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Nonverbal Cognitive Development in Children With Cochlear Implants: Relationship Between the Mullen Scales of Early Learning and Later Performance on the Leiter International Performance Scales–Revised

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Abstract

Methodologically, longitudinal assessment of cognitive development in young children has proven difficult because few measures span infancy through school age. This matter is further complicated when the child presents with a sensory deficit such as hearing loss. Few measures are validated in this population, and children who are evaluated for cochlear implantation are often reevaluated annually. The authors sought to evaluate the predictive validity of subscales of the Mullen Scales of Early Learning (MSEL) on Leiter International Performance Scales–Revised (LIPS-R) Full-Scale IQ scores. To further elucidate the relationship of these two measures, comparisons were also made with the Vineland Adaptive Behavior Scale–Second Edition (VABS), which provides a measure of adaptive functioning across the life span. Participants included 35 children (14 female, 21 male) who were evaluated both as part of the precandidacy process for cochlear implantation using the MSEL and VABS and following implantation with the LIPS-R and VABS. Hierarchical linear regression revealed that the MSEL Visual Reception subdomain score significantly predicted 52% of the variance in LIPS-R Full-Scale IQ scores at follow-up, $F(1, 34) = 35.80, p < .0001, R^2 = .52, \beta = .72$. This result suggests that the Visual Reception subscale offers predictive validity of later LIPS-R Full-Scale IQ scores. The VABS was also significantly correlated with cognitive variables at each time point.

Keywords

Mullen; Leiter; Vineland; nonverbal intelligence; cognitive functioning; cochlear implant; adaptive behavior

Methodologically, longitudinal assessment of cognitive development in young children has proven difficult because few measures span infancy to school age. For this reason,

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researchers typically have to change assessment measures over the course of a study or limit their investigations to a limited age span. Even well-accepted measures of cognition, such as the Wechsler Scales, change substantially from age 2½ years to middle childhood. Furthermore, few measures of cognitive development begin at birth, and of those that do, few persist beyond toddlerhood. The Vineland Adaptive Behavior Scale–Second Edition (VABS; Sparrow, Cicchetti, & Balla, 2005) is a measure that provides valuable information regarding adaptive functioning through the life span, and it has been found to correlate highly with measures of intellectual functioning (Kushalnagar et al., 2007). However, scores are based on parental perceptions of behavior rather than objective performance. There is a paucity of performance-based measures of development that can be administered across childhood without relying solely on parent report.

The Mullen Scales of Early Learning (MSEL; Mullen, 1995) have been used in a variety of populations to provide information regarding cognitive development of infants, toddlers, and young children. Normative information is available from birth to age 5 years, 8 months across a variety of domains. While patterns of performance in groups of children with Down syndrome (Fidler, Hepburn, & Rogers, 2006), autism spectrum disorders (Landa & Garrett-Mayer, 2006), Prader-Willi syndrome (Milner et al., 2005), Fragile X (Mirrett, Bailey, Roberts, & Hatton, 2004), tuberous sclerosis (Humphrey, Williams, Pinto, & Bolton, 2004), and hypothyroidism (Selva, Harper, Downs, Blasco, & Lafranchi, 2005) have shown expected trends very early in infancy, few researchers have made attempts to link performance on the MSEL with other measures of intellectual functioning appropriate for use with older children. The Visual Reception sub-domain of the MSEL was thought to predict later nonverbal cognitive development, given that it has fewer language demands than other subdomains within the MSEL and capitalizes on nonverbal, cognitive problem-solving skills. Likewise, the Leiter International Performance Scale–Revised (LIPS-R; Roid & Miller, 1997) has been used with a variety of patients. This measure assesses nonverbal cognitive development in a format requiring neither verbal instructions nor responses, rendering it particularly useful for children with hearing impairment and/or language delay. However, little information is available regarding the relationship of this measure to others commonly used (for exceptions, see Ratcliffe & Ratcliffe, 1980; Roid & Miller, 1997). The VABS, a validated measure of adaptive functioning along several subdomains (including Motor Skills, Communication, Daily Living Skills, and Socialization), has been found to correlate highly with both these measures of cognitive development and has been used with hearing-impaired children to assess both appropriateness for implantation and progress after cochlear implantation (Horn, Pisoni, Sanders, & Miyamoto, 2005; Kushalnagar et al., 2007, Kutz, Wright, Krull, & Manolidis, 2003; Stevenson et al., 2010.).

This problem of discontinuity over time is exacerbated in populations with special needs. For children with hearing impairment, even the most accepted measures of cognitive functioning are largely inappropriate because of the inherent language/hearing demands and the fact that few tests provide appropriate norms for hearing-impaired children. At our site, we follow hearing-impaired children through the cochlear implantation process, often beginning in infancy, and follow the children annually indefinitely. The purpose of this article is to provide data to support the notion that nonverbal intellectual functioning as measured by the MSEL is predictive of later nonverbal intellectual development as measured by LIPS-R. Although it is well accepted that cognitive development and adaptive skill development are highly correlated, little has been done to clarify the nature of the relationship between specific cognitive domains and particular areas of adaptive functioning. The exceptions are two studies that have examined performance on individual subdomains of the VABS (first edition; Sparrow, Balla, & Cicchetti, 1984) prior to cochlear implantation in samples of hearing-impaired children. Both groups determined that motor skills appear to be best developed among adaptive domains in this population (Horn et al., 2005; Kutz et al.,

2003), and Horn and colleagues further determined that the motor domain of the VABS was most related to language outcome measures following implantation (Horn, Pisoni, & Miyamoto, 2006).

Hearing impairment has been associated with cognitive deficits. However, when those subjects with neurological complications are removed from the sample, most studies examining the nonverbal cognitive development of hearing-impaired children find that this population generally falls within the average range (Khan, Edwards, & Langdon, 2005). While scores are on average somewhat lower than for the population as a whole, LIPS-R Full IQ estimates among severe to profoundly deaf children without cochlear implants have been found to range from low average (e.g., Kutz et al., 2003) to average (e.g., Khan et al., 2005). Several studies have suggested that nonverbal IQ improves after cochlear implantation, with an average gain cited of about 2/3 standard deviation (*SD*) for LIPS-R Full IQ (Khan et al., 2005) and for specific LIPS-R subtests (Shin et al., 2007). To these authors' knowledge, similar study of the progressive development of adaptive skills has not been undertaken. However, an inverse relationship between the overall Adaptive Behavior Composite (ABC) score from the VABS and age of testing has been found in a group of hearing-impaired children (Kutz, et al., 2003).

The primary goal of this study is to establish the relationship between two measures of cognitive functioning that have been found useful with children with hearing impairment (MSEL and LIPS-R). It is hypothesized that correlations between the two measures will be high, with the strongest relationship anticipated to be between the Visual Reception domain of the MSEL and the LIPS-R Full IQ. We also anticipate replicating the findings of others in that an improvement will be observed on measures of cognitive functioning such that our patient population is expected to perform better on average on the LIPS-R following cochlear implantation than they did on the MSEL pre-implantation. Although direct comparisons are impossible given the differences in the two measures, improvements in performance as evidenced by age-corrected standard scores are expected. With regard to adaptive functioning, we hypothesize that domains requiring the fewest language demands will correlate most strongly with cognitive measures, including Motor Skills (Motor), Daily Living Skills (DLS), and, to a lesser degree, Socialization (Soc), with the Communication (Comm) domain expected to have the lowest correlation. We postulate that adaptive functioning performance at the initial evaluation will be predictive of both adaptive functioning and cognitive functioning following implantation. Finally, we expect to find the well-established relationship between adaptive functioning and cognitive functioning both prior to and following implantation.

Method

Design

This is a longitudinal study that compared performance of children with hearing loss considered for cochlear implantation on the MSEL at their baseline evaluation and the LIPS-R at follow-up evaluation.

Participants

All children who were considered for cochlear implantation at our site receive a neuropsychological evaluation as part of their standard medical care prior to and at regular intervals following cochlear implantation. For children evaluated prior to cochlear implantation, results of the neuropsychological evaluation provide valuable information and are considered as part of the candidacy criteria by our multidisciplinary team. As such, informed consent was not received from parents, as this study is a retrospective chart

review. In total, we evaluated 276 children between July 1998 and July 2008. Of those children, 35 children (14 female, 21 male) were evaluated both as part of the precandidacy process for cochlear implantation using the MSEL and following implantation with the LIPS-R. The remaining 240 patients did not return for follow-up evaluation within the dates included, were initially old enough to complete an LIPS-R (and therefore never completed an MSEL), or at follow-up were not old enough to complete an LIPS-R and were again assessed using the MSEL. All participants were determined to have bilateral sensorineural hearing loss of adequate severity to qualify for cochlear implantation, and all children were prelingually hearing impaired. The children ranged in age from 6 to 45 months at the time of the initial evaluation with the MSEL (average age = 24.71 months). The average duration between evaluations was 32.29 months (range = 11–75 months), resulting in an average age of 57.91 months at the time of evaluation with the LIPS-R (range = 36–103 months; see Table 1). In each case, if more than one follow-up evaluation using the LIPS-R was performed, the results from the last evaluation were analyzed, resulting in the maximum interval between assessments. For 10 of the patients, the primary language spoken in the home was Spanish. For these families, a Spanish language interpreter was present for the duration of the evaluation.

All children were implanted at Texas Children's Hospital by one of two surgeons and followed by one of two audiologists. Inclusion criteria included the following: (a) nonverbal cognitive functioning falling within 2 *SDs* of the population mean on at least one of the two measures, (b) no significant visual impairment (as this would have affected nonverbal cognitive performance), (c) no past or present diagnosis of an autism spectrum disorder, and (d) no known significant neurological complications (e.g., meningitis or documented brain injury). These criteria were established prior to participant determination; however, no children were excluded based on these criteria. All children had hearing parents. Etiology of hearing loss varied but included nonsyndromal (Connexin 26), syndromal hearing loss (including Usher), a syndromal-other category (including Waardenburg and Pendred), prenatal exposure to cytomegalovirus (CMV) and asymptomatic at the time of the evaluation, ototoxicity, and inner ear malformation. Consistent with the existing literature, approximately one third of our subjects had an unknown etiology for hearing loss (see Table 1).

Measures

The MSEL is a measure designed for young children to estimate functioning across areas thought to predict later intellectual development. The age range for the MSEL is birth to 5 years, 8 months. Items administered for this test load onto four or five scales (depending on the child's age), including Visual Reception, Gross Motor, Fine Motor, Expressive Language, and Receptive Language. Each scale is composed of items that are developmentally appropriate and that use engaging materials. Scores are also tabulated across scales (with the exception of Gross Motor) to provide an overall Early Learning Composite, reflecting general cognitive development. Because verbal and nonverbal domains are assessed separately, this measure is particularly useful in the assessment of children who have suspected language delays and/or hearing loss. Normative scores for each scale are provided in *T*-score format. For the purposes of comparison, these *T*-scores were converted statistically to standard scores with a mean of 100 and an *SD* of 15. The Early Learning Composite normative score is provided in standard score format.

The LIPS-R provides a measure of nonverbal cognitive functioning in children ranging in age from 2 to 20 years, 11 months. This measure is entirely nonverbal in terms of both administration and responses, making it an appropriate measure for use with hearing-impaired children. For this study, the subtests constituting the Visualization and Reasoning

Battery were administered to assess visualization skills, reasoning skills, and spatial ability. All subtests appropriate for a child's age were administered allowing for the determination of several composite scores including Full IQ, Brief IQ, Fluid Reasoning, and Fundamental Visualization. All composite scores are represented by standard scores with a mean of 100 and an *SD* of 15.

The VABS is a parent/caregiver-completed questionnaire for use with children with or without disabilities (Sparrow et al., 1984). The second edition of this measure was released and put into use in this center in 2005. As such, some caregivers completed the original version of the measure at the first evaluation. Given the high correlations found between the two versions (most ranging from .80 to .90; Sparrow et al., 2005), scores were collapsed across the two versions in this study. The VABS examines a child's ability to function adaptively within his or her environment. The number of items completed depends on the age of the child, with the age range starting at birth and extending to adulthood. Standard scores (mean = 100, *SD* = 15) are available for an overall ABC and for each of the subdomains (including Comm, DLS, Soc, and Motor). For Spanish-speaking families, a Spanish language interpreter from our hospital was present for the entire interview and assisted with translation of all items and responses. When completed by the parent/caregiver of children with disabilities, this instrument provides a reliable measure of the impact of developmental delay on adaptive behavior and the ability to function in everyday situations and environments such as the school and home.

Procedures

All children were tested as part of the routine cochlear implantation screening process prior to implant surgery. Children were reevaluated approximately 12 months following the initial activation of their implant and approximately every 12 months thereafter. Testing was administered by a Licensed Psychological Associate during the child's visit for neuropsychological evaluations. Testing was scored by the original evaluator and double scored by a second evaluator to ensure accuracy. All testing was supervised by the neuropsychologist (SEC), who also interviewed each caregiver and observed a portion of the testing with the child. Testing data were de-identified and entered into a database for analyses. All analyses were conducted using SPSS 16.0. All data were initially double coded and analyzed for skewness and kurtosis using frequency distributions. Descriptive statistics were completed for all key variables. Pearson correlations were then used to compare scores on the MSEL, LIPS-R, and VABS. Hierarchical linear regression analyses were completed as well to test each hypothesis. Additionally, *t* tests were completed to compare scores within nomenclature groups, as outlined in the Results section. This study was approved by the institutional review board of the Baylor College of Medicine.

Results

Description Statistics for Variables of Interest

Overall, LIPS-R scores were higher at follow-up when compared with MSEL scores at baseline, as hypothesized. Notably, VABSs scores remained relatively stable over the two time points. MSEL, LIPS-R, and VABS descriptive statistics for all subscales and composite score are presented in Tables 2 and 3.

Comparison of MSEL to LIPS-R

The MSEL Visual Reception score at Time 1 was correlated with the LIPS-R Fluid Reasoning score ($r = .44, p < .05$) and the Fundamental Visualization score ($r = .62, p < .01$). Additional analyses revealed that primary language spoken in the home ($p = .80$), maternal education ($p = .71$), and paternal education ($p = .86$) did not account for additional

variance in this model (see Table 4). In addition, as hypothesized, a significant relationship emerged between the MSEL Visual Reception scores at Time 1 and the follow-up LIPS-R Full-Scale IQ score when a hierarchical linear regression was completed, with the MSEL Visual Reception subdomain score significantly predicting 52% of the variance in LIPS-R Full-Scale IQ scores at follow-up, $F(1, 34) = 35.80, p < .0001, R^2 = .52, \beta = 0.72$. Also as predicted, we found an improvement in scores from Time 1 to Time 2; specifically, when the Time 1 MSEL Visual Reception *T*-score was converted to a standard score, a dependent samples *t* test demonstrated significant improvement in scores when compared with LIPS-R Full-Scale IQ scores at Time 2, $t(34) = 40.01, p < .001$. Given the large span of time and variable intertest interval, we also controlled for the large variation in time between the two evaluations for the sample. When time between evaluations was first entered into the model, followed by LIPS-R Full-Scale IQ, with MSEL Visual Reception as the predictor, the relationship between the LIPS-R and the MSEL Visual Reception scores remained, and time between evaluations did not account for additional variance ($\beta = .002, p = .99$). Post hoc, age at initial evaluation was thought to be an additional predictor of later LIPS-R Full-Scale IQ scores, with an older age at initial evaluation having greater predictive validity for scores at follow-up. However, when entered into the hierarchical linear regression equation, MSEL Visual Reception scores were the primary predictor of LIPS-R Full-Scale IQ scores, with age at initial evaluation accounting for only an additional 9% of the variance, $F(1, 34) = 24.38, p < .0001, \Delta R^2 = .09, \beta = .30$.

Comparison of MSEL and LIPS-R With the VABS

MSEL Visual Reception scores were significantly correlated with the VABS ABC scores at Time 1 ($r = .51, p < .01$) and Time 2 ($r = .51, p < .01$). For correlations, see Table 5. With regard to the VABS, the ABC at Time 1 significantly predicted variance in both the VABS: ABC at Time 2, $F(1, 31) = 14.36, p < .001, R^2 = .32, \beta = .57$, and LIPS-R scores at Time 2, $F(1, 32) = 10.56, p = .003, R^2 = .25, \beta = .50$, consistent with our hypotheses (see Table 6). Furthermore, it was hypothesized that subdomains of the VABS at Time 1 and Time 2 would be significantly correlated with cognitive measures at each time point, with DLS, Motor, and Soc being more highly correlated than Comm. As can be seen in Tables 5 and 6, significant correlations were seen between most subdomains of the VABS among MSEL scores at Time 1 and LIPS-R scores at Time 2, with no specific sub-domains emerging as more highly correlated than the others. No significant differences were seen between VABS scores at Time 1 and Time 2 (see Table 3).

Post Hoc Analyses

Follow-up analyses were conducted to further determine the clinical utility of using the MSEL Visual Reception subscale as a predictor of future nonverbal cognitive development. Thus, MSEL Visual Reception subdomain standard scores and LIPS-R Full Scale IQ scores were divided into three nomenclature groups based on 1 *SD* from the mean: (a) below average (scores of 84 and below), (b) average (scores of 85–115), and (c) above average (scores of 116 and above). Nomenclature groups at Time 1 and Time 2 were then compared and are presented in Table 7. Twenty-two children remained in the same nomenclature group at Time 1 and Time 2, with 13 children changing from one group to another. Only 1 child's score decreased over time, whereas the remaining 12 children increased an average of 24.46 standard score points ($SD = 11.11$) over time.

To further illustrate the nature of change over time, we also calculated a difference score for each child for select variables. This information is presented in Table 8 and Figure 1. Far more children evidenced a positive change over time on the cognitive measures (e.g., MSEL Visual Reception score to LIPS-R Full IQ score) than a negative change, with a ratio of 30:5. Furthermore, the range of negative change was restricted in comparison with the range

of positive change. Changes in scores over time were less uniform for VABS variables, though for most domains, children generally evidenced improvement rather than showed decline, with the Comm subdomain having more improvement than decline and the DLS and Motor subdomains being approximately half improved to half declined. The exception was the Soc subdomain, where only 12 children had a positive difference score and 21 earned a lower score at the second evaluation point.

Discussion

Results of this study suggest that the Visual Reception subtest of the MSEL is a valuable tool for predicting the development of nonverbal intellectual functioning over time, at least for young, deaf children. Among this group of children, the correlation between the Visual Reception scale from the MSEL and the Full IQ score from the LIPS-R, which was administered on average 32 months later, was an impressive .72. Furthermore, approximately two thirds of the children remained in the same nomenclature group over the span. The Visual Reception scale was also found to correlate significantly with adaptive functioning estimates, particularly the VABS: ABC score at Time 2. Although we acknowledge that by definition, a strong correlation does not imply causality, these results suggest that clinicians can, with some confidence, predict a range of later nonverbal intellectual functioning based on early MSEL Visual Reception results.

When difference scores between Time 1 and Time 2 were analyzed more closely, several characteristics of the data were notable. As Table 8 and Figure 1 show, most children showed less than a standard score change of 20 (either positive or negative) over time in any domain (e.g., IQ or adaptive functioning), and more than half showed a change of less than 15 points (1 *SD*). Of those children whose scores changed enough from the MSEL to the LIPS-R to change their group membership, only 1 demonstrated a decline over time, whereas the remaining 12 showed improvement.

Difference scores among the VABS domains were less consistently positive. This suggests that while this group of children showed the expected gains in nonverbal intellectual functioning, these improvements did not generalize to promote development of functional skills within the home environment. Rather, a larger than expected proportion of our participants showed significant declines across domains over time. We hypothesize that such declines likely reflect a combination of factors, including the increasing importance of strong language skills for all adaptive domains and the relatively few items on the VABS requiring strong language skills during infancy (when the MSEL was more likely to be administered). Whereas the relationship between language skills and the Comm and Soc domains seems clear, it is less clear why children were about as likely to show declines in the areas of DLS and Motor Skills. However, this may be related to increasing demands as children continue to develop, with more demands required to meet “age-appropriate” scores as children increase in age. Although not available for analysis in this study, other researchers have shown a relationship between developing language functions and improved motor functioning as measured by the VABS (Horn et al., 2006). It is clear that strong DLS depend on fine motor skills (e.g., for dressing, bathing, feeding, etc.). It would be very interesting to determine whether those children who are showing the slowest language development with a cochlear implant are also those who show declines across adaptive scales as well.

These findings are important for clinicians who test young children and follow those children over time, especially in the hearing-impaired population. The relationship between the MSEL and LIPS-R has not been previously examined to the authors’ knowledge, despite the fact that these measures are commonly administered and each has unique properties.

These results offer clinicians some degree of certainty regarding predicted levels of functioning at least 2½ years following administration of the MSEL. Furthermore, the MSEL Visual Reception subtest is correlated not only with later nonverbal intelligence but also with overall adaptive functioning. Establishing this relationship between early nonverbal reasoning skills and later nonverbal intellectual assessment is especially important to those making judgments about whether an individual child is a good candidate for a procedure such as cochlear implantation and for providing parents with additional information regarding expectations for later nonverbal intellectual functioning. Research indicates that in addition to variables such as age at implantation (Geers, 2003; Miyamoto, Houston, & Bergeson, 2003; Robbins, Koch, Osberger, Zimmerman-Phillips, & Kishon-Rabin, 2004; & Yoshinaga-Itano, 2004), important predictors regarding the outcome and development of oral language in this population include: frequency of speech and language therapy, using an Auditory-Verbal approach to therapy (Nicholas & Geers, 2006), educational environment, cochlear implant characteristics (newer model with more electrode channels), and level of intellectual functioning (Tobey, Geers, Brenner, Altuna, & Gabbert, 2003).

It is very notable that, on average, about two thirds of a *SD* increase was observed from MSEL Visual Reception scores to later LIPS-R Full-Scale IQ scores, as hypothesized based on the existing literature. Although this suggests that the nonverbal intellectual functioning improved following implantation, the use of different measures pre- and post-implantation precludes such a conclusion. Very similar improvements over time have been noted in other samples of children who receive a cochlear implant, with children completing the LIPS-R both before and after implantation over varying testing intervals (see, e.g., Schlumberger, Narbona, & Manrique, 2004; Shin et al., 2007). Furthermore, implanted children have been shown to perform more similarly to their hearing peers than deaf children who have not been implanted (e.g., see Khan et al., 2005). Together, such studies suggest that our results reflect actual improvement in nonverbal cognitive development as is typically seen in children who are implanted. Future research in this area will help clarify the significance of our results.

Unfortunately, information about the frequency and type of therapeutic interventions is not available for this sample of children. The increase in functioning for this sample and others may simply reflect the cumulative effects of ongoing therapy that is typically provided for children actively seeking to develop oral language skills following implantation. Further examination of the effects of intervention (viz., speech/language therapy) on nonverbal intellectual functioning would be highly interesting and will help shed light on additional factors at work in the cognitive development of these young children. For example, it may be that the work involved in speech/ language therapy with these children increases the degree to which they are able to benefit from classroom instruction and their opportunities to participate in language-based problem-solving, thereby increasing all problem-solving skills, both verbal and nonverbal. It has been postulated that language has an important role in the development of many cognitive functions other than language (Schlumberger et al., 2004). In particular, research has shown that attention processes improve with implantation. Khan et al. (2005) theorized that it may be that overall cognitive functioning improves following cochlear implantation because of these documented improvements in attention skills. However, this relationship between attention and nonverbal cognitive functioning is only inferred at this point, and this area also deserves greater attention in future studies.

Although it is very encouraging for those of us who regularly assess very young children, this study included a group of children who were prelingually deaf and who were candidates for cochlear implantation, with severe to profound sensorineural hearing loss of multiple etiologies. This is an atypical sample, and results need to be confirmed with a more diverse population, specifically in a sample of typically developing children, in order to generalize

results to other populations. Furthermore, our sample size was rather small, and replication with a larger sample will increase confidence in these findings. It would be even more enlightening if future studies include a typically developing and hearing control group to help parcel out the nature of the observed increases over time of nonverbal intellectual functioning. Inclusion of a control group would, for example, help determine whether the increase over time is better explained by the use of different measures over time or by the provision of therapeutic support to the treatment group, which can be theorized to improve the nonverbal as well as verbal aspects of functioning. Finally, although it is tempting to believe that the relationship between the MSEL and LIPS-R continues to be strong for longer durations, this remains to be seen. In particular, it would be helpful to know whether early estimates of nonverbal skills have predictive utility into middle childhood, when most experts agree intellect becomes more stable. The ability to predict later cognitive functioning during the cochlear implant candidacy process will offer clinicians an additional tool when assisting parents and medical personnel to make important decisions regarding appropriate amplification.

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References

- Fidler DJ, Hepburn S, Rogers S. Early learning and adaptive behaviour in toddlers with Down syndrome: Evidence for an emerging behavioural phenotype? *Down Syndrome Research and Practice*. 2006; 9:37–44.
- Geers AE. Predictors of reading skill development in children with early cochlear implantation. *Ear and Hearing*. 2003; 24(Suppl. 1):58S–68S.
- Horn DL, Pisoni DB, Miyamoto RT. Divergence of fine and gross motor skills in prelingually deaf children: Implications for cochlear implantation. *Laryngoscope*. 2006; 116:1500–1506. [PubMed: 16885761]
- Horn DL, Pisoni DB, Sanders M, Miyamoto RT. Behavioral assessment of prelingually deaf children before cochlear implantation. *Laryngoscope*. 2005; 115:1603–1611. [PubMed: 16148703]
- Humphrey A, Williams J, Pinto E, Bolton PF. A prospective longitudinal study of early cognitive development in tuberous sclerosis: A clinic based study. *European Child & Adolescent Psychiatry*. 2004; 13:159–165. [PubMed: 15254843]
- Khan S, Edwards E, Langdon D. The cognition and behaviour of children with cochlear implants, children with hearing aids and their hearing peers: A comparison. *Audiology & Neurotology*. 2005; 10:117–126. [PubMed: 15650303]
- Kushalnagar P, Krull K, Hannay J, Mehta P, Caudle S, Oghalai J. Intelligence, parental depression, and behavioral adaptability in deaf children being considered for cochlear implantation. *Journal of Deaf Studies and Deaf Education*. 2007; 12:335–349. [PubMed: 17449899]
- Kutz W, Wright C, Krull K, Manolidis S. Neuropsychological testing in the screening for cochlear implant candidacy. *Laryngoscope*. 2003; 113:763–766. [PubMed: 12671445]
- Landa R, Garrett-Mayer E. Development in infants with autism spectrum disorders: A prospective study. *Journal of Child Psychology and Psychiatry*. 2006; 47:629–638. [PubMed: 16712640]
- Milner KM, Craig EE, Thompson RJ, Veltman MW, Thomas NS, Roberts S, Bolton PF. Prader-Willi syndrome: Intellectual abilities and behavioural features by genetic subtype. *Journal of Child Psychology and Psychiatry*. 2005; 46:1089–1096. [PubMed: 16178933]
- Mirrett PL, Bailey DB, Roberts JE, Hatton DD. Developmental screening and detection of developmental delays in infants and toddlers with fragile X syndrome. *Journal of Developmental & Behavioral Pediatrics*. 2004; 25:21–27. [PubMed: 14767352]

- Miyamoto RT, Houston DM, Bergeson T. Cochlear implantation in deaf infants. *Laryngoscope*. 2005; 115:1376–1380. [PubMed: 16094108]
- Mullen, EM. Mullen Scales of Early Learning. Circle Pines, MN: American Guidance Service; 1995.
- Nicholas JG, Geers AE. Effects of early auditory experience on the spoken language on deaf children at 3 years of age. *Ear and Hearing*. 2006; 27:286–298. [PubMed: 16672797]
- Ratcliffe MW, Ratcliffe KJ. A comparison of the Weschler Intelligence Scale for Children–Revised and Leiter International Performance Scale for a group of educationally handicapped adolescents. *Journal of Clinical Psychology*. 1980; 36:310–312. [PubMed: 7391248]
- Robbins AM, Koch DB, Osberger MJ, Zimmerman-Phillips S, Kishon-Rabin L. Effects of age at cochlear implantation on auditory skill development in infants and toddlers. *Archives of Otolaryngology: Head & Neck Surgery*. 2004; 130:570–574. [PubMed: 15148178]
- Roid, GH.; Miller, LJ. Leiter International Performance Scale–Revised. Wood Dale, IL: Stoelting; 1997.
- Schlumberger E, Narbona J, Manrique M. Non-verbal development of children with deafness with and without cochlear implants. *Developmental Medicine & Child Neurology*. 2004; 46:599–606. [PubMed: 15344519]
- Selva KA, Harper A, Downs A, Blasco PA, Lafranchi SH. Neurodevelopmental outcomes in congenital hypothyroidism: Comparison of initial T4 dose and time to reach target T4 and TSH. *Journal of Pediatrics*. 2005; 147:775–780. [PubMed: 16356430]
- Shin MS, Kim SK, Kim SS, Park MH, Chong-Sun O, Seung H. Comparison of cognitive function in deaf children between before and after cochlear implant. *Ear and Hearing*. 2007; 28(Suppl. 2): 22S–28S. [PubMed: 17496640]
- Sparrow, SS.; Balla, DA.; Chicchetti, DV. Vineland Adaptive Behavior Scales. Circle Pines, MN: American Guidance Service; 1984. .
- Sparrow, SS.; Chicchetti, DV.; Balla, DA. Vineland Adaptive Behavior Scales: Second edition. Circle Pines, MN: American Guidance Service; 2005.
- Stevenson J, McCann DC, Law CM, Mullee M, Petrou S, Worsfold S, Kennedy CR. The effect of early confirmation of hearing loss on the behavior in middle childhood of children with bilateral hearing impairment. *Developmental Medicine & Child Neurology*. 2010; 53:269–274. [PubMed: 21121905]
- Tobey EA, Geers AE, Brenner C, Altuna D, Gabbert G. Factors associated with speech production skills in children implanted before age 5. *Ear and Hearing*. 2003; 24(Suppl. 1):36S–45S. [PubMed: 12612479]
- Yoshinaga-Itano C. Levels of evidence: Universal newborn hearing screening (UNHS) and early hearing detection and intervention systems (EHDI). *Journal of Communication Disorders*. 2004; 37:451–465. [PubMed: 15231425]

Figure 1.

Difference scores between evaluations by measure/domain: Absolute values of the differences between scores on the MSEL Visual Reception subscale and LIPS-R IQ score and comparisons between VABS scores at the two time points

Note. LIPS-R = Leiter International Performance Scales-Revised; MSEL = Mullen Scales of Early Learning; VABS = Vineland Adaptive Behavior Scale.

Table 1

Demographic Information

Variable	N = 35	M	SD	Minimum	Maximum
Age at Testing Time 1 (months)		24.71	10.75	6	45
Age at Testing Time 2 (months)		57.91	15.45	36	103
Duration between evaluations (months)		32.29	16.20	11	75
Age between implant and LIPS-R (months)		29.10	15.96	3	65
Gender					
Female	14				
Male	21				
Handedness					
Right	26				
Left	7				
Ethnicity					
Caucasian	16				
Hispanic	21				
African American	1				
Unknown	6				
Primary language					
English	21				
Spanish	10				
Unknown	4				
Bilingual Spanish and English	12				
Etiology of hearing loss					
Cytomegalovirus	9				
Connexin 26	5				
Syndrome—other	4				
Syndrome—Usher	2				
Ototoxicity	2				
Malformation	1				
Unknown	12				
Mother' s education (years)		13.22	2.42	6	18

Variable	N = 35	M	SD	Minimum	Maximum
Father's education (years)		12.92	4.18	0	19

Note. LIPS-R = Leiter International Performance Scales-Revised.

Table 2

Descriptive Statistics of MSEL and LIPS-R

	Minimum	Maximum	<i>M</i>	<i>SD</i>
MSEL Gross Motor	55	125.5	85.36	22.40
MSEL Visual Reception	55	134.5	90.61	19.34
MSEL Fine Motor	55	133	87.61	20.86
MSEL Receptive Language	55	101.5	59.32	11.14
MSEL Expressive Language	55	79	59.46	6.78
MSEL Early Learning Composite	49	101	70.50	13.52
LIPS-R Fluid Reasoning	65	122	99.07	14.70
LIPS-R Fundamental Visualization	69	128	110.12	13.91
LIPS-R Brief IQ	65	143	103.14	15.28
LIPS-R Full IQ	68	143	105.49	15.59

Note. LIPS-R = Leiter International Performance Scales–Revised; MSEL = Mullen Scales of Early Learning.

Table 3

VABS Scores Compared at Time 1 and Time 2

	Time 1				Time 2				<i>t</i>	<i>p</i>
	Minimum	Maximum	<i>M</i>	<i>SD</i>	Minimum	Maximum	<i>M</i>	<i>SD</i>		
VABS: Communication	53	110	73.21	14.16	46	127	76.74	17.08	1.47	.15
VABS: Daily Living Skills	55	118	86.38	17.54	42	119	88.4	15.12	0.46	.65
VABS: Socialization	65	118	88.15	13.01	57	118	84.63	12.6	1.48	.15
VABS: Motor Skills	53	122	88.79	13.56	45	119	93.65	16.77	1.50	.15
VABS: Adaptive Behavior Composite	54	111	80.94	14.85	46	120	82.97	13.84	0.68	.50

Note. VABS = Vineland Adaptive Behavior Scale.

Table 4

Pearson Correlations Between MSEL and LIPS-R

Measure	1	2	3	4	5	6	7	8	9	10
1. LIPS-R Fluid Reasoning	1.00									
2. LIPS-R Fundamental Visualization	.30	1.00								
3. LIPS-R Brief IQ	.87*	.55*	1.00							
4. LIPS-R Full IQ	.80*	.69*	.95*	1.00						
5. MSEL Gross Motor	.31	.47**	.34	.42*	1.00					
6. MSEL Visual Reception	.44**	.62*	.64*	.72*	.49*	1.00				
7. MSEL Fine Motor	.30	.61*	.50*	.55*	.56*	.65*	1.00			
8. MSEL Receptive Language	.34	.24	.39**	.45*	.35	.37**	.42**	1.00		
9. MSEL Expressive Language	.28	.14	.28	.33	.25	.33	.29	.67*	1.00	
10. MSEL Early Learning Composite	.41**	.53*	.55*	.62*	.61*	.75*	.78*	.65*	.59*	1.00

Note. LIPS-R = Leiter International Performance Scales-Revised; MSEL = Mullen Scales of Early Learning.

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

Table 5

Pearson Correlations Among Mullen Scales of Early Learning and Vineland Adaptive Behavior Scales at Time 1 and Time 2

Measure	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1. MSEL Gross Motor	1.00															
2. MSEL Visual Reception	.49*	1.00														
3. MSEL Fine Motor	.56*	.65*	1.00													
4. MSEL Receptive Language	.35	.37**	.42**	1.00												
5. MSEL Expressive Language	.25	.33	.29	.67*	1.00											
6. MSEL Early Learning Composite	.61*	.75*	.78*	.65*	.59*	1.00										
7. VABS Communication Time 1	.16	.46*	.61*	.48*	.51*	.55*	1.00									
8. VABS Daily Living Skills Time 1	.30	.47*	.55*	.41**	.33	.56*	.81*	1.00								
9. VABS Socialization Time 1	.15	.53*	.48*	0.31	.33	.49*	.73*	.66*	1.00							
10. VABS Motor Time 1	.52*	.47*	.53	.47*	.58*	.62*	.66*	.67*	.52*	1.00						
11. VABS Adaptive Behavior Composite time 1	.29	.51*	.59*	.51*	.49*	.61*	.93*	.92*	.81*	.79*	1.00					
12. VABS Communication time 2	.24	.46*	.44*	.36**	.51*	.39**	.68*	.39**	.41**	.44**	.53*	1.00				
13. VABS Daily Living Skills time 2	.34	.41**	.47*	.25	.41**	.50*	.49*	.44*	.23	.40**	.49*	.65*	1.00			
14. VABS Socialization Time 2	.15	.43*	.36**	.24	.34	.35**	.46*	.39**	.34	.29	.44**	.70*	.58*	1.00		
15. VABS Motor Time 2	.36	.45**	.32	.13	.35	.41**	.21	.29	.18	.58*	.35	.37**	.55*	.48*	1.00	
16. VABS Adaptive Behavior Composite time 2	.29	.51*	.48*	.31	.48*	.44*	.60*	.47*	.38**	.51*	.57*	.87*	.83*	.83*	.70*	1.00

Note. MSEL = Mullen Scales of Early Learning; VABS = Vineland Adaptive Behavior Scale.

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

Table 6

Pearson Correlations Between LIPS-R and VABS at Time 2

Measure	1	2	3	4	5	6	7	8	9
1. LIPS-R Fluid Reasoning	1.00								
2. LIPS-R Fundamental Visualization	0.30	1.00							
3. LIPS-R Brief IQ	0.87*	0.55*	1.00						
4. LIPS-R Full IQ	0.80*	0.69*	0.95*	1.00					
5. VABS: Communication standard score	0.51*	0.59*	0.50*	0.56*	1.00				
6. VABS: Daily Living Skills standard score	0.53*	0.43**	0.58*	0.54*	0.65*	1.00			
7. VABS: Socialization standard score	0.65*	0.54*	0.56*	0.62*	0.70*	0.58*	1.00		
8. VABS: Motor Skill standard score	0.36*	0.54*	0.50*	0.52*	0.37**	0.55*	0.48*	1.00	
9. VABS: Adaptive Behavior Composite	0.64	0.61	0.66	0.68	0.87	0.83	0.83	0.70	1.00

Note. LIPS-R = Leiter International Performance Scales-Revised; VABS = Vineland Adaptive Behavior Scale.

* $p < .01$.

** $p < .05$.

Table 7

Nomenclature Groups at Time 1 (MSEL) and Time 2 (LIPS-R)

		LIPS-R Full Scale IQ		
		<85	85–115	>115
MSEL ELC	<85	3	7	0
	85–115	0	15	6
	>115	0	0	4

Note. MSEL ELC = Mullen Scales of Early Learning Early Learning Composite.

Table 8

Direction in Change of Scores over Time by Measure/Domain

Direction of Change, N = 35	MSEL/LIPS-R	VABS: Adaptive Behavior Composite	VABS: Communication	VABS: Daily Living Skills	VABS: Socialization	VABS: Motor Skills
Positive (range)	30 (1 to 42)	19 (2 to 24)	20 (3 to 30)	18 (2 to 33)	12 (2 to 24)	15 (6 to 25)
Negative (range)	5 (-1.5 to -11.5)	15 (-1 to -22)	13 (-2 to 17)	15 (-4 to -29)	21 (-1 to -29)	13 (-2 to -29)
No change	0	0	1	1	1	2
Not available	0	1	1	1	1	5

Note. LIPS-R = Leiter International Performance Scales-Revised; MSEL = Mullen Scales of Early Learning; VABS = Vineland Adaptive Behavior Scale.