
Knock and Tap	27.8	1.6	27.1	2.8	28.7	1.4	$F(2, 65) = 3.61$	$p = .03$
Day–Night/One–Two time	207.6	36.8	196.1	58.1	174.1	33.8	$F(2, 64) = 3.89$	$p = .03$
Day–Night/One–Two errors	11.2	5.6	10.1	6.0	4.8	4.6	$F(2, 64) = 10.85$	$p < .001$
Card Sorting correct sorts	5.6	3.4	5.5	3.5	9.6	2.6	$F(2, 65) = 17.31$	$p < .001$
Card Sorting repeated sorts	1.0	1.0	1.0	1.3	0.4	0.7	$\chi^2(2) = 5.52$	$p = .06$
Card Sorting attempted sorts	7.9	2.6	7.5	3.0	10.3	2.3	$F(2, 65) = 10.22$	$p < .001$

Note. The CI group comprised 22 children in all EF tests except the Day–Night/One–Two tests, where $n = 21$. The HA and NH groups comprised, respectively, 25 and 22 children for all EF tests.

Table 6 Pairwise comparisons on children's EF test performance

Variable	<i>F</i> value (<i>df</i>) or Mann–Whitney <i>U</i>	<i>p</i>
Tower rule violations		
CI versus NH	$U = 86.5; N_1 = 22; N_2 = 22$	$p < .001$
HA versus NH	$U = 172.0; N_1 = 25; N_2 = 22$	$p = .008$
CI versus HA	$U = 210.0; N_1 = 22; N_2 = 25$	$p = .15$
Knock and Tap		
CI versus NH	$F(1, 41) = 4.02$	$p = .05$
HA versus NH	$F(1, 44) = 5.80$	$p = .02$
CI versus HA	$F(1, 44) = 1.17$	$p = .29$
Day–Night/One–Two time		
CI versus NH	$F(1, 40) = 10.39$	$p = .003$
HA versus NH	$F(1, 44) = 4.92$	$p = .03$
CI versus HA	$F(1, 42) = 0.02$	$p = .90$
Day–Night/One–Two errors		
CI versus NH	$F(1, 40) = 18.78$	$p < .001$
HA versus NH	$F(1, 44) = 11.76$	$p = .001$
CI versus HA	$F(1, 43) = 0.32$	$p = .57$
Card Sorting correct		
CI versus NH	$F(1, 41) = 20.29$	$p < .001$
HA versus NH	$F(1, 44) = 31.52$	$p < .001$
CI versus HA	$F(1, 44) = 1.46$	$p = .23$
Card Sorting attempted		
CI versus NH	$F(1, 41) = 10.14$	$p = .003$
HA versus NH	$F(1, 44) = 19.62$	$p < .001$
CI versus HA	$F(1, 44) = 1.61$	$p = .21$

Note. The CI group comprised 22 children in all EF tests except the Day–Night/One–Two tests, where $n = 21$. The HA and NH groups comprised, respectively, 25 and 22 children for all EF tests.

below the level of NH children on all these measures (see Table 5). HA and NH groups also significantly differed on most of these EF variables. In particular, HA children performed significantly worse (see Table 5) than NH children on the number of rule violations in the Tower test, on the Day–Night/One–Two task (in terms of the total number of errors), and on the number of correct sorts and number of attempted sorts in the D-KEFS Card Sorting test. The differences between HA and NH children on the completion time for the Day–Night/One–Two tasks, as well as on the Knock and Tap test, were only significant prior to applying Bonferroni corrections. No significant differences were found between the CI and HA groups on any EF variable. When language skill, as represented by BPVS scores, was entered as a covariate in addition to age, all the EF differences lost their significance (Day–Night/One–Two time: $F(2, 63) = 0.02$, $p = .98$; Day–Night/One–Two errors: $F(2, 63) = 1.76$, $p = .18$; Knock and Tap: $F(2,$

$64) = 1.88$, $p = .16$; Card Sorting attempted sorts: $F(2, 64) = 0.78$, $p = .46$; Card Sorting correct sorts: $F(2, 64) = 1.63$, $p = .21$). When the TROG-2, which was highly correlated with the BPVS ($r = 0.88$, $p < .001$), was entered as an independent covariate the same findings were obtained. Similarly, results were not altered when a “receptive language composite” covariate, which combined the TROG-2 and BPVS scores, was used.

Relationship between Children's Language and EF Skills

The individual variables in the language and the EF test domains were grouped together, respectively, into a global language and a global EF score by converting each raw score to a z-score and adding the z-scores together. This was done to reduce the total number of correlations conducted and thereby reduce the risk of Type I errors. The new, global variables were normally distributed. Parametric analyses of the association

between the global language and global EF variables, with age partialled out, were performed. Pearson's product moment correlation coefficients (Pearson's r) are reported. Correlations were carried out separately for the groups of hearing (NH) and deaf children (CI and HA groups combined). The CI and HA groups were combined because they were not significantly different.

As expected, significant positive correlations emerged between the overall language score and the overall EF score, both for the deaf children ($r(41) = 0.59, p < .001$) and the NH group ($r(19) = 0.52, p = .01$). Therefore, as hypothesized, better performance on the language tests was associated with better performance on the EF tests for all children, even after age had been partialled out. For the deaf (combined CI and HA) group, the correlation between the overall language score and the overall EF score was recalculated, this time partialling out not only age but also the average level of hearing loss, and the number of years during which children had been equipped with their current device. The same pattern of results emerged, with a highly significant positive correlation between language performance and overall performance on the EF tests ($r(30) = 0.71, p < .001$).

Discussion

This study hypothesized that language ability is associated with the development of some EF skills and that differences in language ability across groups of hearing and deaf children would predict differences in some of their EF skills. The hypotheses were confirmed inasmuch as: (a) significant differences emerged in the language performance of hearing versus deaf children, (b) significant differences across the hearing and deaf groups were also apparent on a number of EF tests (these differences disappeared once language skill was taken into account), and (c) high correlations between language and EF ability were obtained. However, there were no differences between the implanted and non-implanted deaf groups.

Language

NH children had better receptive vocabulary and grammar than CI and HA children, supporting the

critical dependence of aural–oral language development on spoken language exposure. Given that cochlear implants facilitate access to sound, CI children were expected to have better language than their nonimplanted deaf peers, but this was not the case. It is interesting to speculate why.

The CI and HA groups were not well matched for degree of hearing loss, number of years using their current device, or age at device fitting. Previous studies with better group matching along these variables did obtain language performance differences between CI and HA children (Geers & Moog, 1994; Lejeune & Demanez, 2006; Tomblin et al., 1999; Van Lierde et al., 2005). Level of deafness (even within the profound range) and length of device use have been shown to impact deaf children's language acquisition (Boothroyd, Geers, & Moog, 1991; Geers, Nicholas, & Sedey, 2003). Age at implantation is another crucial variable (Fryauf et al., 1997; Harrison et al., 2001; Kirk, Miyamoto, Ying, Perdew, & Zuganelis, 2000; Miyamoto, Kirk, Svirskey, & Sehgal, 1999), with children implanted before 2 years progressing at significantly faster rates than those implanted after 2 years (Manrique et al., 2004). All our CI children were implanted after the age of 2, whereas many of the HA children had been fitted with their hearing aid before this age. Nicholas and Geers (2006) report that, when cochlear implants are fitted before 3 years of age, the best predictors of language development are pre-implant aided hearing thresholds and duration of cochlear implant use. We were unable to take into account the level of aided hearing in the better ear because this information was not available for the HA group. Importantly, Nicholas and Geers (2006) also showed that the amount of preimplant intervention with a hearing aid was not related to language outcomes at 3.5 years of age, which suggests that, in our study, use of hearing aids prior to implantation is unlikely to have significantly positively impacted on language development. It is therefore possible that CI children did not outperform HA children because they had started off with a greater disadvantage (given their more severe losses) and had had less time to catch up on language development (given the shorter time of device use in this group).

This study's cross-sectional design allowed no determination of the developmental trajectories of children's competencies. Language skill differences between the CI and HA groups might have become apparent later, when more time had elapsed for CI children to benefit from implantation. Alternatively, differences might have been present earlier, but not maintained. Many studies where CI versus HA differences emerged included younger children (Geers & Moog, 1994; Nicholas, 1994), whereas no differences were obtained in a study with older participants (Peterson, 2004). Next, there are great individual variations in benefit from implantation (Le Normand, Ouellet, & Cohen, 2003; Pisoni & Geers, 2000), and this variability may have obscured true differences. Finally, there may have been a selection bias for HA children: to facilitate test administration, teachers may have inadvertently selected those HA children with superior language skills.

Executive Function

Significant intergroup differences emerged in children's performance on many, but not all, of the EF tests. According to fractionated models of EF (Baddeley, 1998; Garavan et al., 2002; Miyake et al., 2000), it is possible for some EF skills to be preserved whereas others are impaired (Burgess, 1997; Shallice & Burgess, 1991a). We interpret our results by grouping EF tests together according to the particular skills on which they apparently predominantly rely.

Impulse control, inhibition, and working memory. Taking the child's age into account, significant differences were revealed between hearing and deaf children's performance on the combined Day–Night/One–Two task, the Knock and Tap test, and the number of rule violations in the Tower test. All these tests reflect children's impulse control and inhibition skills (Diamond & Taylor, 1996; Korkman et al., 1998a). Within different response modalities (verbal vs. motor), the Day–Night, One–Two, and Knock and Tap tests all require children to inhibit the tendency to respond automatically, because they must give a nonprepotent response. Children in the CI and HA groups were slower on the Day–Night/One–Two task than chil-

dren in the NH group. Although greater impulsivity might be expected to lead to *shorter* response latencies, deaf children had *longer* response latencies because they probably had to exert more effort to inhibit dominant responses, thus needing more time. CI and HA children's greater difficulties inhibiting prepotent responses were reflected in their higher error rates. Meichenbaum and Goodman (1971) found that impulsive children exercise less verbal control over motor behavior, and use private speech in a less instrumental fashion, than do reflective children; consequently, it has been argued that language (especially self-talk) may facilitate impulse regulation (Harris, 1978; Mayberry, 1992).

The Day–Night/One–Two and Knock and Tap tasks also place demands on working memory. Bull, Massie, and Brown (2003) and Gerstadt, Hong, and Diamond (1994) argue that it is probably the combination of inhibition and working memory skills that makes the Day–Night task particularly difficult. More rule violations in the Tower test may likewise reflect children's difficulties inhibiting the tendency to move two balls at once (a response that often facilitates reaching the desired end state, but violates test rules), as well as poor working memory (keeping the test rules in mind). Deaf children's poor performance on the Day–Night/One–Two, Knock and Tap, and Tower tests (in terms of rule violations) is congruent with previous research pointing to their difficulties with working memory (Cleary et al., 2001; Dawson, Busby, McKay & Clark, 2002; Lichtenstein, 1998; Todman & Seedhouse, 1994) and with inhibition and impulse control (Altshuler, 1978; Mitchell & Quittner, 1996; O'Brien, 1987; Shlesinger & Meadow, 1972).

Zelazo (2000) and Frye, Zelazo, and Palfai (1995) suggest that language plays a crucial role in the development of working memory and goal setting: given its representational nature, language allows the decoupling of action from reality, so that goal-directed behavior can be guided by action plans that are internally stored in working memory, rather than by immediate environmental triggers. Intergroup differences on our EF tasks disappeared when language was covaried. Deaf children's disinhibition and poor working memory may thus have been linked to poorer language: it may have been harder for them to use internal speech

or “self-talk” to hold test rules in working memory and to plan and guide motor behavior.

Cognitive set shifting. Zelazo (2000) highlights the links between grammar and set-shifting skills (moving from one cognitive framework to another): shifting across sorting dimensions in Card Sorting tasks, for instance, may rely on the development of “rule-embedded reasoning” (the ability to formulate “if-then rules”, such as “if playing the color game, then if red card, then place here”). Significant intergroup differences emerged on the Card Sorting test in our study. Surowiecki et al. (2002) contrasted CI versus HA children’s set-shifting abilities using the intra/extradimensional shift test in the CANTAB battery and found no significant differences across the two groups. The current study also found no differences in cognitive set shifting of implanted versus nonimplanted deaf children but did find a difference in the skills of hearing versus deaf children. The fact that intergroup differences disappeared when language was covaried suggests that language underpinned the set-shifting difficulties we found.

Verbal versus spatial creativity. The Design Fluency test, as well as the number of “attempted” (rather than correct) sorts on the Card Sorting test, can both be considered to assess cognitive initiation and creativity (Delis et al., 2001; Korkman et al., 1998a). Significant differences emerged between the hearing and the deaf children in the number of total attempted sorts but not on the Design Fluency test. There is an important difference in terms of the language loadings of the two tasks: card sorting relies on verbal ability (inasmuch as both verbal and perceptual categories can be labeled), whereas Design Fluency is primarily a visual-spatial task. Thus, deaf children’s verbal creativity appeared to be impaired relative to hearing children, but their visual-spatial creativity was not. Previous research on nonverbal creative thinking has produced inconsistent findings, in terms of fluency, elaboration, originality, and flexibility (early studies are reviewed by Marschark, 1993). A recent study by Fawzy (2006) has not fully clarified the situation but, on balance, the evidence seems to indicate equivalent nonverbal creative abilities between deaf and hearing

children or, in some cases, superior abilities amongst the deaf children. The intergroup differences on the Card Sorting task disappeared when language was covaried, once again suggesting that deaf children’s difficulties with this EF task were secondary to their language difficulties.

Planning and problem solving. Deaf children’s planning and problem-solving abilities, as assessed by correct items on the Tower test, were equivalent to those of their hearing peers. Earlier research using other assessment methods found differences between hearing and deaf groups (Das & Ojile, 1995; Marschark & Everhart, 1999). These studies relied on evaluation procedures that heavily loaded on children’s verbal processing. The target identification task of Marschark and Everhart (1999) required children to verbally formulate questions in a planned, logical sequence. Although the planning test of Das and Ojile (1995) would superficially appear to be a perceptual task (figuring out a color sequence on the basis of limited information), it also significantly tapped children’s verbal skills: at each step, children were told how many chips of the right color they had laid in the correct position and had to use verbal mental calculation to solve the problem. In contrast, the Tower test can be regarded as a more visually based measure of planning: using self-talk to work out movement sequences may help (e.g. “if I put the red ball here, I can put the blue ball there”), but verbally based planning is not an essential task requirement as solutions can be worked out using purely visuo-spatial skills. It may therefore be that deaf children’s planning and problem-solving abilities are compromised in tasks with a strong verbal component but not in those that rely less heavily on language and more on visuo-perceptual skills.

Attention. No significant intergroup differences emerged on the Visual Attention test of the NEPSY battery, which assesses children’s visual selective attention. Previous studies on deaf children’s visual attention have yielded mixed results. Mitchell and Quittner (1996) reported that deaf 6- to 14-year olds performed worse than NH controls on tests of sustained and selective attention. This is consistent with the finding of Khan et al. (2005) that CI and HA

children's performance on the Sustained Attention subscale of the Leiter-R was inferior to that of their hearing peers. However, when controlling for age and nonverbal intelligence, Tharpe et al. (2002) failed to find differences in hearing versus deaf children's performance on visual attention tests. The mean Visual Attention test scores of the NH, CI, and HA groups in the present sample were also comparable when age was taken into account.

In sum, our results confirm a link between language and EF, as the two were positively correlated for both hearing and deaf children, even after age had been partialled out. In line with fractionated models of EF, the results suggest that language may be linked to the development of only *some* EFs because deaf children's EF difficulties were not universal: CI and HA children's performance was below that of NH children only on tests assessing EF skills that were apparently more reliant on language skill. It was also found that, when receptive language was covaried, the initial intergroup differences in children's performance on the EF tests no longer reached statistical significance. It is concluded that deaf children's deficits in EF are not an intrinsic consequence of deafness but are linked to delayed language acquisition (in the same way that deaf children's delays in Theory of Mind development are associated with delayed language—see Courtin, 2000; Figueras-Costa & Harris, 2001; Peterson, 2004).

Methodological Issues

Some constraints limit the generalization of the present findings across the overall population of severely to profoundly deaf 8- to 12-year-old children. Firstly, children were recruited from within a relatively restricted geographical area, mostly including urban and suburban settings within and around London. Secondly, children suspected to suffer from significant developmental delays were excluded: this made the current sample less representative of the overall population of CI and HA children as specific learning disabilities, developmental delays, and complex needs are frequent concomitants of deafness (Fortnum, Marshall, & Summerfield, 2002). Finally, only first-

generation deaf children were included: our results therefore do not address the cognitive abilities of deaf children born to deaf parents. Previous research has shown that the cognitive development of second-generation deaf children who learn sign language as their native language is comparable to that of their hearing peers and superior to that of first-generation deaf children, at least in some domains (Bandurski & Galkowski, 2004; Conrad & Weiskrantz, 1981; Sisco & Anderson, 1980; Spencer, Deyo, & Grindstaff, 1990). The current study could thus be expanded to include a group of deaf native signers.

Conclusions

Differences were found between hearing and deaf children in some areas of executive functioning, particularly where the tests assessed EF skills that were more closely linked to language ability. From a theoretical perspective, the findings support the interdependence of language and EFs but also suggest that EFs themselves may be dissociable.

It is argued that the behavioral manifestations of EF difficulties observable in deaf children are unlikely to be a consequence of deafness per se but rather result from the language delays that are a consequence of the deafness. The finding that deaf children do experience deficits in EF (regardless of whether these difficulties are dependent on language delay) has both clinical and educational implications. Clinical assessment of deaf children should take into account their potential difficulties with EF and the ways in which this might interfere with their performance in other areas, including both the cognitive and social domains. Deficits in EF may be manifest in difficulties organizing thoughts for writing tasks, organizing materials or possessions for lessons or homework, organizing time, and implementing lengthy verbal instructions. Poorer EF skills may also show behaviorally through difficulties in play and in social situations, such as turn taking in games and in conversation. Behavioral management and classroom teaching may be facilitated by using learning strategies that emphasize visual cues and place minimal demands on language, so that deaf children's EF abilities can be maximized. In addition, enhancing particular aspects of language use, such as

teaching deaf children to practice and implement self-talk strategies for planning and problem solving, may help them make better use of their existing EF skills and develop them more fully.

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