Consonant and sign phoneme acquisition in signing children following cochlear implantation

Brenda C Seal[1,2], Debra B Nussbaum[3], Kate A Belzner[1,4], Susanne Scott[3], Bettie Waddy-Smith[3]

[1]Department of Communication Sciences and Disorders, James Madison University, Harrisonburg, VA, USA, [2]Department of Hearing, Speech, and Language Sciences, Gallaudet University, Washington, DC, USA, [3]Cochlear Implant Education Center (CIEC), Laurent Clerc National Deaf Education Center of Gallaudet University, Washington, DC, USA, [4]Eaton-Peabody Laboratory, Massachusetts Eye and Ear Infirmary, USA

Deaf children from signing programs provide new opportunities to investigate changes in sign and speech acquisition following cochlear implantation. We describe the acquisition of sign *phonemes* (location, movement, and handshapes) and speech phonemes (consonants) in 22 implanted children with diverse demographic backgrounds. New consonants and new sign phonemes emerged in developmentally expected sequences and with statistically significant correlation coefficients between cumulative number of new consonants and new sign phonemes over time. Regression slopes from plotted *z* scores revealed a burst in consonant and sign growth in early months post-implant, with continuous but plateauing growth over time. These results and documentation of developmental levels of sign and speech phoneme trajectories should be helpful to other researchers and to clinicians working with signing children who have cochlear implants.

Keywords: Pediatric cochlear implants, Consonant acquisition, Sign phoneme (location, movement, and handshape) acquisition

Many young deaf children who undergo cochlear implant surgery come from early intervention programs that promote sign language or the use of signs as lexical complements to spoken language input. Hearing parents of deaf children are not likely to know sign language or have fluency in any of the sign systems that are paired with spoken languages, yet they may learn signs to communicate with their child and allow professionals fluent in sign language to use it as visual communication support during early months of impoverished auditory input and in later speech–language–hearing sessions. Early intervention professionals who use sign language with deaf babies, toddlers, and preschoolers generally assure hearing parents that signing will not deter their child's speech acquisition, and may even encourage it.

This clinical assurance comes from evidence that early gestural communication is an important link to spoken language acquisition in typically developing infants (e.g. Bates *et al.*, 1979; Butcher and Goldin-Meadow, 2000; Goodwyn *et al.*, 2000; Iverson and Fagan, 2004; Iverson and Thelen, 1999; McEachern and Haynes, 2004; Rowe and Goldin-Meadow, 2009; Watt *et al.*, 2006). Infant gestures are described as the natural bridge between comprehending and producing language. A baby's response to 'wave bye-bye' at 6–9 months of age coincides with other social gestures that represent early receptive and expressive communication. The *give, show, point, reach*, *clap*, and *wave gestures* typically emerge by the end of a child's first year; they can also be assessed for developmental communication milestones (e.g. *MacArthur Communicative Development Inventories*; Fenson *et al.*, 1992).

Watt *et al.* (2006) reported on the gesture inventories of 160 of 1000 typically developing children in a FIRST WORDS Project that tracked children between 6 and 24 months of age for 5 years. The children's inventories of gestures and consonants early in the second year of life – around 13–15 months – correlated highly with their inventories of words at 18–20 months of age. Gesture and consonant inventories also correlated significantly with each other, suggesting 'significant continuity' in gestures, speech, and words in the second year of language acquisition (p. 1230).

The synchronous acquisition of manual and vocal gesture in babies has also received considerable

Correspondence to: Brenda C Seal, James Madison University, Harrisonburg, VA, USA; Department of Hearing, Speech and Language Sciences, Gallaudet University, 800 Florida Ave., NE, Washington, DC 20002, USA. Email: brenda.seal@gallaudet.edu

DOI 10.1179/146701010X12711475887351

attention. Butcher and Goldin-Meadow (2000) reported that a baby's first symbolic gestures are independent of vocalization, but become synchronized with vocal productions over time. This combined production – a child's point to and spoken production of 'ball', for example – facilitates the two-word stage and continues into the synchronous manual gesture–spoken language combination common to adult communication. McEachern and Haynes (2004) similarly reported temporally synchronized gesture–speech combinations in monthly visits measured from 15 to 21 months of age. They observed the children to double their vocal and gestural combinations 1–3 months before the onset of their first two-word combinations, and then saw a steady decline in gesture–vocalization combinations as word phrases became more intelligible.

Evidence of support for both sign language and spoken language has also come from early intervention reports on babies with hearing loss. Yoshinaga-Itano (2005), in describing parent choices in Colorado, explained that 'it has become relatively common for families to choose combinations' of both sign language and spoken language development for their children with hearing loss (p. 301). In a series of studies from 1994 to 2003, Yoshinaga-Itano and colleagues reported that the best predictor for speech development in children with hearing loss is expressive language development, whether measured in speech only, speech plus sign, or sign only. She reported that babies enrolled in early intervention before 6 months of age were likely to have more consonants and more intelligible speech than babies enrolled in intervention after 12 months (Apuzzo and Yoshinaga-Itano, 1995; Yoshinaga-Itano *et al*., 1998; Yoshinaga-Itano, 2003), with communication mode accounting for only a small portion of the variance in speech production by 12 and 60 months of age and speech acquisition appearing to benefit from a sign language foundation (Mayne *et al*., 2000; Yoshinaga-Itano and Apuzzo, 1998; Yoshinaga-Itano and Sedey, 2000).

In contrast to a literature that supports signing for babies with hearing loss, there is a sizeable cochlear implant literature that reports better post-implant outcomes in oral communication (OC) children than in total communication (TC) children. One possible explanation for a superior OC result involves a 'mismatch' theory (Pisoni, 2000) in which sign, a visual language, competes with an auditory language and increases demands on children's working memory (p. 74). This theory implies difficulty listening to and watching a speaker's face while attending to his or her signing. Evidence to the contrary has been reported in hearing children (Cook *et al*., 2008; Goldin-Meadow *et al*., 2001; Wagner *et al*., 2004), with statements claiming that the combined use of speech and gesture 'places less demand on working memory than expressing the same information in speech alone' and that gesture facilitates memory (Cook *et al*., 2008, p. 1055). In addition, observations of babies as young as 2 weeks old show a preferential attending to their caregivers' faces, imitating their tongue protrusion and reaching gestures (Meltzoff and Moore, 1977). This preferential attention to the face remains throughout childhood and into adulthood, such that we hearing adults watch speakers' faces, not their hands, as they gesture, and deaf adults watch signers' faces, not their hands, as they sign (De Filippo and Lansing, 2006).

Several methodological concerns complicate comparisons of communication outcomes in TC and OC children. One involves sorting children's shared or exclusive use of the two communication modalities. Geers *et al*. (2002) compared the relative proportions of sign and speech use in 27 implanted children from TC programs, reporting a negative correlation ($r = -0.76$); as the proportion of signing increased, the proportion of talking decreased. Spencer and Bass-Ringdahl (2004) followed 19 TC children for up to 60 months to determine change in their communication mode. None of the children's narratives during story-telling included sign only, but 92% of their spoken words were produced without signs. They also reported that children reached an average of 70% accuracy in phoneme production by 36 months post-implant. Other measures of speech production in OC and TC children have involved phoneme accuracy (Tobey *et al*., 2007), articulation test results (Chin and Kaiser, 2000), onset of babbling and first words (Moore and Bass-Ringdahl, 2002), and speech intelligibility ratings (Chin *et al*., 2003). None of these measures address children's sign production. Identifying a standard measure for comparing sign acquisition and speech acquisition is important to questions surrounding intervention modality and communication outcomes in deaf children. In the absence of a standard protocol, however, their productive or expressive sign and speech samples are commonly inventoried for evidence of change.

Sign and speech phoneme acquisition

Videotaped samples of children of signing deaf parents have revealed predictable milestones in the onset and progression of movements that represent meaningful signs. Three articulatory categories characterize these sign movements – handshape, location, and movement – and were first described by Stokoe *et al*. (1965) as sign 'phonemes' because they are the most basic or identifiable segment of a sign (Liddell and Johnson, 1989). Table 1 offers the 19 handshapes, 24 movements, and 12 locations used in American sign language (ASL), along with expected stages or levels

Table 1 Developmental hierarchy for consonants and sign phonemes

Level 1	
Sign locations	Neutral space, lower face, upper face, trunk
Sign movements	Contact/touch, toward the body, down, up-and-down, closing
Sign handshapes	5-hand, G-hand, B-hand, C-hand, A-hand, O-hand
Consonants	/m, n, b, p, d, t, w, h/
Level 2	
Sign locations	Side of face, mid face, whole face, or head
Sign movements	Side to side, up, away from the body, to and from the body, nodding/bending, opening, twisting
Sign handshapes	L-hand, V-hand, H-hand, E-hand, 3-hand
Consonants	/ŋ, g, k, s, f, j/
Level 3	
Sign locations	Supinated wrist, pronated wrist, elbow/forearm, neck
Sign movements	Right, wiggling, circular, supinating rotation, pronating rotation
Sign handshapes	K-hand, X-hand, F-hand, Y-hand
Consonants	/v, ʃ, l, z, ʧ, ʤ/
Level 4	
Sign locations	Upper arm
Sign movements	Left, approach/converge, crossing, linking, interchanging, diverging, entering
Sign handshapes	R-hand, W-hand, I-hand, allocheric Y
Consonants	/ð, θ, r, ʒ/

Sign levels adapted from Bonvillian and Siedlecki (1996, 1998, 2000); consonant levels adapted from Stoel-Gammon (1985) and Grunwell (1987).

of acquisition adapted from those identified by Bonvillian and Siedlecki (1993, 1996, 1997, 1998) in babies of deaf parents.

The speech acquisition of young children has also been documented over time and reveals several developmental stages for American English consonants across three articulatory categories – manner of production, location, and voiced/voiceless patterns (Grunwell, 1987; Stoel-Gammon, 1985). Nasals, plosives, and glides emerge before liquids, fricatives, and affricates. Bilabials emerge before alveolars, palatals, velars, and glottal consonants. Word-initial voiced stops are produced before voiceless stops, and word-final voiceless stops are produced before word-final voiceless stops. These typically emerging consonants are also included as developmental levels in Table 1.

Sign and speech changes in implanted children

In this investigation, we documented and analyzed changes in sign and consonant production in young deaf children following their cochlear implantation. We questioned whether implanted children already in signing programs would show developmental acquisition of consonants, important to speech intelligibility, and if so, whether their acquisition of sign phonemes, important to sign intelligibility, would continue in the presence of newly acquired consonants. We also wondered if the growth patterns of sign and speech phonemes would vary across children implanted at different ages and with different demographic profiles.

Method

Participants

Twenty-two participants implanted at an average age of 44 months, with a range from 13 months (1 week post-activation for the youngest child) to 84 months old (6 months post-implant for the oldest child), met the two inclusion criteria: enrolled in signing programs and under 7 years of age at implant. Twelve children were seen at Gallaudet University's Cochlear Implant Education Center. The other 10 children were seen at James Madison University (JMU) in the speech–Language–Hearing Applied Lab. The 12 Gallaudet children were fully enrolled in sign language programs. Most children at JMU were enrolled in their local schools, three fully mainstreamed with sign language interpreters, and the others in early intervention and self-contained hearing-impaired classes where teachers and speech-language pathologists (SLPs) used sign language paired with spoken language. Three of the mainstreamed children had received early intervention support from personnel at a deaf school. Two others had been part of the preschool program at the same deaf school and one child continued there as a day student.

Two children had a deaf and hearing parent, one child from a home where ASL was used and the other from a home where spoken English and sign language were used simultaneously. Sign language was also used in all other children's homes, but at different levels of proficiency across parents. Spanish and Amharic were spoken predominantly in the homes of two children; spoken English was used in the remaining homes. Three of the 22 children were adopted, 2 from Russian orphanages and 1 within the United States.

In addition to their age and language backgrounds, the 22 children also represented several demographic backgrounds that are not common to the implant outcomes literature (see Belzner and Seal, 2010). Ten children were from minority backgrounds, 13 were from poverty, and 11 children had additional disabilities including autism, attention-deficit disorder with hyperactivity, seizures, cerebral palsy, and low cognitive functioning. Table 2 provides demographic information on all children, including educational placements at the time of their participation.

Procedures

We tracked the communication production of the children for the duration of their participation (up to 24 months for most but 36 months for a few) through routine video-recorded sessions every 3–6 months with their speech–language pathologists. Activities in the taped sessions varied across children and time, but a typical session at both sites began with the Ling 6-Sound Test or behavioral training for detection of the sounds with the youngest children. Listening activities typically followed those in *Bringing Sounds to Life* (Koch, 2002). A book-sharing event with phonological process goals for older children and vocabulary goals for younger children was common to each session, and a play activity or snack activity often ended the sessions. Simultaneous spoken and sign language was used for directions and conversation; signing was weaved in and out of activities as needed for goal achievement.

All vocal (non-meaningful productions for the younger children) and verbal (spoken and signed productions for the older children) were transcribed independently by four graduate students using the international phonetic alphabet (IPA) for consonant production and Stokoe notation for signed production. The second author resolved disagreements between any two transcribers assigned to the same tape. Some children entered the investigation in the second year and some were recorded more frequently than others for a total of 102 videotaped sessions across the 22 children. Eighteen tapes were randomly chosen for later recoding with reliability between transcribers held at an 85% or higher agreement.

Data analysis

We determined each child's consonant and sign phoneme inventories at his or her first session, and then recorded newly demonstrated phonemes over subsequent sessions to compare the sequence and level of acquisition with the stages shown in Table 1. We tallied the progressive sums of consonants, sign locations, movements, and handshapes as raw data and compared the number demonstrated at the first session to the number demonstrated at the last session. We ran repeated measures correlations across the children's consonant and sign phoneme inventories at three age groups: 10 children implanted between 12

Table 2 Implanted children's demographic profiles

ID	Sex	Race/ ethnicity	Age at implant (yrs;mos)	Hearing loss etiology	Nonverbal IQ	Neuro-motor disabilities	Intervention/education program
1	F	C	0;12	Congenital	Low	Spinal bifida	Hearing pre-school to school for the deaf
2	F	C	5;5	Unknown	WNR	None	Deaf preschool to hearing school with interpreter
3	F	AA	2;9	Congenital	Low	None	School for the deaf
4	F	AA	1;6	Congenital	WNR	None	School for the deaf
5	M	Hispanic	3;1	Congenital	Low	None	School for the deaf
6	M	Ethiopian	3;0	Congenital	Low	None	School for the deaf
7	M	AA	2;3	Congenital	WNR	None	School for the deaf
8	F	C	3;9	Congenital	Low	None	School for the deaf
9	M	AA	6;2	Unknown	Low	None	School for the deaf
10	M	AA	7;0	Congenital	Low	None	School for the deaf
11	M	C	3;5	Congenital	NA	PDD	Hearing school, deaf class
12	F	C	6;11	Unknown	NA	ADHD	Hearing school, deaf class
13	M	C	4;2	Congenital	NA	Autism	Hearing school, special education class
14	F	C	0;12	Genetic	NA	None	Home intervention
15	F	C	2;2	Meningitis	NA	None	Deaf preschool to hearing school with interpreter
16	M	Russian	2;8	Unknown	NA	None	Deaf preschool to hearing school
17	M	C	3;7	Unknown	NA	CP; seizures	Deaf preschool to hearing school, deaf class
18	F	C	4;5	Genetic	NA	None	Deaf preschool to hearing school with interpreter
19	F	C	4;7	Genetic	WNR	None	Deaf school to hearing school with interpreter
20	F	C	2;7	Genetic	WNR	None	School for the deaf
21	F	Hispanic	1;6	Congenital	WNR	None	School for the deaf
22	F	Russian	2;8	Congenital	WNR	None	School for the deaf

WNR, within normal range; NA, not available; PDD, pervasive developmental disorder; ADHD, attention deficit with hyperactive disorder; CP, cerebral palsy; C, Caucasian; AA, African American.

and 36 months, 8 implanted between 37 and 60 months, and 4 implanted between 61 and 84 months.

In order to compare sign and consonant acquisition within each child, and then to compare acquisition trajectories across these diverse children, we calculated individual *z* scores. We then plotted the *z* scores as a function of session (time) to obtain slope measurements. When plotted against a log scale of session, the slope of the linear trend line served to represent rate of acquisition or acquisition trajectory. Comparisons were made between the rate of acquisition for consonants and for each of the three sign phonemes for the group as a whole.

Results

Tables 3–6 offer consonants and sign phonemes (by location, handshape, and movement) produced in the children's first and subsequent sessions post-implant. Tables are ordered to reveal the most to least prevalent phoneme production across the children's inventories over time with divisions between levels marked at 40, 60, and 80% production. Table 3 shows four levels of consonant acquisition by percentage of production across the children's sessions. Level 1 consonants (m, n, b, p, d, g, w, and h) were produced by 80% or more of the children over the course of their participation. Level 2 consonants (p, t, k, j, l, r, s, ʃ, and f) were demonstrated in 60–79% of the children's inventories by their fifth session. Level 3 consonants (v, ŋ, ʧ, ʧ, and ʤ) fell between 40 and 59% of the children's inventories and Level 4 consonants (ð, θ, and ʒ) were produced in less than 39% of the children's acquisition inventories.

Table 4 shows four levels of sign locations, with the majority (80% and higher) falling in Level 1: neutral space, trunk, and on the face or head. Level 2 locations included only one, the supinated wrist, occurring in 68% of the children's inventories by session 6. Level 3 locations, pronated wrist, neck, and elbow, occurred in about one-third of the inventories, and Level 4, the upper arm, appeared in only one child's signing.

Table 5 represents sign configurations, with the majority (5-, G-, A-, B-, C-, O-, 3-, and V-hand) occurring in 80–100% of the children's sign productions over the investigation. Level 2 handshapes (Y-, W-, E-, and F-hand) occurred in 60–79% of the children's signs. Level 3 handshapes (L, X, H, and K) occurred between 40 and 59% of their signs and three Level 4 handshapes (I-hand, R-hand, and allocher Y-hand) appeared in less than 40% of the children's inventories.

Table 6 represents sign movements. Most sign movements (15 of the 24) occurred in more than 80% of the children's sign inventories over their participation. Three movements – left, pronating rotation, and to and from the body – occurred in 60–79% of the children's signs. Only one Level 3 movement – approaching/converging – fit the 40–59% acquisition pattern, and the remaining five movements occurred in less than 39% of the children's acquisition inventories as Level 4 movements.

Another calculation was made to determine the percentage change in each phoneme category for each child from his or her first to last session. Only three children failed to show growth in all four phoneme categories over the entire investigation. Participants 2 and 16 showed no gains in sign locations and Participant 18 showed no new consonants. Using the number of total phonemes possible (24 consonants, 12 sign locations, 19 handshapes, and 24 movements) as

Table 3 Consonant acquisition across sessions (% of children producing)

Level	Consonant	Session 1 (%)	Session 2 (%)	Session 3 (%)	Session 4 (%)	Session 5 (%)	Session 6 (%)
1	m	82	91				
	b	73	82		91		
	w	59	86	91			
	h	59	77	86		91	
	d	55	64	77	91		
	n	50	73	82	86		
	g	45	59	86	91	95	
	p	41	64	77	82		
2	t	32	55	73	77		
	j	27	50	64	68	77	
	r	32	45	59	68		
	l	27	55	59	64		
	s	23	41	55	59	68	
	ʃ	23	41	59	64	68	
	k	18	55	73	77	82	
	f	18	55	73	77		
3	v	23	27	36	55		
	ŋ	18	32	41	55		
	ʧ	14	23	36	41	45	
	z	14	18	23	32	41	
	ʤ	5	23	36	45	59	
4	ð	5	15	23	32		36
	θ	5	18		27		
	ʒ	5		9			

Table 4 Acquisition of sign locations demonstrated across sessions (% children)

Level	Location	Session 1 (%)	Session 2 (%)	Session 3 (%)	Session 4 (%)	Session 5 (%)	Session 6 (%)
1	Neutral	100					
	Lower face	77	95	100			
	Trunk	55	73	86	95		
	Side face		59	86	91		
	Upper face	55	68	86			
	Whole face		64		91		
	Mid face		55	64		86	
2	Supine wrist			55	59	64	68
3	Pronated wrist			27	32	36	
	Neck			23	27	36	
	Elbow			32			
4	Upper arm			5			

Table 5 Acquisition of sign handshapes demonstrated across sessions (% children)

Level	Movement	Session 1 (%)	Session 2 (%)	Session 3 (%)	Session 4 (%)	Session 5 (%)	Session 6 (%)
1	5-hand	100					
	G-hand		100				
	A-hand			100			
	B-hand			100			
	C-hand				100		
	O-hand					95	100
	3-hand				82	86	91
	V-hand				77	82	
2	Y-hand				55	68	73
	W-hand				55	64	
	E-hand					64	68
	F-hand				50	68	
3	L-hand				55		59
	X-hand					50	55
	H-hand					50	55
	K-hand					50	55
4	I-hand					36	
	R-hand				18		
	Allocheric Y				14		

Table 6 Acquisition of sign movements demonstrated across sessions (% children)

Level	Movement	Session 1 (%)	Session 2 (%)	Session 3 (%)	Session 4 (%)	Session 5 (%)	Session 6 (%)
1	Away from the body	100					
	Side to side	64	82	95	100		
	Opening	59	82	91	100		
	Contact	73	82	91	95		
	Downward	68	91		95		
	Up and down	55	82	86	95		
	Wiggling	50	68	77	95		
	Nodding/bending	41	64	82	95		
	Toward the body	73	91				
	Right	41	68	73	86	91	
	Upward	64	82	86		91	
	Closing	55	73	91			
	Circling	50	68	77	86		
	Supinating rotation	50	73		86		
	Twisting	32	68	86			
2	Left	27	41	59	73	77	
	Pronating rotation	36	41	45	68		
	To and from the body	32	45	55	64		
3	Approaching/converging	9	32	50	55	59	
4	Crossing	9	14	23	27	36	
	Diverging		23		32		
	Linking	5	9	18		27	
	Interchanging		9	14	18	23	
	Entering		9	23			

denominators and total observed phonemes at each time interval as numerators, percentage change, or growth was calculated for each child. As a group, the children averaged 38% gain (s.d. = 23%) in consonants with a range of increase from 4 to 23 consonants by the last session. They averaged 39% gain (s.d. = 17%) in sign handshapes with a range of increase from 6 to 18 across sessions. They averaged 35% gain (s.d. = 21%) in sign movements, ranging from 13 to 23 movements by the last session, and 33% gain (s.d. = 18%) in sign locations, with a low of 3 and a high of 11 locations demonstrated at the last session. Paired *t*-tests revealed the growth from first to last session to be statistically significant across all children in all four dependent variables: $t(21) = -7.71$ for consonants, -10.4 for handshapes, -7.74 for movements, and -8.09 for locations, with $P < 0.0001$.

Pearson correlation coefficients were also calculated using the progressive number of consonants, sign locations, movements, and handshapes that each child gained over the duration of the investigation. Because of the broad age range of the children, we treated these repeated measures as a function of age at implantation. Table 7 shows the statistically significant relationships between consonants and sign locations, handshapes and movements for the three age groups. Fig. 1 illustrates the children's trajectory of consonant and sign phoneme acquisition, as reflected in the pooled *z* scores. Points lying below zero indicate scores below the group's mean and scores above zero indicate scores higher than the means. Data points are representative of the development of each communication variable plotted for the 22 children.

Discussion

Results from this longitudinal investigation provide several insights to changes in speech and sign acquisition following cochlear implantation of 22 signing children. The diverse demographic backgrounds of the children set up expectations for diverse performance in their speech and sign phoneme development following implantation. While variability across means was evident in several calculations, almost all children showed gains across the four variables of interest, and most gains in phoneme inventories were similar across children, suggesting relatively uniform acquisition patterns regardless of age at implant and other demographic differences. As a group, the average growth in the children's consonants from the beginning of their participation until the end was 38%; average growth in sign handshapes was 39%. Sign locations grew an average of 33% and sign movements grew an average of 35%. Changes per child (dependent *t*-tests) from the first session until the last session were statistically significant across all four phoneme categories. Furthermore, the relationships between consonant growth and sign location, handshape and movement growth were statistically significant and of low-to-moderate strength for the two younger groups of implanted children. The relationship between the older children's consonant and sign movement growth was much stronger and accounted for about 64% of their developmental variance.

Rank ordering the consonant and sign phoneme inventories allowed for the comparison of developmental changes against expected acquisition patterns. Trajectories were similar but not identical to those offered in Table 1, lending support to graded levels of developmental difficulty previously reported in typically developing children acquiring spoken English from their hearing parents and typically developing babies acquiring ASL from their deaf parents. The sign phoneme levels offered by Bonvillian and Siedlecki (1996, 1998, 2000) were derived from infants much younger (8–11 months old) at the onset of their investigation than our children, who ranged in age from 13 months to 7 years at the time of our first recordings. Bonvillian and

Table 7 Pearson correlations (one-tailed) for consonant and sign phoneme acquisition

	Handshape	Movement	Location	Consonants
Group 1: children receiving implants prior to 3 years of age				
Handshape	1.000	0.879**	0.854**	0.545**
Movement		1.000	0.925**	0.557**
Location			1.000	0.455*
Consonants				1.00
Group 2: children receiving implants between 3 and 5 years of age				
Handshape	1.000	0.821**	0.848**	0.556**
Movement		1.000	0.799**	0.423**
Location			1.000	0.452**
Consonants				1.000
Group 3: children receiving implants after 5 years of age				
Handshape	1.000	0.527*	0.615**	0.574**
Movement		1.00	0.407	0.799**
Location			1.000	0.405
Consonants				1.000

*$p < .05$; **$p < .01$.

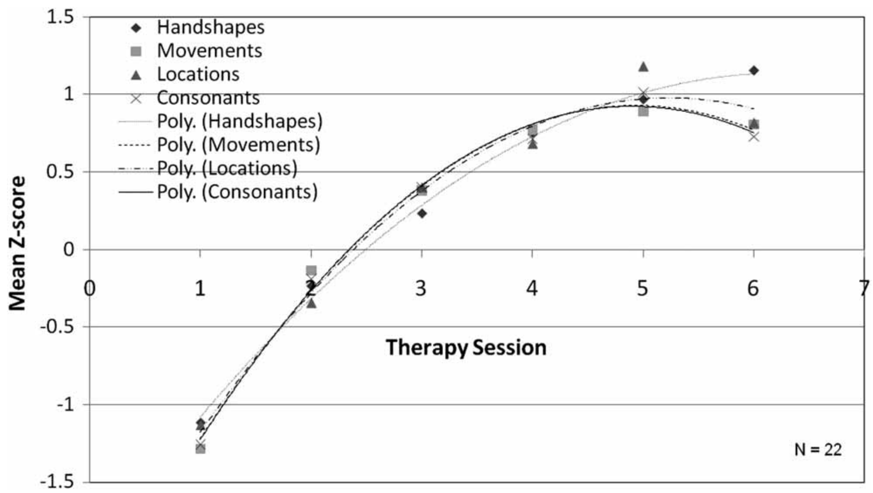

Figure 1 Average rate of acquisition of sign movements, handshapes, and locations, and consonants as a function of session (average interval of 3–6 months). Individual *z* scores were re-plotted against a log scale of session (not shown) for linear measurements of acquisition.

Siedlecki also stopped tracking their children's sign phoneme acquisition at the point of two-sign combinations, again much earlier than the termination point of this investigation. The children in their longitudinal study achieved an average of 83.5% match or maturity in producing sign locations like those of their parents, but only 61.4% match in their sign movements and 49.8% match in their handshapes, suggesting substantial room for growth in their sign phoneme maturation, particularly in movements and handshapes. In contrast, the consonant acquisition milestones from Stoel-Gammon (1985) and Grunwell (1987) began with 15- and 18-month-olds and continued several years in documenting later-developing consonants. The implanted children's consonant acquisition levels in the current investigation closely resembled those expected of hearing children. Exceptions include two Level 1 consonants (n and g in Table 2) listed as Level 2 consonants in Table 1 and five additional consonants that were documented either one developmental level earlier or later than those listed in Table 1. Tables 3–6 offer developmental acquisition patterns of the implanted children who represented atypical, as well as typical, motor and cognitive development and a broad age range. While their sign and consonant trajectories align closely with expected milestones and suggest a strong developmental pattern in spoken and sign language acquisition post cochlear implantation, they may not represent the trajectories of all implanted children.

Overall, changes in the children's sign and speech acquisition following their cochlear implants revealed a primary acquisition trajectory in which both new consonant and new sign phonemes co-developed, and with the same 'significant continuity' observed by Watt *et al.* (2006) in the manual gestures and consonants of typically developing children during their second year of language acquisition. When plotted over time, this acquisition trajectory revealed an initial burst across the early months post-implant and continuous but plateauing growth across subsequent sessions (return to Fig. 1). Growth in consonants is important to improved speech intelligibility, just as growth in sign phonemes is important to improved sign intelligibility in children's early language learning years. Consonant growth has previously been documented in implanted children who sign (e.g. Tomblin *et al.*, 2008), but sign phoneme growth has not been reported in implanted children prior to this investigation.

These sign and speech acquisition findings have several important applications. Firstly, the results did not support theoretical concerns about cognitive mismatch or competing auditory–visual linguistic demands (Pisoni, 2000) in implanted children exposed to both sign language and spoken language. Consequently, evidence from this investigation should be useful in counseling hearing families that use of signs should not impede their children's acquisition of speech, and in counseling deaf families that use of speech should not impede their children's acquisition of signs. Secondly, the developmental acquisition levels for consonant and sign phonemes provided here should be beneficial to those who want to promote both sign and speech acquisition with speech and sign targets for home and clinical intervention. Following these developmental targets should facilitate progressive growth in spoken language, sign language, or both. In addition, because these developmental levels were observed in children from multiple demographic backgrounds, including those from low socioeconomic conditions, from racial and ethnic minorities, and with additional disabilities, and because the results were observed in children across a broad age range, the results should be applicable to children across a broad demographic spectrum, not just to those who fit homogenous age and ability profiles. Finally, the early steep and later plateauing trajectory of consonant and sign phoneme growth demonstrated in the first 24 months of this investigation may have application to other longitudinal investigators in suggesting a shorter, rather than longer, timeframe in which to explore and expect change in phoneme development.

Signing children who acquire useful audition from their cochlear implants offer never-before-possible opportunities to explore the hands' influence on speech development and audition's influence on both spoken and sign language development. Several limitations beyond the small heterogeneous sample in this project should be disclosed, however, in promoting replication or continuation of this research. The lack of signing deaf children with and without hearing aids, and otherwise similar backgrounds as comparative controls compromises statistical rigor in this investigation. We also were unable to document baseline sign and speech productions before the children's implants and record post-implant productions at equal intervals and for equivalent durations across all children. Recording the children's speech and sign productions as they first appeared in the videotaped sessions also questions their reliability. Any of these consonants and sign gestures could have emerged earlier but were only demonstrated in a later session because earlier communication contexts and interactions had not facilitated their demonstration. It is equally possible that a child's new productions were only just emerging and not truly part of the child's consonant or sign inventories, but were prematurely prompted because of the communication context and adult interaction models. We also did not judge our children's sign or consonant productions as right or wrong. We simply recorded what the children said and what they signed during their speech–language–hearing sessions, without regard to number of productions in judging the validity of the vocal or gestural production. This, too, posed an unexpected liability in that several children approached, but none reached, maturation ceilings in their sign and speech phoneme acquisition.

These limitations could be improved with complementary standardized testing, using developmental norms for speech acquisition and, if one were available, for sign acquisition. A standardized sign articulation test should also benefit researchers who have little or no knowledge of signs and or ways to prompt sign vocabulary to reflect developmental milestones. Such a test should improve efforts to compare sign and speech development in children prior to and after cochlear implantation. Retesting children at later milestones would provide additional insight to the relationship of early phoneme acquisition and later language and literacy outcomes in this special population of implanted children from signing programs and from hearing and deaf signing families. Finally, continued research should be important to the future as advances in implant technology and advances in medical technology enable more questions about the interaction between developmental changes in implanted children's speech and sign acquisition.

In summarizing the major points of this investigation, we offer the following conclusions:

- The number of children from signing programs who receive cochlear implants is growing. Professionals who use sign language with deaf children generally assure hearing parents that continued signing following implantation will not deter speech development. Professionals also assure deaf parents that cochlear implantation will not deter their child's sign development. Results of this investigation support both assurances.
- The 22 children reported here followed expected developmental trajectories for typically developing children in both English consonant acquisition and ASL phoneme acquisition. The most rapid consonant growth occurred following implantation. Similarly, the most rapid sign growth occurred following implantation, suggesting complementary speech and sign phoneme development.
- The acquisition tables provided from this investigation should be helpful to professionals who work with implanted children. These acquisition targets have application across the broad spectrum of children receiving implants, including those from poverty, those from minority backgrounds, those with additional disabilities, and those who are implanted beyond their third birthday.

Acknowledgements

This research was funded in part by the Cochlear Implant Educational Center (CIEC) of the Laurent Clerc National Deaf Education Center at Gallaudet University. Gallaudet funds sponsored JMU audiology doctoral students English King, Kelly Clingempeel, and Kate Belzner, and speech–language pathology master's student, Christi Hess, for transcription and data coding. AuD/PhD student Kate Belzner received additional funding as research assistant. This research was also funded in part by a JMU educational leave to Brenda Seal to investigate spoken and sign language changes in young implanted children. Many thanks are extended to the families who participated, and to Lori Bobsin, CCC-SLP (from the University of Virginia's Medical Center's Cochlear Implant Program), Laura Carr, CCC-AUD (PhD student at JMU), and Sarah Shreckhise, CCC-SLP (Virginia School for the Deaf and Blind in Staunton) for referrals and supervision during the data generation period. Several papers from this project were presented at the 2004, 2005, 2006,

and 2007 annual meetings of ASHA; at the 2006 Beyond Newborn Hearing Screenings International Convention in Lake Como, Italy; at the 2006 Nemours Lecture in Wilmington, Delaware; at the 2007 International Conference on Cochlear Implants in Charlotte, North Carolina; at the 2009 International Conference in Seattle, Washington; and at the Speech and Hearing Association of Virginia's annual conferences in 2006, 2007, and 2008.

References

Apuzzo M., Yoshinaga-Itano C. 1995. Early identification of infants with significant hearing loss and the Minnesota child development inventory. *Seminars in Hearing*, 16: 124–139.

Bates E., Benigni L., Bretherton I., Camaioni L., Volterra V. 1979. *The Emergence of Symbols: Cognition and Communication in Infancy*. New York: Academic Press.

Belzner K.A., Seal B.C. 2010. Children with cochlear implants: a review of demographics and communication outcomes. *American Annals of the Deaf*, 154: 311–333.

Bonvillian J.D., Siedlecki T. 1996. Young children's acquisition of the location aspect of American sign language signs: parental report findings. *Journal of Communication Disorders*, 29: 13–35.

Bonvillian J.D., Siedlecki T. 1998. Young children's acquisition of the movement aspect in American sign language: parental report findings. *Journal of Speech, Language, and Hearing Research*, 41: 588–602.

Bonvillian J.D., Siedlecki T. 2000. Young children's acquisition of the formational aspects of American sign language: parental report findings. *Sign Language Studies*, 1: 45–64.

Butcher C., Goldin-Meadow S. 2000. Gesture and the transition from one- to two-word speech: when hand and mouth come together. In: D. McNeill, ed. *Language and Gesture*. Cambridge: Cambridge University Press, pp. 235–257.

Chin S.B., Kaiser C.L. 2000. Measurement of articulation in pediatric users of cochlear implants. *The Volta Review*, 102: 145–156.

Chin S.B., Tsai P.L., Gao S. 2003. Connected speech intelligibility of children with cochlear implants and children with normal hearing. *American Journal of Speech–Language Pathology*, 12: 440–451.

Cook S.W., Mitchell Z., Goldin-Meadow S. 2008. Gesturing makes learning last. *Cognition*, 106: 1047–1058.

De Filippo C.L., Lansing C.R. 2006. Eye fixations of deaf and hearing observers in simultaneous communication perception. *Ear and Hearing*, 27: 331–352.

Fenson L., Dale P.S., Reznick J.S., Thal D., Bates E., Hartung J.P., *et al.* 1992. *MacArthur Communicative Development Inventories*. Baltimore, MD: Paul H. Brookes Publishing Co.

Geers A., Spehar B., Sedey A. 2002. Use of speech by children from total communication programs who wear cochlear implants. *American Journal of Speech–Language–Hearing Association*, 11: 50–58.

Goldin-Meadow S., Nusbaum H., Kelly S.D., Wagner S. 2001. Explaining math: gesturing lightens the load. *Psychological Science*, 12: 516–522.

Goodwyn S.W., Acredolo L.P., Brown C. 2000. Impact of symbolic gesturing on early language development. *Journal of Nonverbal Behavior*, 24: 81–103.

Grunwell P. 1987. *Clinical Phonology*. 2nd edn. Baltimore, MD: Williams & Wilkins.

Iverson J.M., Fagan M.K. 2004. Infant vocal–motor coordination: precursor to the gesture–speech system? *Child Development*, 75: 1053–1066.

Iverson J.M., Thelen E. 1999. Hand, mouth, and brain: the dynamic emergence of speech and gesture. *Journal of Consciousness Studies*, 6: 19–40.

Koch M. 2002. *Bringing Sounds to Life*. Valencia, CA: Advanced Bionics Corp.

Liddell S.K., Johnson R.E. 1989. American sign language: the phonological base. *Sign Language Studies*, 64: 195–277.

Mayne A., Yoshinaga-Itano C., Sedey A.L. 2000. Receptive vocabulary development of infants and toddlers who are deaf or hard of hearing. *Volta Review*, 100: 29–52.

McEachern D., Haynes W.O. 2004. Gesture–speech combinations as a transition to multiword utterances. *American Journal of Speech–Language Pathology*, 13: 227–235.

Meltzoff A.N., Moore M.K. 1977. Imitation of facial and manual gestures by human neonates. *Science*, 198: 74–78.

Moore J.A., Bass-Ringdahl S.M, 2002. Role of infant vocal development in candidacy for and efficacy of cochlear implantation. *Annals of Otology, Rhinology, & Laryngology – Supplement*, 189: 52–55.

Pisoni D.B. 2000. Cognitive factors and cochlear implants: some thoughts on perception, learning, and memory in speech perception. *Ear and Hearing*, 21: 70–78.

Rowe M., Goldin-Meadow S. 2009. Differences in early gesture explain SES disparities in child vocabulary size at school entry. *Science*, 323: 951–953.

Siedlecki T., Bonvillian J.D. 1993. Location, handshape and movement: young children's acquisition of the formational aspects of American sign language. *Sign Language Studies*, 78: 31–52.

Siedlecki T., Bonvillian J.D. 1997. Young children's acquisition of the handshape aspect of American Sign Language signs: Parental report findings. *Applied Psycholinguistics*, 18: 17–39.

Spencer L.J., Bass-Ringdahl S. 2004. An evolution of communication modalities: very young cochlear implant users who transitioned from sign to speech during the first years of use. Cochlear Implants: Proceedings of the VIII International Cochlear Implant Conference, International Congress Series, vol. 1273, pp. 352–355.

Stoel-Gammon C. 1985. Phonetic inventories, 15–24 months: a longitudinal study. *Journal of Speech and Hearing Research*, 28: 505–512.

Stokoe W.C., Casterline D., Croneberg C. 1965. *A Dictionary of American Sign Language on Linguistic Principles*. Washington, DC: Gallaudet College Press.

Tobey E., Wiessner N., Lane J., Sundarrajan M., Buckley K., Sullivan J. 2007. Phoneme accuracy as a function of mode of communication in pediatric cochlear implantation. *Audiological Medicine*, 5: 283–292.

Tomblin B., Peng S.-C., Spencer L.J., Lu N. 2008. Long-term trajectories of the development of speech sound production in pediatric cochlear implant recipients. *Journal of Speech, Language, and Hearing Research*, 51: 1353–1368.

Wagner S.M., Nusbaum H., Goldin-Meadow S. 2004. Probing the mental representation of gesture: is hand waving spatial? *Journal of Memory & Language*, 50: 395–407.

Watt N., Wetherby A., Shumway S. 2006. Prelinguistic predictors of language outcome at 3 years of age. *Journal of Speech, Language, and Hearing Research*, 49: 1224–1237.

Yoshinago-Itano C. 2003. From screening to early identification and intervention: discovering predictors to successful outcomes for children with significant hearing loss. *Journal of Deaf Studies and Deaf Education*, 8: 11–30.

Yoshinaga-Itano C. 2005. Early identification, communication modality, and the development of speech and spoken language skills: patterns and considerations. In: P Spencer, ed. *Advances in the Spoken-Language Development of Deaf and Hard-of-Hearing Children*. Cary, NC: Oxford University Press, Inc., pp. 298–327.

Yoshinaga-Itano C., Apuzzo M. 1998. Identification of hearing loss after 18 months is not early enough. *American Annals of the Deaf*, 143: 380–387.

Yoshinaga-Itano C., Sedey A. 2000. Speech development of deaf and hard-of-hearing children in early childhood interrelationships with language and hearing. *Volta Review*, 100: 181–212.

Yoshinaga-Itano C., Sedey A.L., Coulter D.K., Mehl A.L. 1998. Language of early- and later-identified children with hearing loss. *Pediatrics*, 102: 1161–1171.