Published in final edited form as:
Am J Speech Lang Pathol. 2012 November ; 21(4): 313–328. doi:10.1044/1058-0360(2012/11-0110).

Monitoring Progress in Vocal Development in Young Cochlear Implant Recipients: Relationships between Speech Samples and Scores from the Conditioned Assessment of Speech Production (CASP)

David J. Ertmer and **Jongmin Jung**
Speech, Language, and Hearing Sciences, Purdue University, West Lafayette, IN

Abstract

Background—Evidence of auditory-guided speech development can be heard as the prelinguistic vocalizations of young cochlear implant recipients become increasingly complex, phonetically diverse, and speech-like. In research settings, these changes are most often documented by collecting and analyzing speech samples. Sampling, however, may be too time-consuming and impractical for widespread use in clinical settings. The *Conditioned Assessment of Speech Production* (CASP; Ertmer & Stoel-Gammon, 2008) is an easily administered and time-efficient alternative to speech sample analysis. The current investigation examined the concurrent validity of the CASP and data obtained from speech samples recorded at the same intervals.

Methods—Nineteen deaf children who received CIs before their third birthdays participated in the study. Speech samples and CASP scores were gathered at 6, 12, 18, and 24 months post-activation. Correlation analyses were conducted to assess the concurrent validity of CASP scores and data from samples.

Results—CASP scores showed strong concurrent validity with scores from speech samples gathered across all recording sessions (6 – 24 months).

Conclusions—The CASP was found to be a valid, reliable, and time-efficient tool for assessing progress in vocal development during young CI recipient's first 2 years of device experience.

Keywords

Children; Cochlear Implants; Speech Production; Vocal Development

Prelinguistic vocal development is a process by which infants and toddlers produce increasingly complex, phonetically diverse, and speech-like vocalizations before they say words on a regular basis (See Ertmer & Nathani Iyer, 2010; Oller, 2000; and Vihman, 1996 for reviews). During the 1970's and 1980's, several research groups identified and classified the prelinguistic vocal sounds that infants and toddlers typically produce during the first 2 years of life. The findings of these studies were remarkably similar in terms of the types of vocalizations identified, the ages at which various types of vocalizations emerged, and the number of developmental levels observed (Koopmans-van Beinum & van der Stelt, 1986; Oller, 1980; Roug, Landberg, & Lundberg, 1989; Stark, 1980; Zlatin, 1975; see Ertmer & Nathani Iyer, 2010; Oller, 2000; and Vihman, 1996 for reviews). Taken together, these studies characterized typical vocal development as a process consisting of overlapping levels of speech production ability in which the frequency of non-speech-like vocalizations (e.g.,

Contact author: David J. Ertmer, 500 Oval Dr., West Lafayette, IN 47907-2038, 765-496-2249, dertmer@purdue.edu.

squeals, grunts, and isolated vowel-like vocalizations) decreases as more speech-like vocalizations (e.g., CV syllables, canonical babbling, and CVC syllables) become increasingly common.

Prior to the introduction of newborn hearing screening (NHS) and the advent of multi-channel cochlear implants (CI), deaf infants and toddlers exhibited critical deficits in vocal development (e.g., Kent, Osberger, Netsell, & Hustedde, 1987; Oller & Eilers, 1988). More recently, the widespread adoption of NHS and the provision of CIs early in life, have resulted in substantial advancements in vocal development for many, although not all, children who receive their devices by 3 years of age (Ertmer, Young, & Nathani, 2007; McCaffrey, Davis, MacNeilage, & von Hapsburg, 1999; Moore & Bass-Ringdahl, 2002; Schauwers, Gillis, Daemers, De Beuklaer, & Govaerts, 2004). These advancements are among the first observable indications of sensory aid benefit and provide evidence of auditory-guided speech development (See Ertmer & Nathani Iyer, 2010, for review). As such they can offer important information for monitoring benefit from sensory aids (CIs or hearing aids) and early progress in the acquisition of spoken language.

Recent research has shown that children who have secondary disabilities in addition to hearing loss may make limited advancements in vocal development after receiving CIs (Ertmer et al., 2007). For such children, identification of delayed vocal development--in conjunction with the results of other assessments of communicative, behavioral, and audiological status-- can lead to timely adjustments in interventions such as CI remapping, increasing the amount of intervention, and changes in children's modes of communication, among others. Monitoring progress in vocal development can also be useful in identifying young children who have no secondary disabilities but, none the less, show slow progress and may require adjustments to hearing devices or intervention programs. Thus, children's vocal behaviors provide important information for intervention planning during a critical developmental period.

Classification of Children's Vocal Productions

Several researchers have constructed systems for classifying infant and toddler vocalizations into developmental levels (see Oller, 2000 and Vihman, 1996 for reviews). A classification system based on the work of Rachel E. Stark (e.g., Nathani, Ertmer, & Stark, 2006; Stark, 1980) was selected for the current study because it has been shown to be a reliable measure of vocal development in both typically developing (TD) children (Nathani et al., 2006) and young CI recipients (Ertmer & Jung, 2011; Ertmer & Mellon, 2001; Ertmer et al., 2007). Table 1 contains the five levels of *The Stark Assessment of Early Vocal Development-Revised* (SAEVD-R) and examples of vocalization types identified with this tool.

The validity of the SAEVD-R was demonstrated in a cross-sectional study of 30 typically developing children ages 1 – 20 months (Nathani et al., 2006). The children were divided into five age-groups and child utterances (i.e., a speech-like vocalization or group of vocalizations separated from all others by either audible ingressive breaths or by judges' intuitions about utterance boundaries often indicated by a silence of one second or longer; Lynch, Oller, Steffens, & Buder, 1995) from audio-recorded samples were classified into the five categories of the SAEVD-R according to the highest level associated with component vocalizations. For example, if a child produced two isolated vowels (e.g., /i/ /i/) and a canonical syllable (e.g., [ba]) within the same utterance, the entire utterance would be classified at SAEVD-R level 4; Basic Canonical Syllables. Results showed that that infants up to 8 months old primarily produced vocalizations from levels 1 (Reflexive), 2 (Control of Phonation), and 3 (Expansion) of the SAEVD-R. Infants from 9 – 20 months also produced a sizable amount of vocalizations from level 4 (Basic Canonical Syllables). Only infants from the 16 – 20 months age-group produced vocalizations from level 5 (Advanced Forms) in significant quantities. The validity of the SAEVD-R was shown through the detection of age-related changes in child vocalizations. A comprehensive description of the five levels of the SAEVD-R and operational definitions for the 23 kinds of vocalizations represented in this system are available in Nathani et al. (2006).

The SAEVD-R has also been used to examine speech samples from young deaf children after cochlear implantation (Ertmer, Young, & Nathani, 2007). In a longitudinal study of the sequence and time-course of vocal development in seven children implanted between 10 and 36 months, the authors found that six of the seven participants made advances to higher SAEVD-R levels after implantation, that all but the child implanted at the youngest age (10 months) followed the sequence predicted by the SAEVD-R, and that the Basic Canonical Syllables and the Advanced Forms level were often established with fewer months of robust hearing experience (i.e., auditory access to speech at conversational intensity levels) than reported in the literature for children who are typically developing.

Our recent research with young CI recipients streamlined the SAEVD-R from a five-level system into a three-level system to make it even more reliable and easier to use in research and clinical settings (Ertmer & Jung, 2011). The *Consolidated SAEVD-R* combines the vocalization types from SAEVD-R levels 1 – 3 into a single “Precanonical” (PC) level (see Table 1). The merging of SAEVD-R levels 1 – 3 was possible because vocalization types from each of these levels are relatively immature and are routinely observed in TD children and those with severe-profound hearing loss who use hearing aids (Ertmer & Mellon, 2001; Iyer & Oller, 2008; Oller, Eilers, Bull, & Carney, 1985; Stoel-Gammon & Otomo, 1986). Because both hearing and deaf children produce similar vocalization patterns at the initial phases of vocal development, separating the first three levels of the SAEVD-R provides little information about the effects of CI-aided hearing. However, vocalizations from the fourth and fifth levels are later-emerging, and progressively more speech-like than those of levels 1 – 3. Thus, vocalizations from SAEVD-R level 4, “Basic Canonical Syllables” (BCS), and level 5, “Advanced Forms” (AF) are classified separately in the Consolidated SAEVD-R system (Table 1). Audio examples of some of the vocalization types found in Table 1 can be accessed at www.vocaldevelopment.com.

The Consolidated SAEVD-R was recently used in a longitudinal study of vocal development during the first year of CI use. Ertmer and Jung (2011) examined the sequence and time course of vocal development in13 children who received CIs between 8 and 35 months and compared the percentages of PC, BCS, and AF utterances produced during speech samples with those of 11 TD children. Data were collected and analyzed at 3 month intervals beginning after 3 months of device experience in the CI group and after 6 months of age in the TD children. The investigation revealed that, on average, the CI group established the Basic Canonical Syllables level and the Advanced Forms level (i.e., criterion = 20% of the sample) with fewer months of robust hearing experience than the TD group. The findings also indicated that PC vocalizations decreased from 70% at 3 months post-activation to 40% after one year of CI use, indicating that more mature and speech-like utterances had become the majority of the sample by one year. Further, the BCS level emerged and became established before the AF level, although data for two participants indicated that both levels were established within the same 3-month interval. In sum, the CI group made more rapid advancements than younger children in the TD group and the majority of young CI recipients followed the sequence predicted by the Consolidated SAEVD-R. The rapid progress of young CI recipients was hypothesized to be due to their relatively greater maturity in speech-motor, social, and cognitive development than younger children who were typically developing.

Two Methods of Assessing Vocal Development

1. Speech sampling

Up to this point, the cited research has relied on the most naturalistic method for monitoring changes in young children's speech following cochlear implantation: speech sampling. To use this approach with the Consolidated SAEVD-R, researchers and early interventionists video- and audio-record children during 20 – 30 minute play-sessions with familiar adults, and then classify protophones (i.e., vocalizations that become more speech-like with age; Oller, 2000) into the Precanonical, Basic Canonical Syllables, or Advanced Forms levels. Reflexive vocalizations such as sneezes burps, crying, and laughter are not analyzed because they do not become more speech-like with age. A sample of 50 utterances is gathered and the PC, BCS and AF levels are considered established when they account for ≥ 20% of the child's utterances during a sample.

Recent research has shown that speech samples can reveal specific indicators of auditory-guided vocal development (see Ertmer & Nathani Iyer, 2010 for review). These include (1) increased vowel and diphthong diversity soon after receiving a CI, (2) increased production of canonical syllables (i.e., CV combinations with rapid transitions like those found at the BCS level) and the eventual dominance of adult-like syllables in children's samples, (3) increased production of complex syllable shapes (e.g., CVC syllables and those found at the AF level), and (4) increased diversity of consonant types, especially those with less-visible places of articulation such as /d/, /n/, /l/, /k/, and /g/, and later-emerging manners of production, such as fricatives and affricates (i.e., /f/, /v/, /s/, /z/, /ʃ/, /ʒ/, /d ʒ/, and /tʃ/). These indicators can help early interventionists identify progress during everyday situation, as well as during formal speech sample analysis.

However, early interventionists may encounter difficulty in classifying prelinguistic utterances from samples for several reasons. For example, it may be difficult to identify individual utterances reliably. In research studies, individual utterances are identified when they are separated from other utterances by either audible ingressive breaths or pauses of 1 second or longer (Ertmer & Nathani Iyer, 2010; Lynch, Oller, Steffens, & Buder, 1995; and Stark, 1980). Making this decision commonly requires a review of audio-recordings and, sometimes, visual inspection of computer-displayed waveforms and spectrograms. The latter tools are not commonly available in intervention settings. Further, early interventionists might find vocalizations difficult to conceptualize due to a mismatch between their own mature phonological systems and children's incompletely developed systems. That is, infant and toddler utterances often differ from mature speech patterns in timing (e.g., slow transitions between consonants and vowels), and some types of vocalizations may not resemble adult-like phonemes (e.g., slowly changing vowel glides). Utterances that lack adult-like timing and well-produced phonemes and transitions can be difficult to classify without special training and practice. Further discussions of sample analysis procedures and classification challenges can be found in Ertmer (2005), Nathani and Oller (2001), and Ertmer and Nathani Iyer (2010).

In summary, although speech sampling is an ecologically valid approach to examining vocal development and has demonstrated usefulness in identifying progress in auditory-guided speech development, it may be impractical for routine clinical use due to the need for special training and additional equipment and software, as well as the substantial time investment for collecting and analyzing samples.

2. The Conditioned Assessment of Speech Production (CASP)

Recognizing that speech sampling can be problematic and time-consuming for early interventionists, Ertmer and Stoel-Gammon (2008) developed an alternative procedure for assessing vocal development in children with hearing loss. The Conditioned Assessment of Speech Production (CASP) is an elicited imitation task in which familiar adults provide spoken models of 10 utterances from the three levels of the Consolidated SAEVD-R and ask young children to imitate them. Because increased vowel diversity is an early indicator of auditory-guided speech development, three different vowel types serve as stimuli at the Precanonical level of the CASP (Ertmer, 2001): a single central vowel (/Λ/), two high-front vowels (/i/ /i/), and three low-front vowels (/æ/ /æ/ /æ/). These items require the ability to reproduce three different vowel types and to match the number of vowels that are modeled.

Five individually produced CV syllables comprise the second part of the CASP: three CV syllables with highly visible consonants (i.e., [bɑ], [mɑ], and [wɑ]) and two CV syllables containing consonants that have minimal speechreading cues (i.e., [kɑ] and [sɑ]) serve as stimuli from the Basic Canonical Syllable level. The former items contain consonants that typically emerge early in life and may be imitated correctly soon after CI activation. Speechreading cues are also apparent as these bilabial sounds are presented. Imitation of [kɑ] and [sɑ] is likely to be observed after a longer period of sensory aid use as these consonants emerge relatively later in typically developing children (Smit, Hand, Freilinger, Bernthal, & Bird, 1990; Shriberg, Gruber, & Kwiatkowski, 1994). Models of these targets provide very limited speechreading information.

Finally, two stimulus items represent the Advanced Forms level on the CASP: a C + diphthong syllable [naI], and a CVC syllable [tʌk]. These items are used to assess the ability to produce the rapid vowel-to-vowel formant transitions associated with diphthongs and the ability to produce closed syllables. Both types of abilities emerge relatively late in typically developing toddlers (Nathani et al., 2006) and young CI recipients (Ertmer et al., 2007). Speechreading cues for these syllables are minimal so that successful imitation relies mainly on auditory perception.

CASP items are presented in the following way. After the introduction of two practice items, an early interventionist models the first stimulus item (i.e. /Ə/), for a parent or another adult with whom the child is familiar. A second adult imitates the stimulus item. A reward (a plastic star from a Playskool Classical Stacker ring-post toy) is given to the adult as the child listens and watches. The second adult then turns to the child, models the same item and then passes the star to the child after an imitative attempt has been made. The child places the star on the post and watches as the post lights up and music is played for a short time. This game-like elicitation activity is repeated a second time for the same item if the child's response, as transcribed by the early interventionist, is not a fully acceptable match. The same process is repeated for the remaining items although modeling can be discontinued if Basic Canonical Syllable have not been observed (See Appendix A). The child's best response is scored according to a graduated scale in which 0 points are assigned for not responding or for a vocalization that is not a close approximation of the model; 1 point is given for a partially acceptable imitation, and 2 points for a fully acceptable match. Complete instructions can be found in Appendix A and a score sheet can be found in Appendix B. A video-recorded demonstration of CASP procedures is available at http://nc.agbell.org/NetCommunity/Page.aspx?pid=533.

The CASP was field-tested with children with hearing losses who were between 12 and 47 months-old and attended an oral intervention program (Ertmer & Stoel-Gammon, 2008). The 13 participants had severe-to-profound hearing losses and used either CIs or hearing aids. The CASP was given to each child twice; the mean age at the first administration was 33.5 months and 43.5 at the second. Data analysis showed significantly higher scores for the second administration (mean gain = 11 points). In addition, CASP scores were found to be positively correlated with children's ages and amount of sensory aid experience, but not with aided hearing levels. Field testing data also revealed that children as young as 12 months participated in the CASP. CASP scores approached ceiling level (20 points) for most children who were 40 months of age or older. Although these findings supported the use of the CASP for documenting changes in vocal development, the relationship between CASP scores and children's sampled levels of vocal development was not examined.

Purpose of Investigation

The main purpose of the current investigation was to determine how closely CASP scores were associated with children's sampled level of vocal development at the same point in time (concurrent validity). To address this issue, young CI recipients provided speech samples and completed the CASP at four intervals: 6-, 12-, 18-, and 24-months after CI activation. The concurrent validity of the CASP was assessed by examining correlations between CASP scores, expressed as the percentage of total points earned, and the percentage of speech-like utterances (i.e., those judged to contain Basic Canonical Syllables or Advanced Form vocalizations) observed across the four data collection intervals. If the two sets of scores are found to be highly correlated across the first 2 years of CI use, then the CASP would be shown to be an effective and time-efficient tool for monitoring vocal development in young CI recipients.

Methods

Participants

A total of 19 children with CIs (eight boys and 11 girls) participated in the current study. All of the children had bilateral, severe to profound hearing losses. The mean age at activation was 21.47 months (*SD* = 8.02) and all were implanted before their third birthdays (range = 8–35 months). Each child was enrolled in an auditory-oral program and came from English-speaking homes. Sixteen children were reported as having typical development except for hearing loss. Two boys and one girl were identified as having secondary disabilities after being enrolled in the study. One child (M-27) had behavioral concerns associated with Autism Spectrum Disorder and two others had problems associated with speech motor control; M-31 was suspected by his early interventionist of having developmental speech motor difficulties, and F-27 was diagnosed with hypotonia. Ten of the children wore bilateral CIs; three children (M-13, F-21, and F-27a) received bilateral CIs simultaneously, and seven added another CI during the course of the study. Four children (M-16, F-21, M-27, and F-18a) discontinued participation because of moving away from their programs, being mainstreamed, or enrolling in a total communication program. Speech samples and CASP scores were missing for single intervals for four children (F-13a, F-19, M-31, and F-36) because of illness, a second implant surgery, misadministration of the CASP, or lost DVD recordings. Demographic information can be seen in Table 2.

The Nittrouer Index of Social Position (NISP; Nittrouer & Burton, 2005)--an interview that yields an estimate of societal standing based on parental educational levels and occupations, rather than family income--was conducted with parents of the participants. The NISP procedure was modified slightly to accommodate single-parent families following procedures used by Nittrouer (personal communication, February, 2008). Across all participants, the mean NISP score was 38.5. (*SD* = 18.77) and scores ranged from 12–72 points. Regarding race and ethnicity, 16 children were Caucasian, two were Black, and one was of mixed races. Three children were of Hispanic ethnicity.

Data Collection

Spontaneous speech samples—Speech samples from parent-child interactions were recorded at 6, 12, 18, and 24 months post activation. A standardized set of toys was provided including cars, dolls, animals, blocks, a drawing board, books, and puzzles. Video- and audio-recording were made by using Sony mini-DVD camcorders (model number DCR-DVD405) coupled with Bluetooth wireless microphones (Sony ECM-HW1). A wireless microphone was placed in the pocket on a specially designed vest approximately 4” from the child’s mouth. A total of 61 sessions were recorded. For most of these, parents interacted with their children (~70%). When a parent could not attend, another early interventionist or a day care provider interacted with the child (28% and 1.42%, respectively). In all cases, samples were collected with an adult who was familiar to the child.

The CASP

The CASP was administered during the same sessions (i.e., at 6, 12, 18, and 24 months post-activation) or within 1 week if the child was not available for extended data collection session that particular day (4.9% of sessions). The children’s early interventionists and parents provided models for the CASP in 68% of the sessions. When parents were not available, another familiar early interventionist assumed the parents’ role. If a child was uncooperative for any reason, the CASP was rescheduled as soon as possible. The CASP was administered in a quiet room at the child’s school or in the home. The CASP was video- and audio-recorded using the equipment described above and was completed in approximately 10 minutes or less for most children (See appendices A and B).

Data Analysis

A total of 61 video-recorded speech samples were processed and analyzed by six graduate research assistants who had coursework in phonetics and training in identifying vocalizations with the SAEVD-R. Fifty consecutive utterances of sufficient quality for auditory perceptual analysis from each sample were converted into wave files (.wav) from DVDs by two parsers. Only two sessions yielded less than 50 utterances (M-9 at 6 months (n = 14), and M-16 at 12 months (n = 46). All child utterances were then classified as PC, BCS, or AF by four coders who heard the samples in random order and were blinded to the interval at which the samples were collected. For each sample, percent scores were calculated for the PC, BCS and AF levels. The percentages of utterances from the BCS and AF levels were combined to represent children’s ability to produce speech-like vocalizations.

A total of 61CASP response sets were scored by four graduate research assistants trained to use the 0, 1, or 2 point scale. The maximum score of the CASP is 20 points. In order to assess concurrent validity with speech sample data (i.e. the total percentage of BCS and AF vocalizations per sample), CASP scores were converted to percentages as well (e.g. a score of 10 points = 50% of available CASP points).

Reliability

The intra- and inter-reliability of listener-judges’ classifications of vocalizations from speech samples (i.e., agreement that an utterance belonged at the PC, BCS, or AF level) was examined by having seven graduate research assistants reclassify approximately 11% of all utterances collected during the first 2 years of CI use (n = 6,985) in random order. Cohen’s Kappa for intra-reliability was found to be .976 and inter-reliability was .878. Both values indicated excellent agreement in determining vocalization levels (Fleiss, 1981). The point-to-point agreement scores for intra-judge and inter-judge agreement were 99% and 94%, respectively.

Approximately 25% (15 out of 61) of CASP administrations (13 different children) were re-scored in random order from video-recordings to assess intra- and inter-reliability, separately. The correlation between the total scores of the first and second scores of the original scorer (n = 1) was found to be $r = .95$ ($p<.001$). The correlation between two different scorers (n = 4 different scorers) was found to be $r = .98$ ($p<.001$). Both intra- and inter reliability measures indicated excellent agreement. Point-to-point agreement scores for separate CASP items were 90.7 % for intra- and 85.3% for inter-reliability measures. All re-checking of CASP scores and recoding of speech samples took place at least 3 months after the original scoring/coding.

Statistical Analysis

Pearson correlations were completed to assess the strength of association between CASP scores (represented as percentages of total available points) and the percentage of speech-like vocalization (BCS + AF). The correlations were completed for data from the 6, 12, 18, and 24 month post-activation sessions separately, and for all intervals combined. A *p* value of ≤ 0.01 was selected as the criterion for determining whether the two sets of scores were significantly associated.

Results

Descriptive Findings

Figure 1 displays the mean percentages of speech-like utterances for speech samples and CASP scores (represented as the percentage of total available points) for each interval. As this figure shows, means from the two measures were highly similar at each interval. Speech sample means show that approximately one-third of all utterances were speech-like at 6 months post-activation. At 12 months, speech-like utterances increased to 59%, making them the majority of child utterances. During the 18 and 24 months samples, speech-like utterances became dominant (77 % and 85%, respectively). Similar increases were seen for CASP scores. As Figure 1 shows, the mean CASP score at 6 months was 39.69 %, and consistent growth was observed at 12-month (66.25 %), 18-month (80.00 %), and 24-month (86.33 %) intervals. The trend lines for each measure were closely aligned, ending with nearly identical values at 24 months. These descriptive findings indicate highly similar patterns of increase across the four intervals.

Correlations between Sample Data and CASP Scores

As Figure 2 shows, when all the four intervals were analyzed together, the overall correlation between speech-like utterances from samples and CASP scores was relatively strong and statistically significant ($r = .752$, $p <.001$), indicating a strong association between CASP scores and speech sample measures. As presented in Figure 2, data points for both measures moved toward ceiling levels across the intervals. By the 24 month interval, several children closely approached ceiling level for each measure: five children produced samples in which ≥94% of the utterances were speech-like, and nine had CASP scores of ≥90%. Scores for each child at each interval can be found in Table 3.

Pearson correlation analyses were also conducted to investigate the relationships between the two measures at each interval. Figure 3 shows that a significant correlation was found at 6 months post- activation ($r = .682$, $p = .004$). Correlations at the 12- and 18-months intervals (see figures 5 and 6) were moderate in strength but did not meet criteria for significance ($r = .470$, $p = .066$, and $r = .503$, $p = .066$, respectively; see figures 4 and 5). A very low correlation was found at 24 months post-activation ($r = -.077$, $p = .784$).

Discussion

The main purpose of this investigation was to determine whether CASP scores were closely aligned with estimates of vocal development taken from speech samples. When all intervals are considered together, a strong correlation between these two measures was found. A significant correlation was also found for the 6-month interval, but not for subsequent intervals individually. The lack of significant correlations at months 12, 18, and 24 appears to result from an interaction between limited power at these intervals, increasing ceiling level effects, and the age-related characteristics of the behaviors being studied. Regarding the last point, both sample and CASP scores are not likely to identify substantial progress in vocal development beyond 18 – 24 months of life in typically developing children. That is, by these ages, speech-like productions (BCS and AF) are becoming dominant in the utterances of TD children (Nathani et al., 2006). Similar dominance has also been observed during the first two years of CI use (Ertmer et al., 2007; Ertmer & Jung, manuscript in preparation). Thus, the wide range of scores needed for high-level correlations at later intervals was not expected for later intervals. Considering these methodological and developmental issues, the overall correlation measure (See Figure 2) provides the most comprehensive and representative estimate of the association between CASP scores and speech sample data. Further evidence of a strong association between the two measures can be seen in the similarity of means and standard deviations at each interval (Figure 1). Taken together, these data indicate that CASP scores have high concurrent validity with estimates of the percentage of speech-like productions obtained from spontaneous speech samples.

Clinical Applications of the CASP

The current version of the CASP is intended to be a repeated-measure, criterion-reference task rather than a standardized test of post-implantation vocal development. That is, by administering the CASP at regular time intervals following implant activation (i.e., every 2, 3, or 6 months), early interventionists can track and document progress in auditory-guided speech development in a particular child. Comparisons between children are not recommended and norms based on amount of CI experience norms are not available.

The CASP can reveal progress in vocal development in at least four ways. First, CASP scores provide information about the ability to imitate a variety of vowels in isolation—one of the first indications of auditory-guided speech development (see Ertmer & Nathani Iyer, 2010 for review). Second, further progress can be seen as children imitate well-formed CV syllables and more mature utterances such as diphthongs and CVC syllables. In this way, the CASP provides evidence of progress along a continuum of speech-like utterances. Such progress has been used to infer speech perception benefits during the initial months of CI use (Ertmer, Young, & Nathani, 2007; Ertmer & Jung, 2011). Third, improved ability to imitate a variety of consonant types—especially those with limited speechreading cues—indicates that children are using audition to guided speech development. Fourth, low CASP scores at successive intervals indicate limited ability to use audition to guide speech development and suggest the need for modifications in intervention. Conversely, increasing scores during the first 2 years of CI use provide evidence of auditory-guided speech development. Thus, the CASP is an effective tool for monitoring auditory-guided advancements across a continuum of vocalization types during the first 2 years of sensory aid use. In addition, although the participants in the current study used CIs, the results of field testing indicate that the CASP can also be used to track progress in vocal development with young hearing aid users (Ertmer & Stoel-Gammon, 2008).

Administering the CASP is more time-efficient than collecting and analyzing speech samples. To evaluate vocal development through sampling and analysis with the Consolidated SAEVD-R system, approximately 50 utterances must be recorded and classified into the PC, BCS, and AF levels. This entails 20 – 30 minutes of adult –child interactions and at least1 hour to parse and to classify child utterances. The latter activities also require training and experience in identifying various types of vocalizations. Although training guides are available through textbooks, research articles (Ertmer, 2005; Ertmer & Nathani Iyer, 2010, respectively) and web sites (e.g., www.vocaldevelopment.com), much practice is needed to become competent. In contrast, the CASP can be completed and scored in 5 – 10 minutes with most children, without special training. Further, criteria for judging the acceptability of children's productions are clearly stated on the scoring sheet (Appendix A); eliminating the need to be familiar with the 23 vocalization types identified on the SAEVD-R (see Nathani, Ertmer, & Stark, 2006). In sum, the CASP is easier to use than speech sample analysis, yet yields highly similar estimates of children's vocal development status.

Another advantage of the CASP is that it requires children to produce a wide range of target consonants, vowels, and syllable shapes. Whereas speech samples often elicit consonant and vowel types, and syllable shapes familiar to the child (Warner-Czyz, Davis, & MacNeilage, 2010), the CASP requires children to match specific target utterances that might not be within their current repertoire. On-demand imitation has the potential to reveal much about children's ability to integrate hearing and speech.

Although the available data are quite limited and must be considered only preliminary, findings suggest that CASP scores might eventually be useful for identifying children who have other disabilities in addition to hearing loss. CASP scores from the only children with secondary disabilities who completed the study (F-27a and M-31) were found to be >1.5 standard deviations below the mean CASP scores at 18 months and 24 months (Table 3). Scores for both children were within 1 SD of the mean at 12 months post-activation, but subsequent scores did not match the growth seen in other children. For example, while the CASP scores of other children reached 70% or higher after 12 months of CI experience those for F-27a and M-31peaked at 65% (see Table 3). The challenging nature of the CASP for children can also be seen when CASP scores are compared to sample scores at the 24-month interval for the children with multiple disabilities. The percentage of speech-like utterances in the two children's samples were 94 and 82%, respectively, whereas CASP scores were considerably lower: 65% for both children at the same interval. The possibility that the CASP can be used to identify children with secondary disabilities seems to merit further examination. Clearly, additional data are needed to establish criteria for identifying typical and atypical progress on the CASP. However, the current data suggest that children who show limited increases in CASP scores during the second year of CI use be considered for additional assessments.

The final application note has to do with the administration of the CASP. The CASP was designed to have early interventionists and parents work together as co-administrators. It is recognized however, that parents are not always available to participate in clinical situations. In the current study, familiar early interventionists and day-care providers substituted for parents approximately 32% of the time without noticeable difficulties on the child's part. In fact, because some parents had difficulty presenting stimulus items as expected, early interventionists were often more efficient in modeling stimuli than parents. Thus, including adults who are familiar to the child can be a viable option when parents are not able to participate in the CASP.

Limitations and Future Directions

Four cautions should be kept in mind when using and interpreting the CASP. First, because norms are not currently available, the CASP must be considered solely a repeated measures, criterion-reference task that provides a way to measure of within-child progress during the first 2 years of sensory aid use. CASP scores cannot be compared across children. Second, some young children may have low CASP scores and still have made progress in vocal development. Three children (M-12, F-18, and M-13; see Table 3) had CASP scores of zero but samples revealed that speech-like utterances accounted for 32% and 42% at 6 months, and 62% of their vocalizations at 12 months, respectively. A review of their CASP video recordings showed that these children appeared to be more interested in playing with the Classical Stacker toy than imitating stimuli. Although such situations were relatively infrequent in our experience, observations of children's vocalizations in everyday situations can help determine whether CASP scores underestimate children's actual level of vocal development. Third, although field-testing of the CASP found that children as young as 12 months successfully participated in the CASP (Ertmer & Stoel-Gammon, 2008), it is expected that some very young CI recipients might not have the attention skills needed to complete the CASP at first. Such children are likely to become more successful as they become accustomed to imitation tasks during communication intervention activities. Finally, ceiling level effects may be observed after 18 or 24 months of CI use. Figures 6 and 7 suggest that as BCS and AF vocalizations become dominant, smaller increases in CASP scores are likely. However, administration of the CASP at these intervals can still provide useful clinical information regarding the production of later-developing consonant types, closed syllables, and diphthongs.

In summary, the CASP was found to have high concurrent validity with speech samples taken during the first 2 years of CI experience. It was also found to be more time-efficient than sampling procedures, making it a practical, criterion-referenced tool for monitoring vocal development in individual children. When given at regular intervals, the CASP can help early interventionists monitor and document auditory-guided speech development even before children begin to say words on a regular basis.

Acknowledgments

This research was supported by a grant to the first author from the National Institute on Deafness and other Communication Disorders (NIDCD; R01DC007863). We are especially grateful to the parents and children who made this study possible. Sincere appreciation is also offered to Michele Wilkins, Wendy Ban Deters, Monica Brumbaugh, Jennifer Haney, Monica Lynch, and Lyra Repplinger, at Childs Voice school (Wood Dale, IL); Maria Sentelik, Margo Appenzeller, Megan Mercurio, Carey Evans Ratliff, and Meredith Wessels of Ohio Valley Voices (Loveland, OH); Mary Daniels, Cheryl Broekelmann, Kathy Gallagher, Barb Meyers, Judy Odendahl, and Audrea Strelo at the St. Joseph Institute for the Deaf (Chesterfield, MO); Teri Ouellette and Carrie Tamminga at the St. Joseph Institute for the Deaf (Indianapolis, IN); and Jean Moog, Betsy Moog, Rhonda Bennight, Mariana Helbig, and Laurie Preusser at the Moog Center (Chesterfield, MO) for their indispensible assistance in recruiting participants and collecting speech samples and CASP scores. Katie Connell Kirleis, Christy Macak, Elesha Sharp, Jennifer Slanker, Diana True Kloiber, A. J. Olszewski, and Stephanie Wieczorek helped with data management and analysis.

References

Ertmer DJ. Emergence of a vowel system in a young cochlear implant recipient. Journal of Speech, Language, and Hearing Research. 2001; 44:803–813.

Ertmer, DJ. The Source for Children with Cochlear Implants. East Moline, IL: LinguiSystems, Inc; 2005.

Ertmer D, Jung J. Prelinguistic vocal development in young cochlear implant recipients and typically developing infants: Year 1 of robust hearing experience. Journal of Deaf Studies and Deaf Education. 2011; 17:116–132. [PubMed: 21586617]

Ertmer DJ, Mellon JA. Beginning to talk at 20 months: Early vocal development in a young cochlear implant recipient. Journal of Speech, Language, and Hearing Research. 2001; 44:192–206.

Ertmer, DJ.; Nathan Iyer, S. Prelinguistic vocalizations in infants and toddlers with hearing loss: Identifying and stimulating Auditory-guided Speech Development. In: Marschark, M.; Spencer, P., editors. The Oxford University Handbook Deaf Studies, Language, and Education. Vol. Volume 2. New York, NY: Oxford University Press; 2010. p. 360-375.

Ertmer DJ, Stoel-Gammon C. The Conditioned Assessment of Speech production: A tool for assessing auditory-guided speech development in young children with hearing loss. The Volta Review. 2008; 108:59–80.

Ertmer DJ, Young NM, Nathani S. Vocal development in young children with cochlear implants: A preliminary examination of sequence, time-course, and age-at-implantation. Journal of Speech, Language, and Hearing Research. 2007; 50:393–407.

Fleiss, JS. Statistical Methods for Rates and Proportions. New York, NY: Wiley; 1981.

Iyer SN, Oller DK. Prelinguistic vocal development in typical hearing and infants with severe-to-profound hearing loss. The Volta Review. 2008; 108:115–138. [PubMed: 21499444]

Kent RD, Osberger MJ, Netsell R, Hustedde CG. Phonetic development in identical twins differing in auditory function. Journal of Speech and Hearing Disorders. 1987; 52:64–75. [PubMed: 3807347]

Koopmans-van Beinum, FJ.; van der Stelt, JM. Early stages in the development of speech movements. In: Lindblom, B.; Zetterstrom, R., editors. Precursors of early speech. Basingstoke, Hampshire: Macmillan Press; 1986. p. 37-50.

Lynch MP, Oller DK, Steffens ML, Buder EH. Phrasing in Prelinguistic vocalizations. Developmental Psychology. 1995; 28:3–25.

McCaffery HA, Davis BL, MacNeilage PF, von Hapsburg D. Multichannel cochlear implantation and the organization of early speech. The Volta Review. 1999; 101:5–28.

Moore JA, Bass-Ringdahl S. Role of infant vocal development in candidacy for and efficacy of cochlear implantation. Annals of Otology, Rhinology, and Laryngology. 2002; 111:52–55.

Nathani S, Ertmer DJ, Stark RE. Assessing vocal development in infants and toddlers. Clinical Linguistics and Phonetics. 2006; 20:351–369. [PubMed: 16728333]

Nathani S, Oller DK. Beyond ba-ba and gu-gu: Challenges in coding infant vocalizations. Behavioral Research Methods. 2001; 33:321–330.

Nittrouer S, Burton LT. The role of early language experience in the development of speech perception and phonological processing abilities: evidence from 5-year-olds with histories of otitis media with effusion and low socioeconomic status. Journal of Communication Disorders. 2005; 38:29–63. [PubMed: 15475013]

Oller, DK. The emergence of the sounds of speech in infancy. In: Yeni-Komshian, G.; Kavanaugh, J.; Ferguson, C., editors. Child phonology. New York, NY: Academic Press; 1980. p. 93-112.

Oller, DK. The emergence of the speech capacity. Mahwah, NJ: Lawrence Erlbaum Associates; 2000.

Oller DK, Eilers R. The role of audition in infant babbling. Child Development. 1988; 59:441–449. [PubMed: 3359864]

Oller DK, Eilers RE, Bull DH, Carney AE. Pre-speech vocalizations of a deaf infant: A comparison with normal metaphonological development. Journal of Speech and Hearing Research. 1985; 28:47–63. [PubMed: 3981997]

Roug L, Landberg I, Lundberg LJ. Phonetic development in early infancy: A study of four Swedish children during the first 18 months of life. Journal of Child Language. 1989; 16:19–40. [PubMed: 2925811]

Schauwers K, Gillis B, Daemers K, de Beukelaer C, Govaerts PJ. Cochlear implantation between 5 and 20 months of age: The onset of babbling and the audiologic outcome. Otology and Neurotology. 2004; 25:263–270. [PubMed: 15129103]

Shriberg LD, Gruber FA, Kwiatkowski J. Developmental phonological disorders III: Long-term speech normalization. Journal of Speech, Language, and Hearing Research. 1994; 37:1151–1177.

Smit AB, Hand L, Freilinger JJ, Bernthal JE, Bird A. The Iowa articulation norms project and its Nebraska replication. Journal of Speech and Hearing Disorders. 1990; 55:779–798. [PubMed: 2232757]

Stark, RE. Stages of speech development in the first year of life. In: Yeni-Komshian, G.; Kavanaugh, J.; Ferguson, C., editors. Child phonology. Vol. Volume 1. New York, NY: Academic Press; 1980. p. 73-90.

Stoel-Gammon C, Otomo K. Babbling development of hearing-impaired and normally hearing subjects. Journal of Speech and Hearing Disorders. 1986; 51:33–41. [PubMed: 3945058]

Vihman, MM. Phonological Development: The Origins of Language in the Child. Cambridge, MA: Blackwell Publishers; 1996.

Warner-Czyz AD, Davis BL, MacNeilage PF. Accuacy of consoant-vowel syllables in young cochlear implant recipients and hearing children in the single-word period. Journal of Speech, Language, and Hearing Research. 2010; 53:2–17.

Zlatin, M. Preliminary descriptive model of infant vocalization during the first 24 weeks: Primitive syllabification and phonetic exploratory behaviour. National Institutes of Health Research Gran; 1975. (Final Report, Project No 3-4014, NE-G-00-3-0077)

Appendix A

Directions for Administering and Scoring

The Conditioned Assessment of Speech Production (CASP)

David J. Ertmer and Carol Stoel-Gammon (2008)

(Reprinted with permission from the A. G. Bell Association)

1. Warm-up Items:

- **a.** After getting the child's attention, the early interventionist models the first warm-up vocalization (/u/) while holding a toy reinforcer (e.g., a star-shaped piece for the "Classical Stacker" musical/light-up ring-post toy) next to her mouth. Models are spoken at slightly louder than conversational intensity level and without unusual visual or intonation cues. The early interventionist says /u/ or "Say /u/" while looking at the parent or another adult who is familiar to the child.

- **b.** The parent imitates the modeled vocalization. The parent is given the reinforcer and places it on the post. The parent and early interventionist respond enthusiastically as the stacker toy lights up and plays a few musical notes.

- **c.** The parent gets the child's attention and then models the same vocalization (i.e., /u/ or "Say /u/") while holding the toy reinforcer next to his/her mouth and looking at the child.

  When the child vocalizes, he/she is praised and allowed to place the star on the post. Any vocalization is reinforced. To maintain a game-like situation, the child is allowed to place the star on the post even if no attempt to imitate is made.

- **d.** Repeat steps a – c with the remaining warm-up vocalization /o/ if the child does not respond to /u/. Move to Level 1 if the child attempts to imitate either warm-up item.

  NOTE: EIs may choose to modify these procedures if the child has a different, previously established routine for eliciting speech (e.g., if the reinforcer is typically given to the child before an imitative attempt). In cases where the child responds more consistently to the early interventionist than to the parent, the early interventionist and parent roles can be reversed. Two familiar EIs can also administer the CASP if parents are unavailable. Care should be taken, however, to make sure the parent participates in the process whenever possible and to ensure that three adult models are given before the child is expected to imitate each item.

2. Scored items:

a. The first vocalization of Level 1 is modeled by the early interventionist for the parent as described in step 1a.

b. The parent imitates the vocalization and receives a star reinforcer.

c. The parent turns to the child, gets his/her attention, and then models the vocalization while holding the star next to her mouth. The child imitates the model.

d. All of the child's imitative attempts are praised and reinforced immediately. The EI transcribes the child's response in the space provided on the score sheet.

e. If the child's production is fully acceptable (receives 2 points), go to the next stimulus item and repeat steps 2a – d.

f. If the child does not respond or the imitative response is not fully acceptable, note NR (No Response) or transcribe the child's original attempt on the first line under the stimulus item.

i. Repeat steps 2a – d with the same stimulus to give the child a second chance. Transcribe and score the child's second attempt.

ii. Only 1 repetition is allowed for each stimulus item.

iii. The star reinforcer is given even if the child does not respond.

g. Continue introducing other stimulus items as in steps 2 a – d until all the items at Level 1 (Pre-canonical) have been presented to the child.

h. Present stimulus items from Level 2 (Basic Canonical Syllables) using the procedures in steps 2a – g.

i. Present stimulus items from Level 3 (Advanced Forms) following steps 2a-g if the child has scored at least 1 point on Level 2. Testing may be discontinued if the child does not receive any points on Level 2 and parent reports that canonical syllables (CV syllables) are seldom/never produced. All stimulus items should be presented if the child is reported to produce canonical syllables.

3. Scoring:

a. Scoring criteria are presented on the score sheet.

If more than one imitation is elicited, only the most acceptable imitative response is scored (i.e., the response with the highest score).

b. The child's productions are to be compared with the parent/clinician's model. For example, an imitative production can be fully acceptable if it matches a model that was slightly different from the intended target (e.g., Mother says /tæk/ instead of /tʌk/ and child says /tæk/).

c. Sum the number of points for the total score.

4. Administration intervals:

The CASP can be given at 2-, 3-, 4- or 6-month intervals. Results are compared to previous scores for the same child.

Appendix B

The Conditioned Assessment of Speech Production (CASP)

David J. Ertmer and Carol Stoel-Gammon (2008)

(Reprinted with Permission from the A. G. Bell Association)

Child's Name ____________ DOB _________________________ CA __________ Date ________________

Parent __________ Clinician _______________ Sensory aid type __________

Months of sensory aid use__________

<u>Directions for parents</u>: I am going to say some sounds for you to imitate. Then you will say the same sounds for your child to imitate. Try to say the sounds in the same way and at the same loudness level that I use. We will give (child's name) toys and praise for playing this game with us.

Warm-up Sounds: /u/ : Child imitates readily __________ Imitates after pause __________ No Response __________

/o/ : Child imitates readily __________ Imitates after pause __________ No Response __________

Level 1

Precanonical Vocalizations

Stimuli for Models Transcribed Responses	**0 Points**	**1 Point**	**2 Points**	**Score**
1.Prolonged central vowel in isolation: /ʌ/ 1. __________ 2. __________	1. No response 2. Two or more vowels that do not match target 3. Response is not a vowel (e.g., squeal, raspberry, /m:/) 4. CV syllable(s) without target vowel (e.g., /bu/)	1. Two or more vowels that match target 2. Single vowel that is not /ɑ/ or /ʌ/ 3. CV syllable containing target vowel (e.g., [b(ʌ)	1. One central vowel (i.e., /ɑ/ or /ʌ/)	
2. Two high-front vowels: (/i/ /i/) 1.__________ 2.__________	1. No response 2. Response is not a vowel 3. Syllables with vowels that do not match target (e.g., /bu/)	1. Single vowel that matches target 2. Two vowels that are not /i/ or /I/ 3. Two vowels, only one of which matches the target (e.g., /i/ /ʌ/) 4. CV syllables containing target vowel (e.g., [bibi])	1. Two high front vowels in any combination (e.g., /i/ /or /I/)	
3. Three low-front vowels: /æ/ /æ/ /æ/ 1. __________ 2. __________	1. No response 2. Response is not a vowel 3. Syllables with vowels that do not match target (e.g., [bu])	1. Single /æ/ or / ɛ/ 2. Two matching vowels (e.g., /ææ /, /ɛɛ/) 3. Three vowels, only one /æ/ or /ɛ/ 4. Two or three non-matching vowels (i.e., none are /æ/ or /ɛ/)	1. Three low or mid front vowels (i.e., /æ/ or / ɛ/)	

Stimuli for Models Transcribed Responses	0 Points	1 Point	2 Points	Score
		5. CV syllables containing target vowel (e.g., [bæbæbæ])		

Level 2

Basic Canonical Syllables

Stimuli for Models Transcribed Responses	0 Points	1 Point	2 Point	Score
4. CV syllable with a bilabial stop consonant: [bɑ] 1. ________ 2. ________	1. No response 2. Vowel without consonant	1. CV syllable in which only the C or the V match the model (e.g., [bi] or [kʌ]) 2. Two or more matching CVs (e.g., [bɑbɑbɑ] or [pʌpʌ]) 3. CVC syllable with matching C or V	1. A single CV with a bilabial stop consonant and /ɑ/ or / ʌ / (i.e., [bɑ] [pɑ], [bʌ], or [pʌ])	
5. CV syllable with a bilabial nasal: [mɑ] 1. __________ 2. __________	1. No response 2. Vowel in isolation 3. Consonant in isolation	1. CV syllable in which only the C or the V match the model 2. Two or more matching CVs (e.g.., [mɑmɑmɑ] or [mʌmʌ]) 3. CVC syllable with matching C or V	1. A single CV with a bilabial nasal consonant and /ɑ/ or / ʌ / (i.e., [mɑ] or [mʌ])	
6. CV syllable with a bilabial glide: [wɑ] 1. __________ 2. __________	1. No response 2. Vowel in isolation	1. CV syllable in which only the C or the V match the model (e.g., [wi] or [mɑ]) 2. Two or more matching CVs (i.e., [wɑwɑwɑ] or [wʌwʌ] 3. CVC syllable with matching C or V	1. A single CV with a /w/ and /ɑ/ or / ʌ/(i.e., [wɑ] or [wʌ]	
7.CV syllable with a velar stop: [kɑ] 1. __________ 2. __________	1. No response 2. Vowel in isolation 3. Consonant in isolation	1. CV syllable in which only the C or the V match the model (e.g., [ki] or [tɑ]) 2. Two or more matching CVs (i.e., [gɑgɑ gɑ] or [kʌkʌ]) 3. CVC syllable with matching C or V	1. A single CV with / k/ or /g/ and /ɑ/ or /ʌ/ (i.e., [kɑ], [gɑ] or [kʌ], [gʌ])	
8. CV syllable with a lingua-alveolar fricative: [sɑ] 1. __________ 2. __________	1. No response 2. Vowel in isolation 3. Consonant in isolation	1. CV syllable in which only the C or the V match the model (e.g., [si] or [hɑ]) 2. Two or more matching CVs (i.e., [sʌsʌsʌ] or [zɑzɑ]) 3. CVC syllable with matching C or V	1. A single CV with [s[or [z] and [ɑ] or /ʌ / (i.e., [sɑ], [zɑ], [sʌ], or [zʌ])	

Level 3

Advanced Forms

Stimuli for Models Transcribed Responses	**0 Points**	**1 Point**	**2 Points**	**Score**	
9. C+ diphthong syllable: [naI] 1. __________ 2. __________	1. No response 2. Isolated vowel 3. Isolated C (e.g., [m]) 4. CV without a diphthong 5.Non-matching diphthong (e.g. /aU/)	1. Matching diphthong in isolation 2. /n/ + non-matching diphthong (e.g., [noI]) 3. Non-matching C with matching diphthong (e.g., [maI]) 4. /n/ plus vowel (e.g., [nɑ]) 5. CVC syllable with /n/ and [aI] (e.g., [naIk])	1. /n/ plus matching diphthong (i.e., [naI])		
10. CVC: [tʌk] 1. __________ 2. __________	1. No response 2. Vowel in isolation 3. Isolated consonant (e.g. [s]) 4. VC or CV syllable	1. CVC syllable with non-matching Cs and V (e.g., [pip]) 2. CVC syllable with one or two segmental errors (e.g., [tɑp])	1. CVC syllable with initial /t/ or /d/and final /k/ or /g/ combined with /ɑ/ or /ʌ/ (e.g., [tʌk], [dʌg], [tɑk], [dɑg])		**Total Score**

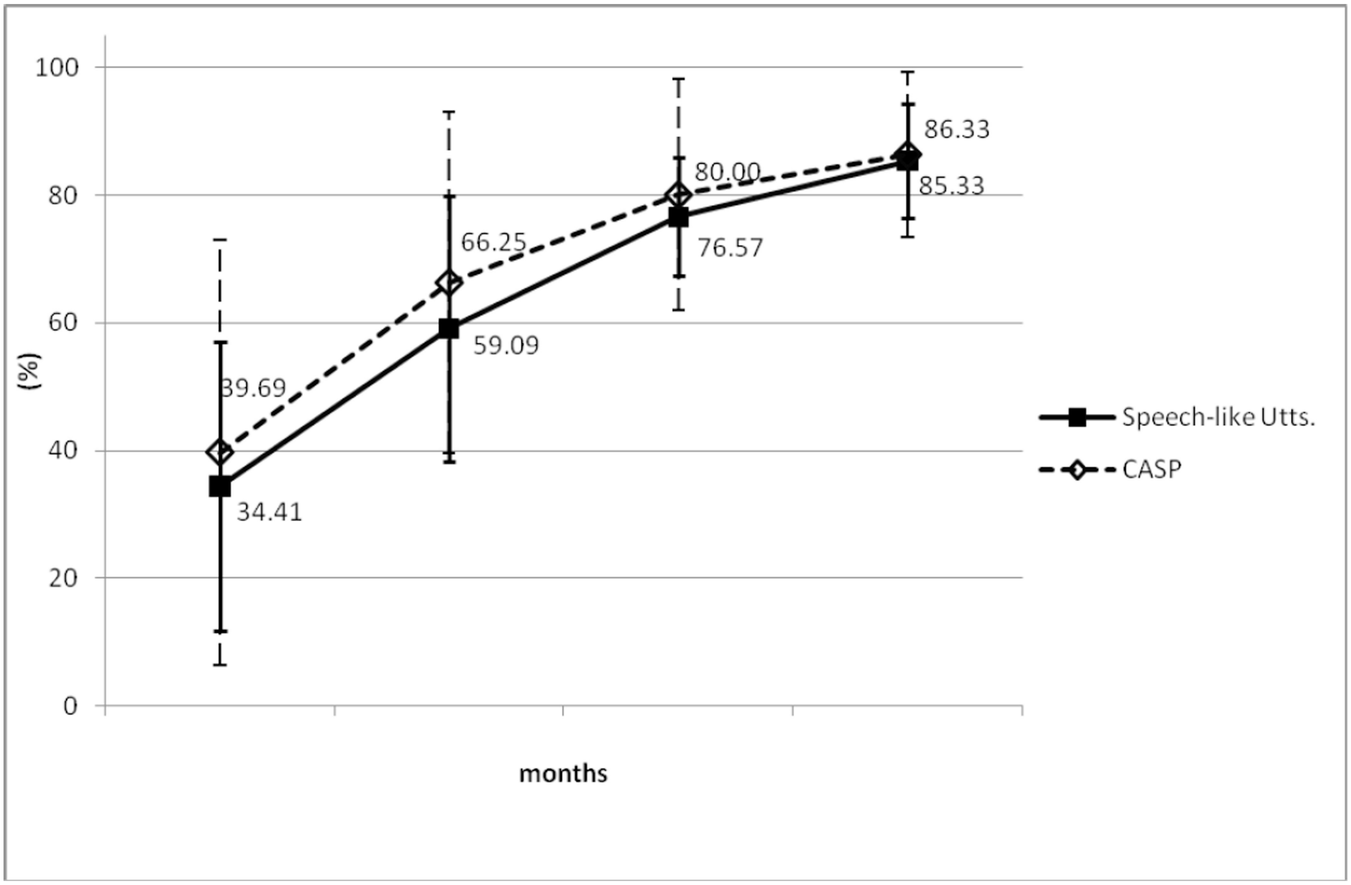

Figure 1.
Percent of Speech-like Utterances and CASP scores at each interval.

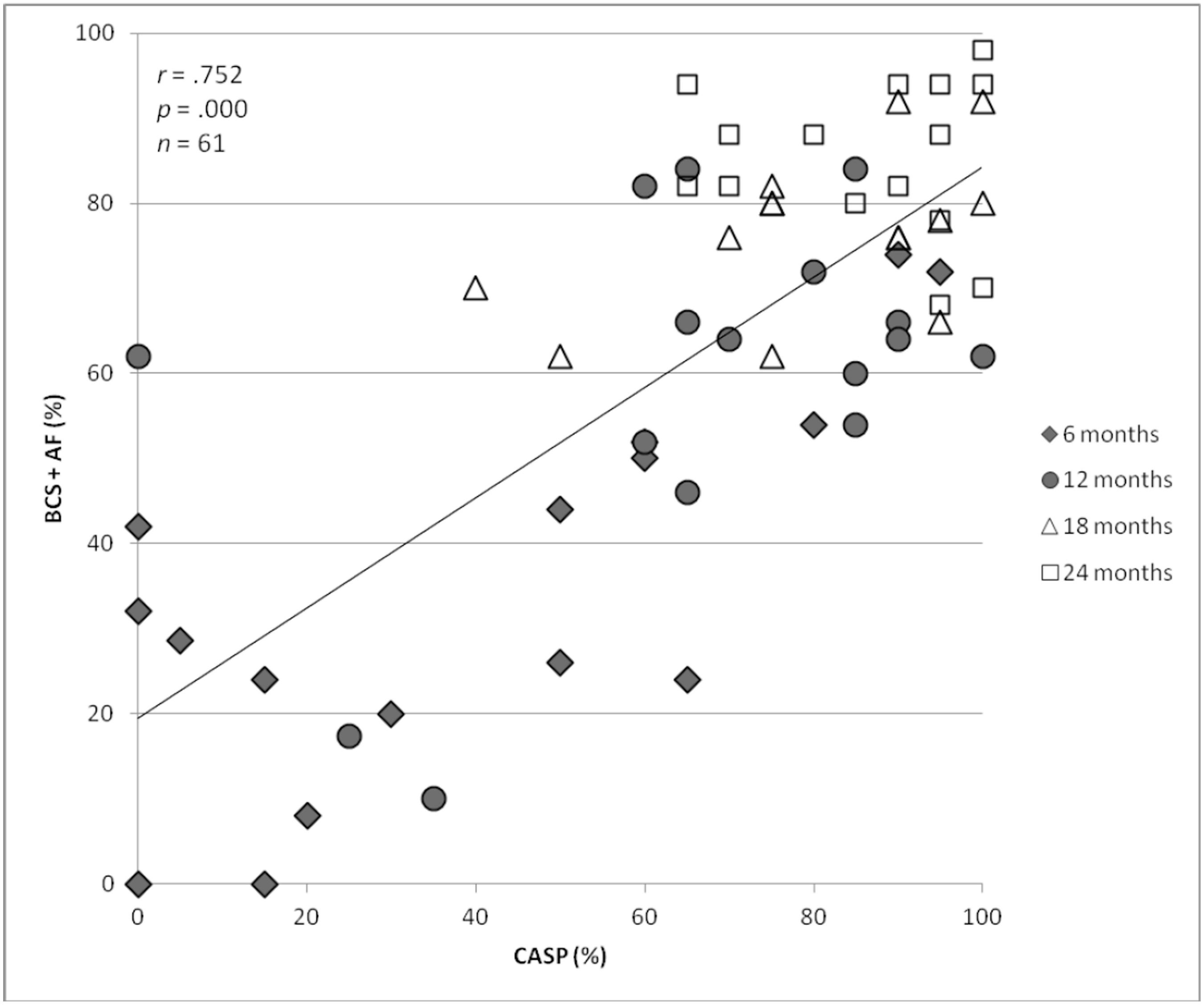

Figure 2.
Scatter plot for all intervals and overall correlation between percentage of speech-like utterances from samples and CASP scores during 2 years of CI use.

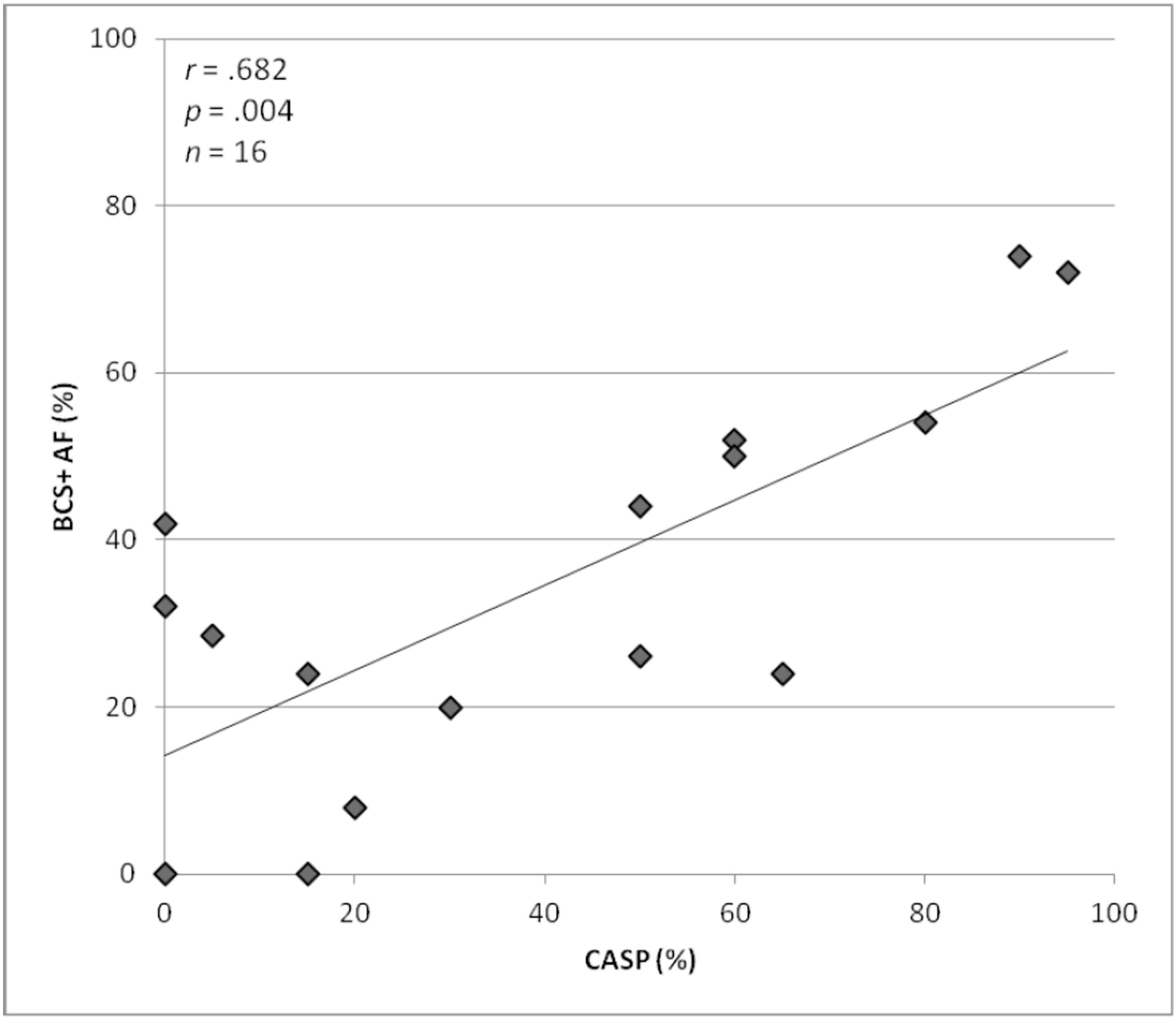

Figure 3.
Scatter plot and correlation between percentage of speech-like utterances from samples and CASP scores at 6 months post-activation.

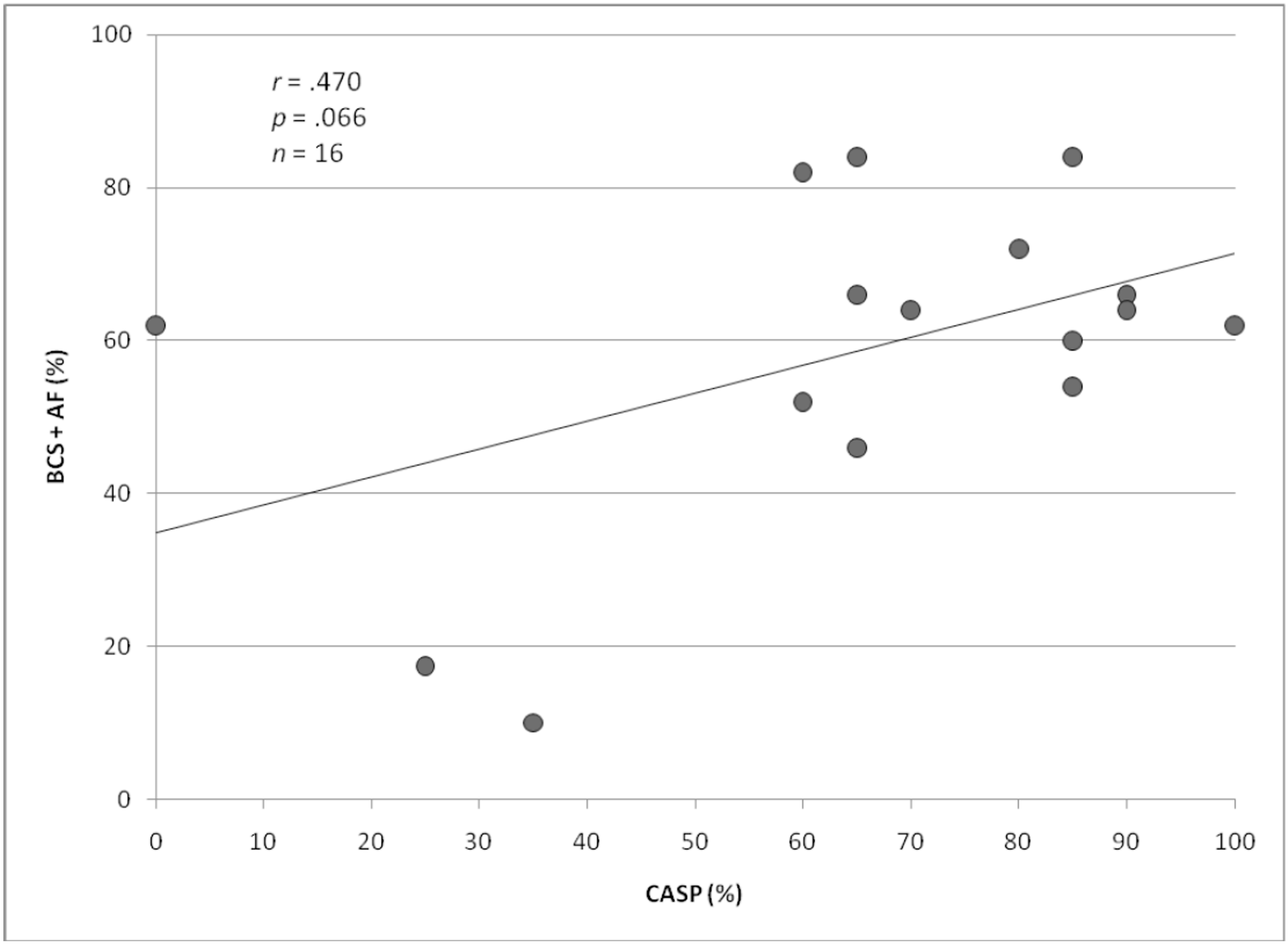

Figure 4.
Scatter plot and correlation between percentage of speech-like utterances from samples and CASP scores at 12 months post-activation.

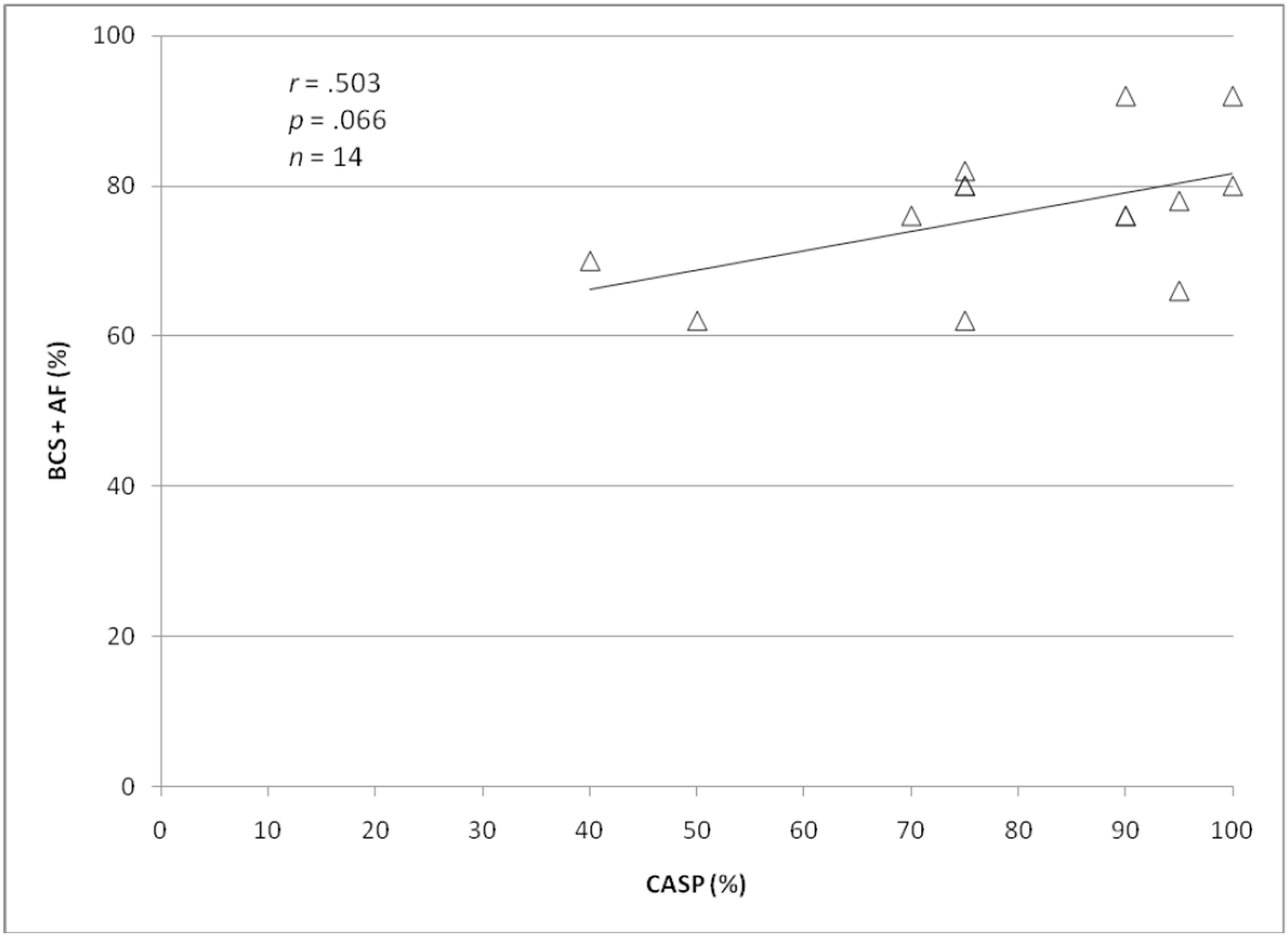

Figure 5.
Scatter plot and correlation between percentage of speech-like utterances from samples and CASP scores at 18 months post-activation.

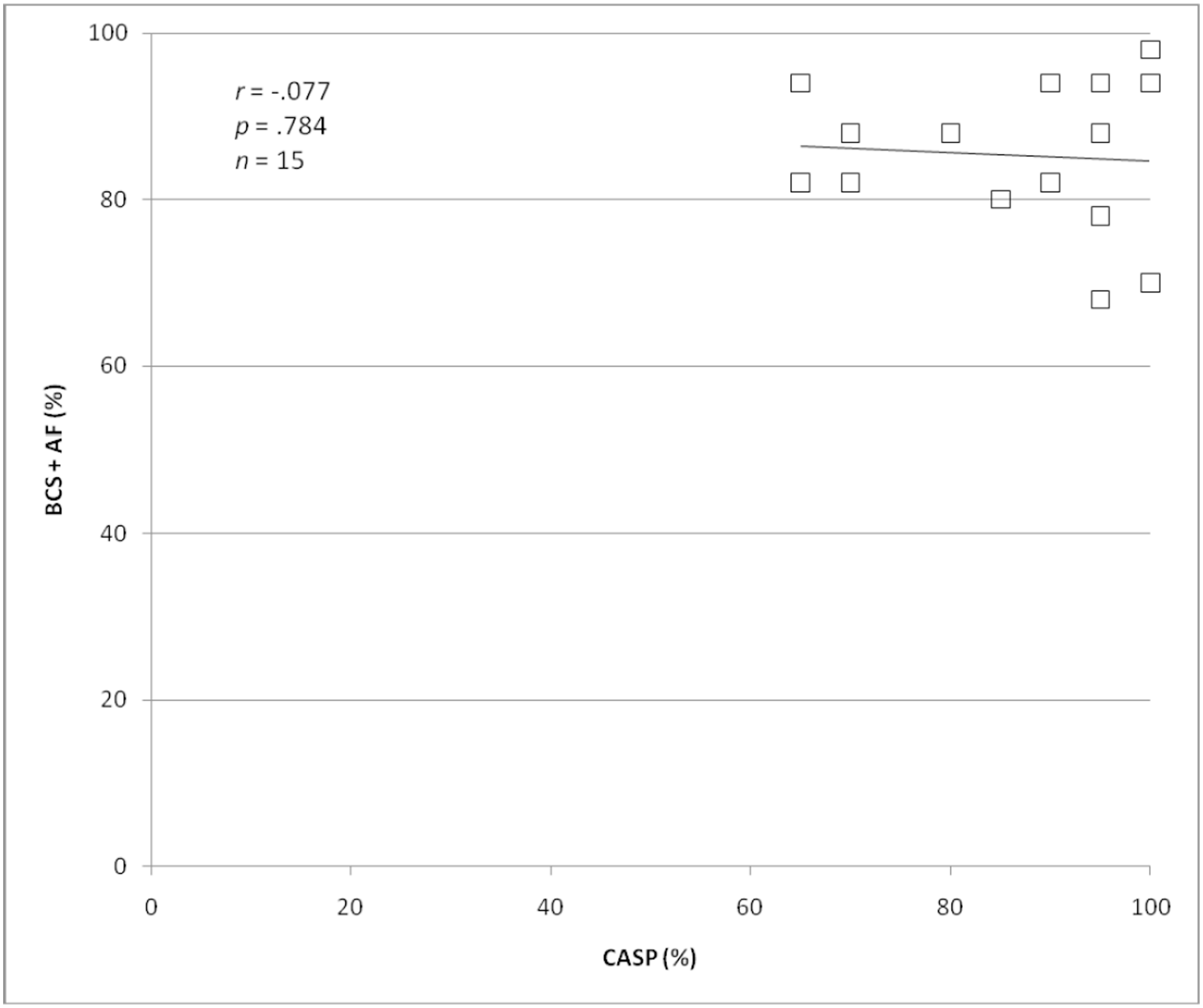

Figure 6.
Scatter plot and correlation between percentage of speech-like utterances from samples and CASP scores at 24 months post-activation.

Table 1

Levels of the Stark Assessment of Early Vocal Development-Revised and the Consolidated SAEVD-R, ages of expected emergence in TD children, and examples of vocalization types for each level (Nathani, Ertmer, & Stark, 2006).

SAEVD-R Levels	Consolidated SAEVD-R Levels	Age of Emergence (months)	Examples of Vocalization Types
Level 1. Reflexive vocalizations	PC	0 – 2	Crying, vegetative (coughs, hiccups), grunts (quasi-resonant nuclei)
Level 2. Control of Phonation	PC	1 – 4	Primitive vowel-like sounds with poor vocal quality (fully resonant nuclei), “goos”, closants (e.g., clicks, smacks, trills)
Level 3. Expansion	PC	3 – 8	Squeals, vowels and vowel-like productions, consonants, marginal babbling **
Level 4. Basic Canonical Syllables	BCS	5 – 10	Consonant-vowel syllables with rapid transitions (e.g., CV, CVCV, CVCVCV), whispered vocalizations
Level 5. Advance Forms	AF	9 – 18 *	Closed syllables (CVC), CCV syllables, diphthongs, VC syllables, jargon ***

* The ages in this table are based on TD children from English-speaking homes. Age of emergence for some Advance Form vocalization types may differ across languages (Vihman, 1993).

** A series of primitive and slowly combined consonant and vowel-like productions.

*** More than two CV syllables containing at least two different consonant and vowel types and the presence of changes in intonation or stress pattern during the series (e.g. [gagadibu] with rising intonation pattern).

Table 2

Demographic and hearing information for the participants

Child Code (Gender-age at first CI activation)	Gender	HL identified (months)	Age at 1st CI activation (months)	Age at 2nd CI implanted (months)	Etiology	Device (Processing Strategy)	Pre-CI thresholds (Unaided better ear-dB HL)	Mean CI-aided Thresholds (SF[1] or better ear) last available audiogram (months post activation)
Unilateral								
M-12	M	NHS[2]	12		Unknown	Freedom (ACE[3])	106	29 (19)
M-16	M	NHS	16		Unknown	PSP[4] (HiRes-P[5])	Bilateral profound[a]	13 (6)
F-18a	F	NHS	18		Unknown/family history	Freedom (ACE)	Aided 78; NR≥4k	30 (10)
M-21	M	11	21		Malformed cochlea	Freedom ACE)	76; NR[6] ≥4k	26 (23)
F-25	F	NHS	25		Unknown/ Dysplasia[b]	Freedom (ACE)	80	26 (24)
M-26	M	20	26		Complicated [c]	Freedom (ACE)	90; NR≥4k	22 (18)
F-27	F	NHS	27		Unknown	PSP (HiRes-P)	89	23 (22)
F-36	F	22	36		Cytomegalo virus	Freedom (ACE)	NR	22.5 (24)
F-36a[d]	F	NHS	36		Unknown	Freedom (ACE)	96; NR≥2k	18 (23)
Bilateral								
M-9	M	NHS	9	22	Unknown	Freedom (ACE)	NR	16.7 (25)
M-13	M	NHS	13	13	Connexin 26	Freedom (ACE)	NR	21.7 (20)
F-13	F	NHS	13	19	Unknown	Freedom (ACE)	NR ABR[7]	25 (18)
F-13a	F	NHS	13	27	Unknown	Freedom (ACE)	100	20 (23)

Child Code (Gender-age at first CI activation)	Gender	HL identified (months)	Age at 1st CI activation (months)	Age at 2nd CI implanted (months)	Etiology	Device (Processing Strategy)	Pre-CI thresholds (Unaided better ear-dB HL)	Mean CI-aided Thresholds (SF[1] or better ear) last available audiogram (months post activation)
F-18	F	13	18	20	Unknown	Freedom (ACE)	100	25 (21)
F-19	F	NHS	19	38	Connexin 26	PSP and Harmony (HiRes-P)	Mod-severe to profound [e]	39 (24)
F-21	F	13	21	21	Unknown	Freedom (ACE)	94	37 (16)
F-27a [*]	F	17	27	27	Unknown	Freedom (ACE)	SDT 90	36 (23)
M-27 [*]	M	NHS	27	34	Unknown	Freedom (ACE)	65 for 2 freq; NR≥4k	29 (12)
M-31 [*]	M	25	31	49	Cytomegalo virus	Harmony (HiRes-P with fidelity 120)	NR	13 (23)
Mean			21.47	27.00				24.84
SD			8.02	10.67				7.38

[*] Children with secondary disabilities

[a] No audiogram on file; hearing loss reported as “bilateral profound”,

[b] Bulbous deformity on apical turns bilaterally,

[c] Apnea of prematurity, indirect hyperbilirubinemia, ototoxic medication exposure, presumed sepsis, and cerebellar hemorrhage,

[d] identified with a mild bilateral loss by ABR testing at 1 month; bilateral mild to severe loss at 19 months, and a moderately severe to profound loss (right ear) with a severe to profound hearing loss (left ear) at 20 months of age, and

[e] No audiogram on file; hearing loss reported as “moderately severe to profound.”

[1] Sound Field,

[2] Newborn Hearing Screening,

[3] Advanced Combinational Encoder,

[4]Platinum Series™ Sound Processor,

[5]HiResolution,

[6]No response to pure- or warble-tones, and

[7]Auditory Brainstem Response.

Table 3

Percent of points earned on the CASP and percent of BCS, AF, and Speech-like (BCS +AF) utterances produced at each interval by the participants. Gray areas indicate missing data.

Child (gender-age at activation)	age at activation (months)	6 months				12 months				18 months				24 months			
		CASP	BCS	AF	BCS+AF	CASP	BCS	AF	BCS+AF	CASP	BCS	AF	BCS+AF	CASP	BCS	AF	BCS+AF
M-9	9	5	29	0	29	65	40	26	66	90	46	30	76	100	22	48	70
M-12	12	0	30	2	32	65	36	48	84	75	28	52	80	70	20	68	88
F-13	13					100	34	28	62	90	28	48	76	90	12	82	94
F-13a	13	30	6	14	20					75	52	28	80	90	44	38	82
M-13	13	0	0	0	0	0	40	22	62	75	26	36	62	80	26	62	88
M-16	16	15	16	8	24	25	17	0	17								
F-18	18	0	36	6	42	85	38	16	54	70	22	54	76	95	20	48	68
F-18a	18	50	24	2	26												
F-19	19					80	64	8	72	75	34	48	82	95	50	38	88
M-21	21	60	38	14	52	90	24	42	66	100	38	54	92	100	20	78	98
F-21	21	20	8	0	8												
F-25	25	95	44	28	72	90	28	36	64	95	46	20	66	95	30	48	78
M-26	26	65	16	8	24	60	40	42	82	90	48	44	92	70	24	58	82
F-27	27	80	46	8	54	85	26	58	84	100	20	60	80	100	12	82	94
F-27a*	27	15	0	0	0	35	10	0	10	50	40	22	62	65	56	38	94
M-27*	27	50	38	6	44	65	44	2	46								
M-31*	31					60	46	6	52	40	52	18	70	65	50	32	82
F-36	36	60	36	14	50	70	24	40	64					85	48	32	80
F-36a	36	90	38	36	74	85	34	26	60	95	22	56	78	95	48	46	94
Mean	21.47	36.69	25.29	9.13	34.41	66.25	34.09	25.00	59.09	80.00	35.86	40.71	76.57	86.33	32.13	53.20	85.33
SD	8.02	33.19	15.60	10.35	22.61	26.68	12.71	18.39	20.80	18.08	11.62	14.67	9.30	13.02	15.39	17.56	9.00

* children with secondary disabilities