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A Systematic Review of the Effects of LENA-Based Feedback on Parent-Child Language Interactions in Families with Young Children

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Abstract

Enhancing parent language interactions with children beginning in infancy is important because it results in better language abilities, social skills, and academic outcomes in children. A number of researchers have suggested that parent language interactions with children could be enhanced by giving parents feedback about their language interactions using the Language ENvironment Analysis (LENA) system. The LENA system records communication exchanges between a child and the adult caregiver and provides an automated analysis of adult word count, child vocalization count, and conversational turn count. We did a systematic review of the studies that investigated the use of LENA-based feedback to enhance parent language interactions with children. Although most previous studies have concluded that LENA-based feedback improves parental language interactions with children, methodological factors and confounding of treatment components in almost all of these studies make it impossible to know whether quantitative feedback from interactions recorded by the LENA system enhances parent language interactions with children. The designs and results of previous studies are discussed to suggest how future research can better address this important issue.

Keywords: LENA-based feedback; systematic review; early intervention; children; deaf or hard of hearing

Acronyms: AWC = adult word count; CTC = conversational turn counts; CVC = Child Vocalization Count; DHH = deaf or hard of hearing; NPC = non-parental caregiver; SES = socioeconomic status

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Parents[1] are almost always their children's first language teachers and play an important role during early childhood, a critical period for speech and language development. A large body of literature supports the significant role of parent-child interactions in the development of spoken language and social communication abilities in children. Roberts and Kaiser (2011) suggested four aspects of parent-child communication interactions that are important for language development in children: (a) the amount of parent-child interaction (e.g., conversations, joint attention activities); (b) responsiveness to child communication (e.g., parents' verbal and nonverbal responses to the child's communication attempts, eye contact, and play); (c) quality of language input (e.g., the diversity of words and complexity of linguistic structures that parents use when talking to their child); and (d) the use of language stimulation strategies (e.g., imitation, expanding and recasting children's communicative attempts, listening and spoken language strategies). Other researchers have shown a strong positive relationship between children's vocabulary size and the amount and quality of their exposure to parentese (Conway et al., 2018; Guralnick et al., 2008; Hirsh-Pasek et al., 2015; Rowe, 2012; Weisleder & Fernald, 2013; Zimmerman et al., 2009). For example, Hirsh-Pasek et al. (2015) found that children's expressive language was positively correlated (r = .34) with maternal words per minute and quality of maternal input predicted 27% of the variance in children's expressive language. Conway et al. (2018) found that intrusive or directive maternal behaviors (in contrast to responsive expansion) were associated with poorer receptive and expressive language outcomes at 36 months and 48 months. For example, each unsuccessful directive was associated with an estimated 0.37 *SD* lower receptive language score at 36 months (95% CI = –0.69, –0.04) and 0.66 *SD* lower score at 48 months of age (95% CI = –0.99, –0.33).

[1]The word *parent* will be used to include all adult caregivers of the child in the home environment.

The early language environment of a child's life not only shapes their language development but also predicts academic success, cognitive outcomes, and social skills (Huttenlocher et al., 1991, 2007, 2010; Leffel & Suskind, 2013; Pan et al., 2005; Tamis-Lemonda et al., 1998; Tomblin et al., 2020). For example, Pan et al. (2005) showed that at 24 and 36 months of age, a child whose mother scored at the 90th percentile on the language and literacy composite produced about 15 more word-types than a child whose mother scored at the 10th percentile. According to Tomblin et al. (2020), children's oral language ability at 5 years predicted 35% to 47% of the variance in reading outcomes at 8 years of age in children with typical hearing.

Children with developmental or intellectual disabilities, those who are deaf or hard of hearing (DHH), and children from families with lower socioeconomic status (SES) are at an increased risk for delays in language development (Campbell et al., 2003; DesJardin & Eisenberg, 2007; Fernald et al., 2013; Leffel & Suskind, 2013; Pace et al., 2017; Suskind et al., 2016). For example, Campbell and colleagues reported that with low maternal education as a risk factor, the odds-ratio of having a speech delay in 3-year-old children was 2.58. Fernald et al. (2013) demonstrated that by 24 months of age, children from higher SES backgrounds produced an average of 150 more words compared to children from lower SES families and this difference in expressive vocabulary was statistically significant as early as 18 months of age. Furthermore, reduced quantity and quality of parental linguistic input can be a reciprocal result of children's poor communication ability (Suskind et al., 2013). For example, as reported by VanDam et al. (2012), language ability in children who were DHH, was positively correlated with the number of conversational turns between parents and children ($r = .62$, $p < .01$) whereas both adult word count (AWC) and conversational turn counts (CTC) was associated with children's pure tone thresholds ($r_{AWC} = -.54$, $p < .01$; $r_{CTC} = -.47$, $p < .03$) and Speech Intelligibility Index or speech audibility ($r_{AWC} = .56$, $p < .01$; $r_{CTC} = .66$, $p < .01$). Additionally, Rufsvold et al. (2018) reported that while the degree of hearing loss did not significantly influence the quantity of adult input, the latter was associated with demographic variables such as the child's age ($r = .38$, $p = .025$) and father education [$F(6, 22) = 3.99$, $p = .008$].

Researchers have shown that children who are DHH, especially those who enroll for intervention after 2 years of age, are typically delayed by 1.0 to 1.5 standard deviations in language scores compared to their peers with typical hearing (Moeller, 2000; Nott et al., 2009; Tomblin et al., 2015; Yoshinaga-Itano, 2003), and mothers of children who are DHH tend to talk less to their children (DesJardin & Eisenberg, 2007; Suskind et al., 2013). Even children that were DHH who were enrolled earlier in intervention programs, performed in the low-average range relative to peers with typical hearing. Therefore, it is not surprising that most people agree that young children who are DHH and are learning spoken language, need access to a language-rich environment to support their development (e.g., Glanemann et al., 2013; VanDam et al., 2012).

Parents are in the best position to create and maintain a rich language environment during the critical language learning period beginning in infancy. Evidence from neuroscience research has also shown that language stimulation in infancy results in significantly better language outcomes and desirable neurophysiological changes in the child's brain, with these relationships being reciprocal (Kuhl, 2010; Ramírez-Esparza et al., 2017a, 2017b; White et al., 2013). Therefore, enrichment of the home language environment is a crucial component of achieving successful language outcomes for children who are DHH.

One method that has been suggested as a way of helping parents improve the language environment for young children is to provide the parents with feedback about the frequency and quality of their language, using data from the Language ENvironment Analysis (LENA) system (Greenwood et al., 2018; Wang et al., 2017). The LENA is a specialized audio-recording system worn by the child in a vest. It captures and automatically analyzes audio recordings on the number of words children use or are exposed to, and the number of language interactions the child engages in with adult caregivers. After a systematic search, nine studies were found that included an examination of whether providing LENA-based feedback to parents about language interactions increases the quantity and quality of their language input (Beecher & Van Pay, 2019, 2020; Elmquist et al., 2020; Gilkerson et al., 2017; Pae et al., 2016; Sacks et al., 2014; Suskind et al., 2013, 2015, 2016; Zhang et al., 2015). Two other studies (Hoffman et al., 2020; Ramírez et al., 2020) were not included because the primary focus of these studies was parent coaching/language intervention and LENA recordings in these studies were made only 4 times over a period of 18 months (Ramírez et al., 2020) and 12 months (Hoffman et al., 2020).

Our long-term research goal is to determine whether LENA-quantitative feedback enhances the quality and quantity of parent-child language interaction in families of children who are DHH. In this article, we first summarize research on language outcomes in children who are DHH to highlight the relevance of the measures generated by the LENA system. Next, we present a systematic review of existing research on the use of the LENA system to provide feedback to parents about their verbal interactions with their children as a way of increasing the frequency and quality of those interactions. We discuss the results, strengths, and limitations of existing studies on this topic in families of young children with and without hearing loss. In conclusion, we offer an evidence-based framework for future studies to investigate the efficacy of using LENA data to provide feedback about the language environment to parents of children who are DHH.

Summary of Language Outcomes in Children who are DHH and the Role of Parent Input

Even though children who are DHH are being identified and provided with intervention earlier and earlier (White, 2014), recent research has shown that most of these children continue to exhibit delays in language

development compared to their peers with typical hearing. For example, a series of population-based studies from three states of Australia investigated the longitudinal outcomes of children who were DHH (Ching et al., 2010, 2013, 2018; Ching & Dillon, 2013). These researchers found that children who were DHH (even those with mild hearing loss) lagged behind their peers by an average of at least 1.0 *SD* and had difficulty learning new words. Tomblin et al. (2015) examined the language outcomes of 2-year-old children with mild to severe hearing loss and found that on average, when fit with hearing devices later than 12 months of age, these children had spoken language scores approximately 1.0 *SD* lower than their chronological age and SES matched peers with typical hearing. Even those children who were fit with hearing devices before 12 months of age averaged about .5 *SD* lower than their peers with typical hearing on language outcomes.

Substantial empirical evidence supports that children who are DHH need increased exposure to language and parental talk compared to their normal hearing peers to reach developmentally appropriate linguistic outcomes (Ambrose et al., 2014; Aragon & Yoshinaga-Itano, 2012; Caskey & Vohr, 2013; Charrón et al., 2016; Tomblin et al., 2020; Wiggin et al., 2012). Using LENA technology, Ambrose et al. (2014) examined how adult word count, adult-child conversational turn count, and electronic media exposure at 6 months of age predicted communication outcomes in children who were DHH. Communication outcomes were measured using the *Mullen Scales of Early Learning* (Mullen, 1995) at 2 years and the *Comprehensive Assessment of Spoken Language* (Carrow-Woolfolk, 1999) at 3 years of age. Positive correlations were found between conversational turn count and children's receptive and expressive language outcomes at 2 years *(r* = .61, $p < .01$ and $r = .45$, $p < .05$, respectively) and composite language at 3 years of age ($r = .45$, $p < .05$). Moeller and Tomblin (2015) concluded there were three primary factors that influenced childrens' access to linguistic input: (a) access to sound through the use of hearing technology; (b) duration and consistent use of hearing devices; and, (c) the quantity and quality of caregiver talk.

Research on parent-child interaction has shown that parents of children who are DHH tend to talk less to their children (e.g., use fewer utterances, fewer words, and fewer variety of words) compared to parents of children with typical hearing (Ambrose et al., 2015; Cross et al., 1980; Nienhuys et al., 1985). Even when quantitative differences were not observed in the communication used by parents of children with and without hearing loss, qualitative differences were evident in communication ability. For example, in a large sample study of 156 children who were DHH and 59 children with typical hearing, Ambrose et al. (2015) found that parents of 3 year old children who were DHH used significantly fewer different words (Standardized Mean Difference Effect Sizes [*SMDES*] = .59, $p = .002$), shorter utterances (*SMDES* = .67, $p < .001$), and greater proportions of directing utterances (*SMDES* = -.55, $p = .002$), compared to parents of children with typical hearing. No significant differences between the groups were observed in the number of total utterances (*SMDES* = .02, $p = .90$) used by parents. The authors concluded that it was the quality of language input at 18 months, not quantity, that predicted 28.3% variance in children's composite language scores at 3 years of age ($p < .05$).

Nienhuys et al. (1985) compared the communication interactions between hearing mothers and their hearing children (ages 2 years or 5 years) with eight hearing mothers and their children who were DHH (age-matched or linguistically matched with the control children). Results revealed that mothers of children who were DHH used language that was simpler in meaning and linguistic structure than mothers of typically hearing children. These findings suggest that parents may benefit from additional support to provide an enriched language environment to children who are DHH. Given the importance of a rich auditory-verbal learning environment for children who are DHH and developing spoken language, the LENA system may be able to provide important information related to children's language environment that could promote positive change in parental language behavior.

Language ENvironment Analysis (LENA) System Overview

In response to research demonstrating the benefits of early language enrichment, the LENA system was developed to measure the spoken language and listening environment (television, electronic sounds, noise, and silence) of infants and young children (Ganek & Eriks-Brophy, 2018). The LENA system consists of a digital language processor and speech recognition software. It functions as a *talk pedometer*. The small wearable recording device uses low-power processors similar to hearing aids. The device records for up to 16 hours and an automated speech recognition cloud-based software is used to process the data and provide information on three primary variables: (a) Adult Word Count (AWC), words spoken to or near the child by an adult; (b) Child Vocalization Count (CVC), such as words, babbling, and single sounds; and (c) Conversational Turn Count (CTC), adult-child alternations when either the adult or child responds to each other within 5 seconds. In addition, the LENA system differentiates and selects audio segments between meaningful speech and non-speech or distant speech. To obtain these measures the cloud processing system uses complex algorithms trained to identify and differentiate adult versus child speech, and tv/electronic noise. The algorithms can also distinguish the (LENA user) child's speech from other children's speech and from non-speech sounds (e.g., cries). The software uses speech sound frequencies and the gaps between sounds and not the actual words spoken to generate data reflecting the quantity of talk in the child's environment. The use of the LENA system has been validated in five languages (www.lena.org).

The majority of published studies about the LENA system have used it to quantify the language environment of young children and to study associations between LENA data and other factors such as SES and children's

language outcomes (reviewed in Greenwood et al., 2018 and Wang et al., 2020). Although such studies are valuable, the current article focuses on a different issue. Specifically, those studies that have used LENA data to provide feedback to parents with the aim of increasing parental language quantity and quality. More recently, studies have also evaluated the reliability and validity of LENA generated classifications of speaker tags, non-speech or distant speech, in comparison to classifications generated from manual transcriptions (Bulgarelli & Bergelson, 2019; Busch et al., 2018; Cristia et al., 2020; Lehet et al., 2021). We do not review these studies here given the scope of the present study which was limited to those studies that used LENA data to provide parents feedback about their child's language environment.

Studies Using LENA-Based Feedback to Improve Children's Home Language Environment

To be included in this systematic review, articles needed to address the efficacy of using LENA data to provide feedback to parents of young children. Articles were limited to populations of children with normal hearing or children who were DHH. Articles were included in the study if they were in peer-reviewed journals, written in English, and published between January 1, 2010 (start year was selected based on the earliest LENA publications in clinical populations as reported in www.lena.org) and December 31, 2021.

Five databases were used to identify relevant articles (APA Psychinfo, Pubmed, Medline, Cinhal complete, and academic search ultimate via EBSCO host). The following keywords were used: Language Environment Analysis, LENA, LENA feedback, parent feedback, LENA-based feedback, children. The database search was performed by the first author. Article titles and abstracts were reviewed and then authors discussed and resolved any discrepancies in selected articles. Following article and abstract review, a full text review was completed by the first author followed by discussion to finalize article selection. Included articles were analyzed to identify general characteristics, methods, participants, and outcomes.

We found nine published studies (Table 1) that used the LENA system to measure and give feedback to adult caregivers as a significant part or all of efforts aimed at improving the child's language environment (Beecher & Van Pay, 2019, 2020; Elmquist et al., 2020; Gilkerson et al., 2017; Pae et al., 2016; Sacks et al., 2014; Suskind et al., 2013, 2015, 2016; Zhang et al., 2015). Results of these studies are discussed below. Importantly, only two of these studies were done in families with children who were DHH (Sacks et al., 2014; Suskind et al., 2016), with the remaining conducted with families of children with normal hearing. We have included a reference to the Beecher and Van Pay (2020) quasi-experimental study which is from the same project as Beecher and Van Pay (2019).

A stated goal of all studies was to investigate the effect on the quality and quantity of parent-child language interactions of LENA-based quantitative feedback. Some of the studies explicitly recognized that LENA feedback was being given in conjunction with additional parent coaching activities by design (Beecher & Van Pay, 2020; Elmquist et al., 2020; Gilkerson et al., 2017; Sacks et al., 2014; Suskind et al., 2015, 2016), while others did not (Pae et al., 2016; Suskind et al., 2013; Zhang et al., 2015). This is an important point to which we will return later. The goal of giving feedback generated by the LENA system was to provide parents with information about their existing quantity/quality of verbal interactions and to encourage them to increase the quantity or improve the quality of the interactions. Three studies randomly assigned participants to experimental or control groups (Gilkerson et al., 2017; Pae et al., 2016; Suskind et al., 2015). The sample size, the total duration of LENA recordings, the duration of the studies, and frequency and nature of feedback varied across studies and is shown in Table 2. In our description of each study below, we focus only on LENA outcome variables relevant to our goal (i.e., AWC, CTC, CVC).

The first three studies summarized below reported no statistically significant changes in the quality or quantity of caregiver child language interactions following LENA-based feedback in families of young children with normal hearing. Zhang et al. (2015) studied twenty-two 5- to 30-month-old children with typical hearing. Each family was given a LENA system to complete weeky or bi-weekly recordings. Feedback was given (at monthly workshops) to parents about their individual LENA AWC and CTC scores as well as the average scores of other families. Pre-post scores over a six month period for AWC and CTC were used to determine if parents' language behavior had changed. For the full sample, although AWC and CTC showed significant increases from baseline to Month 1 and Month 3, the increase was not sustained and returned to baseline levels by 6 months. Families who were below the median at baseline increased more than 7,500 words per day (a 50% gain) from baseline through the first recording that occurred post-feedback and maintained the increase at 6 months significantly above baseline by 3,000 words per day (20%). This finding is indicative of regression to the mean and therefore may not be good evidence that LENA feedback improves language interactions. Given the lack of a control group, a modest sample size, and the wide age-range of children, the need for further research and replication was emphasized by the authors.

Similar results were observed in children with typical hearing by Pae et al. (2016) where ninety-nine families were randomly assigned to either experimental (received weekly LENA-based feedback, one workshop, monthly guidance over the phone, story books at 6 months, and an online book reading guide) or control group (no feedback or support). No significant differences were observed between groups on LENA measures (AWC, CTC) at baseline and at post-test. Pae et al. (2016) reported significant improvements in parent language behavior (AWC) and CTC at 6 months for those families who were below the 50th percentile at baseline (effect sizes = .81 and 1.23 respectively, $p < .01$).

Table 1

Summary of Studies Using LENA-Based Feedback as an Intervention Tool

								SMDES				
Author	Sample size	Age at recruitment (months)	SES	LENA recording	Feedback frequency	Duration	Location	AWC	CTC	CVC	Design, population, and home language	Overall study quality for evaluating outcome of LENA feedback
Beecher & Van Pay (2020)	56	0–30	Middle-High	1 per week, at least 9 recordings over 13 weeks	Weekly	13 weeks	At least 9/13 weekly classes	.36#	.80#	.67#	Quasi-experimental Comparison NH English	Satisfactory
Elmquist et al. (2020)	56	1–36	Low-Mid	16-hr weekly recordings, at least 12 over 13 weeks	Weekly	13 weeks	Weekly classes for 13 weeks	.20	.52	.59	Non-equivalent group design NH English & Others	Satisfactory
Gilkerson et al. (2017)	72	9–21	Middle-High	16 hrs/week	Monthly	3 months	Online + Phone	.53	.28	NR	Randomized NH English	Satisfactory
Pae et al. (2016)	99	4–16	Middle-High	16 hrs/week	One workshop and weekly LENA reports accessible at home	6 months	Center-based & online	-.26	-.44	NR	Randomized NH Korean	Satisfactory
Suskind et al. (2016)	32	< 54	Low	16 total day-long recordings	Weekly	10 weeks	Home visits	.20	-.14	NR	Quasi-experimental DHH English	Unsatisfactory
Suskind et al. (2015)	23	18–36	Low	10 total day-long recordings	Weekly	8 weeks	Home visits	.47	.53	.56	Randomized NH English	Satisfactory
Zhang et al. (2015)	22	5–30	High	Varied (from 3 day-long recordings first 10 days, 1/week, 1/ two weeks, 1/week)	Monthly	6 months	Center-based	-.07	-.28	NR	Pre-Post NH Chinese	Unsatisfactory
Sacks et al. (2014)	11	5–72	Low	5 total 16 hr. recordings	One home visit + 3 phone sessions	NR	Home visit + phone sessions	.71	1.21	.84	Pre-Post DHH English/Spanish	Unsatisfactory
Suskind et al. (2013)	17	10–40	High	8 total recordings	One educational session + weekly LENA feedback	6 weeks	Home-based	.62	.66	NR	Pre/Post NH English	Satisfactory

Note. LENA = Language ENvironment Analysis; SMDES = Standard Mean Difference Effect Size; #Cohen's d as reported by the authors; AWC = Adult Word Count; CVC = Child Vocalization Count; CTC = Conversational Turn Count; NR = not reported; NH = normal hearing; DHH = deaf or hard of hearing; SES = socioeconomic status as reported based on parent education and income.

Table 2

Brief Description of Intervention in Studies Using LENA-Feedback and Quality of Feedback for Interpreting LENA Use

		Feedback quality rating				
Author; Population	**Brief description of intervention**	**Frequency**	**Customized**	**Access mode**	**Average**	**Overall rating**
Beecher & Van Pay (2020) NH	Community-based parent education curriculum (LENA Start™) that included weekly LENA quantitative feedback, a workbook, teacher-facilitated visual presentations, and videos on spoken language and literacy stimulation activities and strategies. Positive reinforcement, encouragement, and help was provided to participants to set goals in addition to weekly text message reminders to report the reading duration (minutes) for the week.	1	1	1	1.00	Good
Elmquist et al. (2020) NH	Same parent education program as Beecher and Van Pay (2020): (LENA Start™) 13-week educational program with 1-hour weekly sessions. The sessions included LENA quantitative feedback reports and their interpretation, presentation, and video modeling of spoken language tips, shared story book reading, use of songs and rhymes and sharing knowledge of children's brain development. Age appropriate reading book provided weekly.	1	1	1	1.00	Good
Gilkerson et al. (2017) NH	Combined interventions that included web-based educational materials (print materials, webinars, videos) and LENA feedback reports viewed using LENA software at home, discussion forums with other parents, and coaching support by trained research staff online or by phone (minimum 1 session to any number; encouraged to engage in three monthly coaching sessions for 3 months). Frequency of feedback not consistent across participants and how often parents accessed materials not confirmed.	2	3	3	2.66	Unsatisfactory
Pae et al. (2016) NH	Video demonstrations, discussions, motivational talks during a single workshop. Individualized LENA reports explained at workshop and weekly LENA reports were accessible to parents on their home computers. Monthly phone calls for encouragement and checks. At 6th month, five story books and an online book guide provided.	1	1	3	1.66	Satisfactory
Suskind et al. (2016) DHH	Caregiver focused language intervention curriculum + video modeling and analysis of learned behaviors by caregivers + goal setting. Intervention provided by a certified early interventionist. In addition, LENA quantitative data were provided. Each home visit was 1 hour long and was provided weekly (10 weeks).	1	1	1	1.00	Good
Suskind et al. (2015) NH	Caregiver focused language intervention curriculum + video modeling and analysis of learned caregiver behaviors + goal setting. In addition, LENA quantitative data provided by early inteventionist during eight weekly 1-hr home visits.	1	1	1	1.00	Good
Zhang et al. (2015) NH	Monthly 90 min feedback workshops (for 6 months) led by senior pediatrician and supported by assistants. Included explanation of LENA reports individually while in a group + group feedback + group discussions, advice, demonstation videos on enhancing home language environment.	2	1	1	1.33	Satisfactory
Sacks et al. (2014) DHH	Educational module developed by authors reviewed and LENA quantitative feedback charts provided and discussed with parents by deaf educator during one 60-min home visit after two baseline recordings and subsequently via phone sessions after each of three LENA recordings + goal setting.	2	1	2	1.66	Satisfactory
Suskind et al. (2013) NH	One-time language focused educational intervention for 1 hr that included LENA data interpretation and goal setting guidance. Weekly LENA quantitative feedback provided for 6 weeks to non-parental caregivers by trained graduate research assistants in the form of paper results with no active discussion or goal setting guidance.	1	1	1	1	Good

Note. LENA = Language ENvironment Analysis; NH = normal hearing; DHH = deaf or hard of hearing; 1 = Good; 2 = Satisfactory; 3 = Unsatisfactory.

The effects of LENA-based feedback were also studied by Gilkerson et al. (2017) in children 9 to 21 months of age. AWC and CTC automatically analyzed by the LENA system were posted each week by the researchers on a website that parents in the treatment group were encouraged to access and use to increase their AWC and CTC scores during the next week. In addition, parents in the treatment group were provided online educational materials and coaching over the phone or online. Results from parents in the treatment group, who also had below average ratings at baseline on LENA measures, demonstrated significant improvement on the same measures at the end of two months (Mean difference$_{AWC}$ = 5.61, p = .01; Mean difference$_{CTC}$ = 6.85, p = .003). However, for the overall sample (N = 72), there were no significant differences in language behaviors of parents who received feedback versus parents who completed LENA recordings, but received no feedback.

In a series of studies, Suskind and colleagues (Suskind et al., 2013, 2015, 2016) showed gains in caregiver language input when using LENA-based feedback and parent coaching. The authors' initial studies (Suskind et al., 2013, 2015) included children with typical hearing and the third study included families of children who were DHH (Suskind et al., 2016). Suskind et al. (2013) evaluated the feasibility and efficacy of using quantitative linguistic feedback to influence adult language behavior (i.e., increase in LENA AWC, CTC scores), and as a consequence, a child's language environment. This study used a prospective case-crossover design, and was conducted with a group of non-parental caregivers (NPCs), who were chosen because of their extensive and consistent periods of time with the children in their care. Baseline scores were obtained from 17 NPCs at the child's home. Children were 10 to 40 months old. All children were from high SES households. During the initial visit, baseline recordings were completed, and each NPC participated in an educational session that focused on enriching a child's home language environment. In this 60-minute session, feedback from the baseline LENA recordings, language goals for the following session, and strategies to increase parental talk and conversational turns were discussed. LENA recordings were done at the child's home weekly for 6 weeks and quantitative LENA feedback was given to the NPC between each recording session. The NPCs were instructed to keep the device turned on for the maximum recording duration (16 hours) and to report on daily time logs on when their interaction time with the child ended for the day. Results at the end of the 6-week study indicated significant differences in language behaviors (AWC and CTC scores) between the pre and post results. The authors acknowledged that due to overlap between the educational session and initial baseline LENA feedback, it was impossible to isolate the influence of LENA feedback from coaching on caregivers' language behaviors recorded subsequently. In addition, the absence of a control group limited generalizability of the study results.

In 2015, Suskind and colleagues published an experimental study which evaluated the effectiveness of a newly developed parent-directed spoken language intervention. This program was designed to increase parental knowledge of child language development and to support parental talk in low SES families. Twenty-three caregiver–child dyads were randomly assigned to an experimental group (n = 12) or a control group (n = 11). Families in the experimental condition received eight weekly 60-minute home visits from trained personnel. The visits included an interactive educational module, feedback about the amount of language the parent had used during the previous week using LENA data, and opportunity for mothers to practice language promoting strategies as modeled via videos, and a goal-setting activity to increase the LENA scores. The control condition consisted of a nutrition intervention that involved eight weekly 10-minute home visits from a research assistant. Home-based data were derived from the LENA sytem (i.e., AWC, CVC, and CTC). LENA outcomes increased significantly during intervention but did not show significant increase when examined 4 months post-intervention. Study results supported the short-term effects of parent directed intervention on children's home language environment. Potentially because of the limited duration of the study and a small sample size, results did not capture sustained changes in parent or child LENA outcomes.

In a subsequent study, Suskind et al. (2016) evaluated the effect of the parent-directed home-visit intervention curriculum (Project ASPIRE) on the language environment of low SES families with children who were DHH. All children were younger than 4.5 years of age and used hearing devices. Participants who completed the study included seven families in treatment and 15 in the control group. Group assignment was not random and children who received a cochlear implant from the first author were assigned to a treatment group whereas other participating children were assigned to a treatment or control group. Caregivers in the experimental group, received 10 weekly 60-minute feedback sessions over a six month period. During these sessions caregivers received quantitative LENA feedback regarding the amount of language the caregivers were using with the children in comparison to their previous recordings and the national average. In addition, they also received home visits by early interventionists during which video modeling and a spoken language curriculum were used to help improve learned parental language behavior. Participants in the control group did not receive home visits but completed LENA recordings. Results at the end of six months indicated no statistically significant differences in LENA scores (AWC and CTC) between the experimental group and the control group.

Sacks et al. (2014) also explored whether participating in Project ASPIRE and receiving weekly feedback about LENA scores would increase AWC, CTC, and CVC scores. Eleven families from low SES backgrounds with children who were DHH (average age 32 months) participated. Two 16-hour LENA recordings provided a baseline of the family's language environment. Using the baseline, a deaf educator conducted the 60-minute educational

home visit that included the ASPIRE spoken language curriculum and a discussion of LENA scores. Parents were asked to set realistic goals for their next LENA recording session. Following the one-time home visit intervention, parents completed three additonal LENA recordings and continued to receive feedback about their LENA scores via phone sessions. Results at the end of the study indicated significant differences in language behaviors (53% increase from baseline in CTC, $p < .01$ and 43% increase from baseline in CVC scores, $p < .05$) between the pre and post results (AWC increased 20% above baseline, but was not statistically significant). However, there was no control group for reference in this study.

The studies by Beecher and Van Pay (2020) and Elmquist et al. (2020) were designed to evaluate the effectiveness of a community-based parent education program (LENA Start™). The program curriculum included parent coaching using strategies to improve spoken language input and thereby children's receptive and expressive language (e.g., shared reading, songs and rhymes, incorporating select vocabulary words, talking strategies, information about childhood brain development, and reflection exercises). The curriculum was implemented via weekly hour-long parent-educator sessions using lectures, discussions, videos and other materials. In addition, parents were provided graphical reports of LENA quantitative measures (AWC, CTC, amount of electronic sound exposure) from LENA recordings that the parents completed and reading times reported from the previous week. Pre-LENA and post-LENA outcomes were AWC, CTC, and CVC. The comparison group in Beecher and Van Pay (2020) included families who attended library visits at two locations and made LENA recordings but did not receive the curriculum or quantitative feedback until after study completion. Elmquist et al. (2020) used a non-equivalent comparison group that received general parent education as part of a statewide Early Childhood Family Education program but no LENA-based feedback or LENA Start™ curriculum. Multilevel linear modeling of growth curves as a function of time (longitudinal) were used by Beecher and Van Pay (2020) for examining outcomes in the intervention group and a propensity matched comparison group. Results suggested significant growth on AWC, CTC, and CVC for the intervention group but not for the comparison group. Pre- post- comparisons in Elmquist et al. (2020) showed that although the intervention group made gains and there was decline in the comparison group, these findings were not statistically significant. In contrast to the comparison group, small to medium effect size gains were found in the intervention group for CTC and CVC, but not for AWC.

In summary, results from the reviewed studies are mixed. The first three studies reviewed (Gilkerson et al., 2017; Pae et al., 2016; Zhang et al., 2015) did not demonstrate improvements on LENA outcomes from quantitative LENA feedback provided to parents when the full sample was considered. However, each study reported improvements for families below the 50th percentile. This regression to the mean poses a significant threat to a valid interpretation of the results. That is, because the families below the 50th percentile scored on the lower extreme to begin with, there was a statistical tendency for improvement in scores (i.e., moving toward the average). Such gravitation of scores toward the mean could have occurred due to chance and not necessarily due to the feedback provided. Although two of the Suskind et al. studies (2013, 2015) supported parent-focused intervention and LENA feedback, study outcomes were not sustained post-intervention. In addition, the effects of LENA feedback could not be isolated due to additional interventions, one of the studies lacked a control group, and both studies included small samples. Similarly, studies by Beecher and Van Pay (2020) and Elmquist et al. (2020) supported the effectiveness of community-based parent education including the use of LENA-based feedback. However, the effectiveness of LENA quantitative feedback alone cannot be isolated in these studies due to inclusion of other intervention components. Suskind et al. (2016) reported no change in LENA outcomes between experimental and control groups, and the assignment to the experimental group was predetermined for families of children who received their cochlear implant from the first author. Finally, Sacks et al. (2014) reported gains in CTC and CVC following LENA feedback to families of children who were DHH, however, their study did not include a control group. Results from studies with no control group would generally not be taken as strong indicators of improvement resulting from feedback (Cuijpers et al., 2016). Despite this issue pre-post studies were included in this review because of the limited number of studies available on this topic.

We conducted analyses to evaluate the overall effect sizes from this literature (reported in Table 1). Standardized Mean Difference Effect Sizes (SMDES) following recommendations of Glass (1976) were calculated for each study. We also rated the studies on their ability to specifically interpret the utility of LENA-quantitative feedback (reported in Table 2). Finally, we evaluated threats to internal validity for each of the nine studies (Campbell & Stanley, 1966).

With the aim of reporting on the quality of LENA quantitative feedback, we rated each study based on (a) frequency of feedback, (b) whether feedback was customized for the family, and (c) the feedback access mode. Ratings (Table 2) provided were 1-*Good*; 2-*Satisfactory*; and 3-*Unsatisfactory*. To be clear, this rating was only related to how effectively the LENA feedback was provided to the families and did not take into consideration the use of other additional interventions. That is, this rating was not meant to classify the entire study components. For example, a rating of 3 was given when LENA feedback was made available to families online with lack of information on whether families actually viewed the data weekly. Similarly, a rating of 3 was given to studies when frequency of feedback was every few months. Monthly feedback and weekly feedback were rated as 2 and 1, respectively. Average scores suggested that one study was rated as *Unsatisfactory* for the quality of LENA-feedback provided. Three of the studies were rated to be *Satisfactory* and five were rated as *Good*.

Evaluating threats to internal validity of the studies was based on Campbell and Stanley (1966). Potential threats are discussed for each study. Based on this evaluation, six were rated as *Satisfactory* and three were rated as *Unsatisfactory* in quality (Table 1).

Discussion

The effect of using feedback from LENA audio sample recordings to increase parents' child-directed spoken communication was reported in nine published studies. In all these studies, the investigators evaluated whether LENA scores (i.e., AWC, CTC, and/or CVC) would increase as a result of giving parents feedback about their LENA scores from earlier sessions in addition to some form of parent coaching. We reviewed these studies and examined their results. Six studies included an experimental and control group in investigating the effects of LENA-based feedback and three used a pre-post design. We also examined the sources of internal validity threats for all the studies.

The first main observation was that all studies combined LENA quantitative feedback with other parent coaching activities, some more extensive than the others. This issue did not allow us to address the main research question which was whether or not LENA quantitative feedback when provided to caregivers leads to an increase in the quantity or quality of parent-child interactions. The effects of LENA feedback could not be isolated due to this confound in the majority of the studies with the exception of Suskind et al. (2013) which had minimal educational intervention for one session.

All studies reported LENA outcomes of AWC and CTC but only four of them examined change in CVC. Feedback to parents is expected to influence the language environment with the main goal of enhancing child language behavior. However, many of the studies did not analyze or report on CVC outcomes. Average SMDES across all the studies demonstrated that the overall effect size was small for AWC and CTC, but was large for CVC. However, more studies with CVC data are needed to substantiate this finding. Overall, for AWC and CTC the overall effect sizes were relatively small which may be due to the nature of methodological differences between the studies. For example, the Suskind et al. (2016) study that was conducted in a clinical population (children who were DHH) showed regression on the CTC score post-intervention in the treatment group after an initial improvement. Furthermore, there was almost a 50% attrition of participants in their treatment group at post-intervention measurement. The studies by Suskind et al. (2016), Elmquist et al. (2020), and Beecher and Van Pay (2020) were also limited by a quasi-experimental design in which the equivalence of the participants in experimental and control groups was not achieved. In three studies, subjects were randomized to control and treatment groups. However, internal validity limitations were noted in the majority of studies.

To better quantify and interpret these limitations we examined the scientific quality of each of the studies (Campbell & Stanley, 1966). Multiple sources of threats to internal validity were examined across all studies. Based on this, as shown in Table 1, six studies were rated as *Satisfactory* (Beecher & Van Pay, 2020; Elmquist et al., 2020; Gilkerson et al., 2017; Pae et al., 2016; Suskind et al., 2013, 2015) and three as *Unsatisfactory* in quality (Sacks et al., 2014; Suskind et al., 2016; Zhang et al., 2015). None were rated as *Good*. As expected, this examination indicated that generally, randomized studies had fewer threats to internal validity. However, this was not the case for all randomized studies. For example, the study by Pae et al. (2016) although randomized had many plausible threats to internal validity such as attrition, regression, and selection and therefore it was categorized as *Satisfactory* in quality.

Three of the studies used a pre-post design without a comparison group (Sacks et al., 2014; Suskind et al., 2013; Zhang et al., 2015). Results from these studies would generally not be taken as strong indicators of improvement resulting from feedback because of the lack of a control group (Cuijpers et al., 2016). Despite this issue all studies were included in SMDES calculation because of the limited number of studies available on this topic. Despite the limitations of pre-post designs, one of these studies was rated to be *Satisfactory* in quality because it was less affected by most sources of internal invalidity that were examined (Suskind et al., 2013). The use of evidence-based criteria, that is, sources of internal invalidity threats to examine the quality of individual studies provided additional important information which was not reflected via SMDES alone. This finding is relevant to designing, implementing, and interpreting studies especially in clinical populations. The major factors that were serious plausible threats to those studies that were categorized as *Unsatisfactory* were attrition, participant selection, history (i.e., plausible events other than LENA-quantitative feedback during the study), and maturation.

Participant factors of some of the studies included recruitment specific to certain socioeconomic groups and the broad age-range of children. Specific to children who are DHH, we noted that only two studies had children with hearing loss as part of their participant pool. The paucity of studies is a limiting factor in arriving at any conclusions about children who are DHH in relation to LENA-based parental feedback.

A design issue in the studies was the mixed nature of the intervention (inclusion of intervention/coaching in addition to LENA-based feedback). Four of the studies used a combined intervention in which feedback about the frequency and quality of parent language was combined with the ASPIRE spoken language intervention program. ASPIRE is an educational intervention curriculum that includes video-modelling of the language behaviors targeted at each module (Sacks et al., 2014; Suskind et al., 2013, 2015, 2016). The five other studies also had additional intervention components such as webinars, parents discussion forums, video demonstrations, motivational talks, and workshops (Beecher & Van Pay, 2020; Elmquist et al., 2020; Gilkerson, 2017; Pae et

al., 2016; Zhang et al., 2015). The fact that there were several intervention components being implemented simultaneously made it impossible to estimate the actual effect of only providing parents with feedback about the frequency and quality of their language with the child. Studies that examine the effectiveness of LENA feedback in isolation are needed to substantiate its utility.

In addition, there was variability across studies on the quality of feedback. We therefore rated each study based on frequency of feedback, customization, and access mode (Table 2). Based on average scores, the Suskind studies (Suskind et al., 2013, 2015, 2016), Beecher and Van Pay (2020) and Elmquist et al., (2020) were rated as *Good* for the quality of LENA-feedback. Three of the other studies were rated to be *Satisfactory* and one as *Unsatisfactory*. Furthermore, we noted that only four studies used LENA CVC as an outcome (Beecher & Van Pay, 2020; Elmquist et al., 2020; Sacks et al., 2014; Suskind et al., 2015). Finally, there is a need for studies evaluating the effects of feedback that are also based on theoretical principles for supporting behavior change (Prochaska & Velicer, 1997). Researchers have supported factors such as timely and frequent goal-oriented feedback as being critical to promote behavior change (Schembre et al., 2018). As an example, to achieve the goal of 10,000 steps per day, feedback would occur during the day to increase the chances of achieving that goal and would include an update on step counts at specified intervals.

Because of the limited number of studies and the scope for methodological improvements, more research is needed to establish whether giving parents LENA-quantitative feedback about the amount of language they are using and encouraging them to use more language will increase the amount and quality of language that parents use with their children. Importantly, future studies using evidence-based theoretical approaches to guide behavior change in language use are needed, similar to approaches more widely used for health related behavior modification such as pedometers.

Future directions

Based on this review several important insights were gained. First, there is a paucity of studies that address the key research question of whether LENA-quantitative feedback when provided to parents results in changing the quality and quantity of parent-child interactions. Existing studies have provided LENA-feedback in combination with other parent coaching interventions thus confounding the study results. Second, the quality of the feedback is influenced by the frequency of feedback and how the quantitative feedback is presented to the parents. Monitoring whether and how parents access the LENA feedback and how often, is crucial. Third, large-sample randomized studies in children who are DHH are much needed given the paucity of studies and the known importance of parent-child interactions to improve language outcomes in children who are DHH. Future studies should be designed to incorporate these factors. For example, LENA recordings should be attempted at least 2 to 4 days per week to capture adequate data for measurements. This is because of the day to day variation that may occur in the number of opportunities for interactions across families. To measure its effectiveness, LENA quantitative feedback should be provided with no additional parent coaching and must be consistent in frequency and quality across participants.

Conclusions

The importance of helping children develop good language skills, including children who are DHH, is widely recognized. Substantial evidence suggests that the quantity and quality of caregivers' language is positively correlated with their children's language development. Considering this, there is a need to facilitate parents to acquire skills that help increase the quantity and quality of their language interactions with their children, and effectively integrate these skills into their daily routines. It is critical that this facilitation occurs early during the child's development and is provided with adequate frequency and dosage. Even though caregivers may be willing and eager to make a change in their communication behavior, they may not have all the tools needed to make the change effectively. The availability of the LENA system makes it economically and logistically practical to systematically gather a large amount of language interaction data. The LENA system can capture communication patterns and help guide needed changes by providing objective, easy to use, and timely feedback about language usage and parent-child interactions. It is important to determine if providing parents with such feedback will promote change in parental behavior, leading to healthier and more productive language environments and outcomes for children. Our evaluation and discussion of existing studies provides a framework for future studies in children, including children who are DHH.

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