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Research Article

# The Role of Audiologists in Assuring Follow-Up to Outpatient Screening in Early Hearing Detection and Intervention Systems

Vickie Thomson[a] and Christine Yoshinaga-Itano[b]

**Purpose:** The purpose of this study was to investigate the role of audiology involvement and other factors associated with failure to follow through from the initial hearing screening to the second outpatient screen.
**Method:** Linear regression, logistical regression, and descriptive analyses were used across demographic and hospital variables associated with infants who did not receive a follow-up outpatient screen.
**Results:** The results included birthing hospital outpatient rescreen rates from January 1, 2005, through December 31, 2005. Variables were collected from the birth certificate and hospital surveys. Results showed higher loss to follow-up/documentation to outpatient screen for (a) infants born in hospitals with low rates for returning for follow-up, (b) infants born in hospitals that did not have an audiologist involved, (c) infants who were Hispanic, (d) infants who were born to mothers who were not married, (e) infants with mother's with < 12 years of education, and (f) infants with Apgar scores of 7 or below.
**Conclusions:** The findings were used to identify quality improvement strategies to decrease the loss to follow-up. Strategies included ensuring audiology support, providing information in the parent's native language, educating personnel in the newborn intensive care units, developing and disseminating information in Spanish in written form, and educating hospitals on the importance of scheduling the outpatient rescreening before hospital discharge.

Although universal newborn hearing screening (UNHS) in the United States was begun more than 20 years ago in some states and was implemented and well established by 2000–2003, the United States has lagged behind in follow-through statistics when compared with other countries such as the United Kingdom and Australia (Wake et al., 2016; Wood, Sutton, & Davis, 2015). The rationale for establishing early hearing detection and intervention (EHDI) systems was to provide an opportunity for children who are deaf or hard of hearing to develop language and cognitive skills commensurate with their cognitive potential (Yoshinaga-Itano, Coulter, & Thomson, 2001; Yoshinaga-Itano, Sedey, Coulter, & Mehl, 1998).

The Centers for Disease Control and Prevention (Grosse et al., 2017) reported that 855 infants were identified in 2000; 2,634, in 2005; 5,118, in 2011; and 6,163 infants, in 2014 (Alam, Gaffney, & Eichwald, 2014; Gaffney, Green, & Gaffney, 2010). The loss to follow-up (LTF) rate in 2006 was reported by the Centers for Disease Control and Prevention to be 47.7% and was reduced in 2014 to 34.4% LTF/loss to documentation (LTF/LTD) or 21,819 infants. This LTF/LTD is concerning because 23.8% or 1,467 of these identified children were additionally LTF/LTD for enrollment into early intervention services. Studies in the United States have demonstrated that infants born in rural areas, who receive Medicaid, and mothers with less than a high school education were at risk for LFT/LTD (Bush et al., 2014; Holte et al., 2012). Although the United States has made significant improvements over the past 17 years in decreasing LTF/LTD rates, they are still too high.

Follow-through to ensure that each child meets the 1-3-6 guidelines, screening by 1 month, diagnosis by 3 months, and enrollment into early intervention by 6 months, is the highest priority of the EHDI systems (Yoshinaga-Itano, Sedey, Wiggin, & Chung, 2017). Most state newborn hearing

[a]Department of Otolaryngology, University of Colorado Denver
[b]Institute of Cognitive Sciences, University of Colorado Boulder
Correspondence to Vickie Thomson: Vickie.Thomson@ucdenver.edu

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screening protocols involve an outpatient hearing screening for infants who do not pass the initial hospital screen. This process reduces the number of infants referred for diagnostic audiologic evaluation but introduces a step that could increase failure to follow-up. Both cost-effectiveness and shortages in audiologists with expertise and equipment for diagnosing hearing loss in infants are key factors in the inclusion of outpatient screening in EHDI systems.

Few studies in the United States examined a state population to determine variables that predicted LTF to outpatient screen (Christensen, Thomson, & Letson, 2008; Cunningham et al., 2017). The first Colorado study (Christensen et al., 2008) included demographic variables of the child and family but did not include characteristics of the hospital screening protocol. Christensen et al. (2008) investigated the maternal and child predictors of being screened at birth and rescreened in an outpatient screen through a population-based logistic regression analysis. Results showed that infants who had high risk factors of low birth weight (< 2500 g) and Apgar scores of less than 7 at 5 min were less likely to receive the initial screen. Infants with Apgar scores of 7 or greater were 10 times more likely to receive the inpatient screen, and those with normal birth weights were four times more likely to receive the inpatient screen. These findings resulted in providing education to neonatal intensive care units (NICUs), and the initial screen rate for NICU infants has improved dramatically (Cunningham et al., 2017). The study also indicated strong factors such as maternal education and race/ethnicity associated with low rescreen rates.

The New York UNHS demonstration project investigated LTF to outpatient screen. Prieve et al. (2000) reported a 72% follow-up or 28% LTF rate to outpatient screen for the eight hospitals and 10 perinatal centers. The project funded follow-up coordinators for these eight hospitals. Predictor variables for LTF/LTD were not examined.

Only one other state population study examined hospital refer rates and the relationship to LTF to diagnosis (Finitzo, Albright, & O'Neal, 1998). Finitzo et al. (1998) described a population study in Texas that decreased false-positive rates at the initial hospital screen through audiology involvement, hospital support, and automated data and information management. Lower hospital refer rates were related to a decrease in LTF to audiologic diagnostic evaluation from 31.55% to 20%.

Another state study investigated the relationship between family/maternal characteristics and LTF/LTD to audiologic diagnostic evaluation and enrollment into early intervention. Liu, Farrell, MacNeil, Stone, and Barfield (2008) reported that 11% of Massachusetts children who did not pass hearing screening became lost to follow-up for the audiologic evaluation and 25% of those with hearing loss did not receive early intervention services. A risk analysis found that LTF/LTD for audiologic evaluation was related to mothers who were non-White, children covered by public insurance, mothers who were smokers during pregnancy, or those residing in western, northeastern, or southeastern Massachusetts compared with those in the Boston region.

Audiologists are not highly represented in the newborn hearing screening process. In large hospitals with audiology departments, the newborn hearing screening program is typically managed by an audiologist. However, most infants are born in hospitals throughout the United States that have neither an in-house audiology department nor an audiology consultant or coordinator who oversees and monitors the individual hospital screening programs. Finitzo et al. (1998) reported that audiology involvement was a significant factor in reducing the refer rate of the initial hospital screen, but there have been no studies related to the audiologist's role in ensuring that families/infants receive an outpatient screen. This study is the first study to pose that question. Such a study can only be conducted in a few states, and because of a significant emphasis on ensuring audiology involvement in the state of Colorado after 2005, this variable could not be studied with today's EHDI statistics. We know of at least one other state that has audiology regional coordinators in the UNHS program, but the inclusion of audiologists in the screening process is uncommon.

This is the first study to investigate the relationship between hospital and EHDI system characteristics related to LTF/LTD to outpatient screen. Characteristics not previously studied are audiology involvement, type of screening personnel, annual hospital birth rate, individual hospital refer and rescreen rates, procedure for making appointments, and location of the outpatient screen.

This research project analyzed the risk characteristics of demographic factors of the family and hospital factors associated with infants not receiving the follow-up outpatient rescreen after hospital discharge in the birth cohort of 2005. The research study included all birthing hospitals in the state of Colorado ($N = 52$). More specifically, these analyses provided the EHDI program with the capacity to develop evidence-based strategies to improve statewide and hospital-specific screening system performance.

This study was designed to evaluate the Colorado EHDI program and identify areas that needed improvement in developing systems that would ensure timely and appropriate follow-up from screening to early intervention. The state of Colorado has used this model three times since 2005, once investigating child/family variables and twice with child/family and hospital variables including audiologists, to analyze the state EHDI program. Cunningham et al. (2017) found that audiologists were not a significant factor, which demonstrates that interventions improved this characteristic between 2007 and 2017. The main improvement was to ensure local audiology regional coordinators were providing technical assistance, quality improvement methodology, and best practices to each hospital in the state.

## Method

### *Participants*

Data analysis included birthing hospital outpatient rescreen rates from January 1, 2005, through December

31, 2005. In 2005, Colorado had 69,487 live births, and 68,478 of those births occurred in 56 birthing hospitals. Of the 68,478 births, there were 67,261 (98.22%) infants who were screened and 1,217 (1.77%) who did not receive a screen. In addition, 3,153 (4.7%) infants did not pass the initial inpatient screen, and 622 (19.7%) of those infants did not receive a follow-up outpatient screen. Of the 2,531 (80.3%) infants who did receive the outpatient follow-up screen, there were 115 infants confirmed with a permanent hearing loss.

**Variables**

Demographic data for the newborn hearing screening program were collected from the state's electronic birth certificate. Hospital birth clerks entered the final hearing screen before hospital discharge in a file downloaded to Vital Records. Birth certificate data include mother's age at delivery and educational level and the infant's gender, race, ethnicity, birth weight, and Apgar score at 5 min.

Hospital surveys were completed by all 56 birthing hospitals either by phone or mail. The surveys were used to determine hospital screening staff, type of technology, and protocols for follow-up. Hospital variables obtained by survey data were analyzed to determine the relationship to low follow-up rescreen rates.

The EHDI Integrated Data System (IDS) is the state surveillance system for the Colorado infant hearing system. The hospital variables used in this analysis from EHDI IDS were the number of births, screen rates, refer (did not pass) rates, and rescreen rates. Hospitals were coded into groups on the basis of their number of birth size, refer rates, and rescreen rates. There are six hospitals that had over 3,000 births annually and account for 42% of the birth population. Twelve hospitals had audiologists on staff who supervised the program and provided diagnostic assessments on infants who did not pass the screen. Currently, there are only two hospitals that have in-house audiologists. The outpatient rescreen variable was broken down into three levels: hospitals that have an outpatient rescreen rate of 90% or greater, hospitals that have a rescreen rate between 80% and 89%, and hospitals that have a rescreen rate less than 79%. Hospitals are encouraged to provide an outpatient rescreen. The outpatient rescreening protocol was introduced in 1992 to reduce the number of expensive audiology evaluations, the paucity of pediatric audiologists, and the stress and anxiety on families. Audiology regional coordinators provide technical expertise to local hospitals in lieu of an onsite audiologist. Monthly reports were manually completed by designated hospital coordinators for any missed screens or outpatient rescreens. Audiologists submitted an audiologic assessment form on any infant who was identified with a permanent hearing loss or who passed their evaluation. In 2013, the EHDI IDS became fully automated, eliminating paper reports and data entry by state staff. Hospital coordinators enter data directly into the EHDI IDS for missed and outpatient rescreen results.

**Analysis**

This study is a population-based study for the state of Colorado, and the resulting analyses produced population parameters rather than sample estimates, as in the Christensen et al. (2008) study. The study results from these analyses are not subject to normal sampling error, confidence intervals, and common issues of sample generalizability. Confidence intervals are included for the logistic regression odds ratios out of convention, even while the extreme power of the test can overwhelm minor differences. The practical or clinical significance of the odds ratios' magnitude is relevant and important, whereas statistical significance is less relevant in a population study. Logistic regression model selection compared values of Akaike's information criterion (Akaike, 1983) across competing models until a parsimonious model (a simple model with great explanatory predictive power) was selected. A backward stepwise regression model was used starting with the hospital variables and then adding the demographic variables. Each independent variable was analyzed with the dependent variable (hospital rescreen rates) to determine significance for the final model. Hierarchical, generalized linear effects mixed models (hierarchical linear regression) were used to account for the clustering of patients within birthing facilities by including birthing facility as a random effect based on hospital rescreen rates. This type of analysis is appropriate for examining contextual effects (e.g., birthing facility characteristics) on patient-level outcomes at the completion of outpatient screening.

A logistic regression analysis for categorical data was performed to determine which variables were important for obtaining the follow-up outpatient rescreens. The confirmed hearing loss cases ($n = 115$) and those missing complete data ($n = 11$) were removed for the regression analysis. There were 3,027 infants in the cohort with 2,469 (81%) receiving the follow-up outpatient screen and 558 (18%) not receiving the follow-up outpatient screen. The logistic regression was performed on the basis of whether the infant did or did not receive the follow-up screen. Table 1 shows the variables and their respective coding for the regression model. To perform the logistic regression, categorical variables were dummy coded. For example, the mother's age at delivery was categorized into three variables. Infants born to mothers over the age of 25 years are the reference variable labeled "0." If there were only two categories, then the regression was based on the larger number (see Table 1). Ethnicity was categorized into Hispanic and non-Hispanic, so the regression was based on the non-Hispanic population.

All covariates significant ($p < .05$) in a univariate analysis were included in the multivariate hierarchical logistical regression treating birthing facility rescreen rates as the dependent variable. In the logistic regression model, the dependent variable was whether the infant received the outpatient rescreen. The independent hospital variables included birth rate, nursery level, whether or not an audiologist was involved in the hospital program, technology used for screening, type of screening personnel, how the outpatient screen was scheduled, the location of the outpatient

**Table 1.** Variables and coding for the logistic regression model.

| Variable | Coding |
|---|---|
| Ethnicity | 1 = Hispanic, 2 = non-Hispanic |
| Gender | 1 = female, 2 = male |
| Gestational age | 0 = > 36 weeks, 1 = < 36 weeks |
| Birth weight | 0 = > 2500 g, 1 = < 2500 g |
| Apgar (appearance, pulse, growth, activity, respiration) at 5 min | 0 = > 7, 1 = < 7 |
| Mother's age (years) | 0 = 25+, 1 = 20–24, 1 = 11–19 |
| Marital status | 0 = yes, 1 = no |
| Mother's level of education (years) | 0 = > 12, 1 = < 12 |
| Birthrate | 0 = > 3001, 1 = 2001–3000, 1 = 1001–2000, 1 = < 1000 |
| Nursery level | 0 = well-baby, 1 = Level 2, 1 = Level 3 |
| Audiologist | 1 = yes, 2 = no |
| Technology | 0 = AABR only, 1 = OAE only, 1 = both |
| Refer rates | 0 = 0%–5%, 1 = 5.1%–10%, 1 = > 10% |
| Screening personnel | 0 = nurses, 1 = techs, 1 = volunteers |
| Follow-up appt. scheduling | 0 = before discharge, 1 = after discharge, 1 = parent responsible |
| Charge | 1 = yes, 2 = no |
| Outpatient screen | 0 = nursery, 1 = audiology dept, 1 = refer out |
| Hospital rescreen rates | 0 = 90%–100%, 1 = 80%–89%, 1 = > 79% |

*Note.* AABR = automated auditory brainstem response; OAE = otoacoustic emission; techs = technicians; appt. = appointment; dept = department.

rescreen, whether or not there is a charge for the rescreen, refer rates at discharge, and rescreen rates. The independent demographic variables included ethnicity, gender, gestational age, birth weight, Apgar score at 5 min, marital status, and mother's educational level. Table 2 shows the logistic regression odds ratios and confidence intervals for each variable predicting whether an infant does or does not receive the outpatient rescreen.

There was a descriptive analysis with a significance level of a $p$ value of less than .05 for each independent variable to be used in the final multiple regression models. These analyses determined what factors affected the outpatient rescreen return rate from newborn hearing screening and delineated potential programmatic changes that could improve the follow-up system from 80% to closer to 100%.

## Results

Several models were designed to identify the variables with the greatest significance. As variables were added to different models, variables were eliminated. The logistic regression odds ratio analysis included four models. In the final model, logistic regression main effects predicting the relative odds of receiving a rescreen are shown in Table 3.

The significant variables in the final model were the hospital rescreen rates (> 90%, 80%–89%, < 79%), audiology involvement, ethnicity, Apgar scores, and mother's educational level. Table 4 provides an explanation of the odds ratios in the final model. The unique finding in this analysis was the role of audiology involvement.

### *Final Regression Model*

The final regression model contained the variables of individual hospital rescreen rate, audiology involvement, ethnicity, gender, Apgar score of less than 7 at 5 min, and the mother's educational level.

There were also significant interactions. Figure 1 shows the percentages of infants not rescreened when the audiology, ethnicity, and rescreen variables are in the model. Infants born in hospitals with rescreen rates of 80%–90% were 2.5 times less likely to receive an outpatient screen than those born in hospitals with rescreen rates of 90% or greater. Infants born in hospitals with rescreen rates of 79% or less were 6.3 times less likely to receive an outpatient screen than those born in hospitals with rescreen rates of 90% or greater ($OR = 2.52$, $p < .001$). Audiology involvement had a significant impact on rescreen rates. Overall, the non-Hispanic population had lower percentages—a better chance—in receiving the follow-up rescreen. The interaction showed that the rescreen rates for the Hispanic population were slightly lower in the hospitals with rescreen rates between 80% and 90% that did not have an audiologist.

There was also a strong association between ethnicity and mother's educational level ($OR = 0.69$, $p < .000$). This meant that non-Hispanic mothers with low education were 45% more likely than Hispanic mothers with low education to obtain the follow-up rescreen. Figure 2 shows this interaction with rescreen rates.

Male infants were 23% ($OR = 1.23$, $p < .04$) less likely to receive the outpatient rescreen than female infants. There was a significant interaction between gender and mother's educational level. Male infants whose mothers had less than a 12th grade education had the lowest rescreen rates, especially when the hospital rescreen rates were < 79%. Figure 3 displays this interaction. There were no other significant interactions between the variables with or without the rescreen rate variable.

Infants who had Apgar scores of 7 or below at 5 min were 45% less likely to receive an outpatient screen

**Table 2.** Logistic regression odds ratios (*OR*s) and confidence intervals (CIs) for each variable predicting whether an infant does not receive the outpatient follow-up screen.

| Variable | Coding | Frequency | | *OR* | 95% CI | Pr > ChiSq |
|---|---|---|---|---|---|---|
| | | *n* | % | | | |
| Ethnicity | 1 = Hispanic | 1,260 | 41.6 | | | |
| | 2 = non-Hispanic | 1,767 | 58.4 | 0.773 | 0.643, 0.930 | .0064 |
| Gender | 1 = female | 1,334 | 44.1 | | | |
| | 2 = male | 1,693 | 55.9 | 1.252 | 1.038, 1.509 | .0188 |
| Gestational age | 0 = > 36 weeks | 2,709 | 89.5 | 1.0 | | |
| | 1 = < 36 weeks | 318 | 10.5 | 1.232 | 0.926, 1.639 | .1521 |
| Birth weight | 0 = > 2500 g | 2,731 | 90.3 | 1.0 | | |
| | 1 = < 2500 g | 294 | 9.7 | 1.123 | 0.83, 1.518 | .4507 |
| Apgar (appearance, pulse, growth, activity, respiration) at 5 min | 0 = > 7 | 2,687 | 88.8 | 1.0 | | |
| | 1 = < 7 | 340 | 11.2 | 1.449 | 1.108, 1.896 | .0067 |
| Mother's age (years) | 0 = 25+ | 1,807 | 59.7 | 1.0 | | |
| | 1 = 20–24 | 870 | 28.7 | 1.292 | 1.127, 1.967 | .0148 |
| | 1 = 11–19 | 350 | 11.5 | 1.489 | 1.093, 1.868 | .0051 |
| Marital status | 0 = yes | 20,681 | 68.6 | 1.0 | | |
| | 1 = no | 945 | 31.4 | 1.568 | 1.296, 1.897 | < .0001 |
| Mother's level of education (years) | 0 = > 12 | 1,209 | 40.7 | 1.0 | | |
| | 1 = < 12 | 1,759 | 593 | 1.522 | 1.251, 1.852 | < .0001 |
| Birthrate | 0 = > 3001 | 1,065 | 35.2 | 1.0 | | |
| | 1 = 2001–3000 | 519 | 17.2 | 1.375 | 1.058, 1.787 | .0173 |
| | 1 = 1001–2000 | 850 | 28.1 | 0.866 | 0.677, 1.108 | .2530 |
| | 1 = < 1000 | 593 | 19.6 | 1.440 | 1.122, 1.848 | .0042 |
| Nursery level | 0 = well-baby | 732 | 24.2 | 1.0 | | |
| | 1 = Level 2 | 1,427 | 47.1 | 0.964 | 0.762, 1.219 | .7604 |
| | 1 = Level 3 | 868 | 28.7 | 1.266 | 0.986, 1.626 | .0644 |
| Audiologist | 1 = yes | 2,168 | 71.6 | 1.0 | | |
| | 2 = no | 859 | 28.4 | 1.628 | 1.341, 1.976 | < .0001 |
| Technology | 0 = AABR only | 1,810 | 59.8 | 1.0 | | |
| | 1 = OAE only | 376 | 12.4 | 0.865 | 0.650, 1.152 | .3215 |
| | 1 = both | 841 | 27.8 | 0.665 | 0.532, 0.832 | .0003 |
| Refer rates | 0 = 0%–5% | 898 | 29.7 | 1.0 | | |
| | 1 = 5.1%–10% | 1,474 | 48.7 | 0.950 | 0.773, 1.169 | .6299 |
| | 1 = > 10% | 655 | 21.6 | 0.571 | 0.431, 0.756 | < .0001 |
| Screening personnel | 0 = nurses | 928 | 30.7 | 1.0 | | |
| | 1 = techs | 1,161 | 38.4 | 0.633 | 0.501, 0.798 | .0001 |
| | 1 = volunteers | 938 | 31.0 | 1.194 | 0.957, 1.491 | .1163 |
| Follow-up appt. scheduling | 0 = hospital schedules | 1,722 | 56.6 | 1.00 | | |
| | 1 = parent schedules | 1,315 | 43.4 | 1.608 | 1.337, 1.933 | < .0001 |
| Charge | 1 = yes | 1,586 | 52.4 | 1.0 | | |
| | 2 = no | 1,441 | 47.6 | 0.902 | 0.750, 1.085 | .2749 |
| Outpatient screen | 0 = nursery | 1,599 | 52.8 | 1.0 | | |
| | 1 = audiology dept | 1,369 | 45.2 | 0.975 | 0.808, 1.176 | .7907 |
| | 1 = refer out | 59 | 2.9 | 2.872 | 1.676, 4.920 | .0001 |
| Hospital rescreen rates | 0 = 90%–100% | 877 | 30.0 | 1.0 | | |
| | 1 = 80%–89% | 1,197 | 39.5 | 2.418 | 1.788, 3.271 | < .0001 |
| | 1 = > 79% | 953 | 31.5 | 6.337 | 4.734, 8.483 | < .0001 |

*Note.* AABR = automated auditory brainstem response; OAE = otoacoustic emission; techs = technicians; appt. = appointment; dept = department.

than infants with Apgar scores above 7 at 5 min ($OR$ = 1.54, $p < .003$). Infants born in hospitals with audiology involvement were 37% more likely to receive the outpatient screen than hospitals without audiology involvement ($OR$ = 1.28, $p < .0212$). Audiology involvement reduced the impact of the following variables: nursery level, technology, refer rates, screening personnel, follow-up appointment scheduling, location of outpatient screen, and rescreen rates. Table 5 explains the odds ratios for variables that lost significance after accounting for audiology involvement.

## Discussion

### *Ethnicity*

There was a significant discrepancy in the follow-up rates when comparing non-Hispanic and Hispanic infants. The Hispanic population accounted for 32.3% of the entire birth cohort and was most likely not to receive the outpatient rescreen. Hispanic infants accounted for 47.7% ($n$ = 261) of the infants who did not receive the outpatient rescreen. Non-Hispanics were 45% more likely to receive the outpatient rescreen than the Hispanic population. The

**Table 3.** Final regression model with odds ratios, 95% confidence interval (CI), and *p* values (Somers' D = .426).

| Variable | Odds ratio | 95% CI | Pr > ChiSq |
|---|---|---|---|
| Hospital rescreen rates | | | |
| > 90% | 1.0 | | |
| 80%–89% | 2.515 | 1.844, 3.431 | < .0001 |
| < 79% | 6.782 | 5.008, 9.186 | < .0001 |
| Ethnicity | | | |
| Hispanic | 1.0 | | |
| Non-Hispanic | 0.704 | 0.569, 0.871 | .0012 |
| Gender | | | |
| Female | 1.0 | | |
| Male | 1.232 | 1.011, 1.501 | .0389 |
| Apgar (appearance, pulse, growth, activity, respiration) at 5 min | | | |
| > 7 | 1.0 | | |
| < 7 | 1.536 | 1.154, 2.045 | .0033 |
| Mother's level of education | | | |
| > 12 | 1.0 | | |
| < 12 | 1.491 | 1.191, 1.856 | .0004 |
| Audiology involvement | | | |
| Audiologist | 1.0 | | |
| No audiologist | 1.277 | 1.037, 1.572 | .0212 |

EHDI program needed to identify ways to improve this process.

A more recent analysis by Cunningham et al. (2017) found that there was not a significant difference between the Hispanic and non-Hispanic populations for the rescreen rate. The Colorado EHDI staff in 2007 began offering public service announcements on a Spanish-speaking radio channel. In addition, the development of the Road Map for Families, designed by Hands & Voices, provided hospitals with information they can give to parents upon discharge. Hospitals were also encouraged by the Colorado Hospital Association, as standard of care, to give the results on any testing to parents in their native language through certified interpreter services.

### *Gender*

Male infants were 25% less likely to receive the follow-up rescreen. This analysis demonstrated that gender was correlated to the mother's educational level. As the rescreen rate decreased, male infants were more likely to miss the screen regardless of the mother's education, but there was a higher percentage of male infants who missed the rescreen if the mother had less than 12 years of schooling. It is important to note that 60% of male infants did not receive the outpatient screen as compared with 40% of female infants. This result could not be explained by nursery level (a higher percentage of male infants admitted to the NICU) or ethnicity. There may be cultural reasons or attitudes beyond the scope of this research for the explanation of this outcome. However, in a subsequent study of predictive variables, gender was not a variable in the more recent analysis by Cunningham et al. (2017). Because the follow-up of Hispanic infants was improved in Cunningham et al. and Hispanic male infants were most likely to miss the outpatient screen, improvement of LTF for Hispanic infants may have also improved the differences by gender.

**Table 4.** Explanation of the odds ratio for variables in the final regression model.

| Variable | Explanation |
|---|---|
| Ethnicity | Non-Hispanic infants are 39% more likely to receive the follow-up outpatient rescreen at $p < .006$. |
| Gender | Male infants are 25% less likely to receive the follow-up outpatient screen at $p < .02$. |
| Apgar (appearance, pulse, growth, activity, respiration) at 5 min | Infants who have Apgar scores of 7 or below at 5 min are 45% less likely to receive the follow-up outpatient screen at $p < .006$. |
| Mother's level of education | Infants born to mothers who have 12 years of education or less are 52% less likely to receive the outpatient follow-up screen than those born to mothers with education of 13 years or greater at $p < .0001$. |
| Audiologist | Infants born in hospitals that do not have an audiologist involved with the screening program are 63% less likely to receive the outpatient follow-up screen at $p < .001$. |
| Hospital rescreen rates | Infants born in hospitals that have rescreen rates between 80% and 89% are 2.5 times less likely to receive the outpatient rescreen at $p < .0001$ as compared with hospitals that have rescreen rates of $\geq 90\%$.<br>Infants born in hospitals that have rescreen rates of less than 79% are 6.3 times less likely to receive the outpatient rescreen at $p < .0001$. |

**Figure 1.** Percentage of infants not rescreened by ethnicity (Hispanic, non-Hispanic), audiologist involvement, and hospital rescreen rates (> 90%, 80%–89%, < 79%).

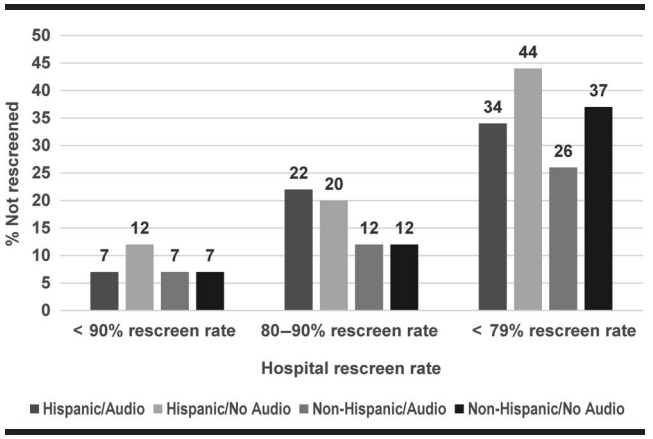
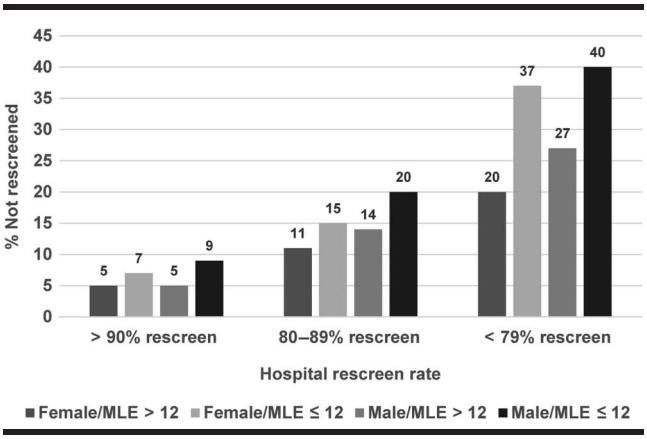



**Figure 3.** Infants not rescreened by gender, mother's level of education (MLE; > 12, < 12), and hospital rescreen rates.



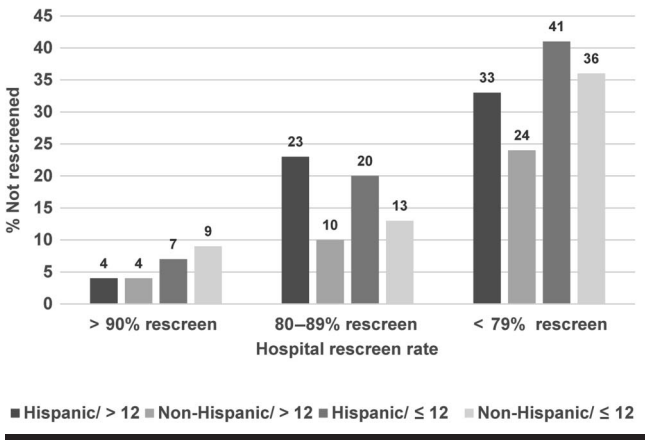

### *Apgar Score of 7 or Less at 5 min*

Thirty-nine infants (1.2%) with low Apgar scores failed the initial screen, and 14 infants (2.3%) did not receive a follow-up rescreen. Infants with a lower birth weight, gestational age, and low Apgar scores have higher percentages in the confirmed hearing loss category. Therefore, every one of these infants missed could be a child with a hearing loss. Infants with a low Apgar score were 54% less likely to receive a rescreen.

### *Mother's Educational Level*

There were 67.3% ($n$ = 368) of infants who were born to mothers with more than 12 years of education and 32% ($n$ = 179) born to mothers with 12 years of education or less, and these 32% were 49% less likely to obtain the rescreen. As noted in the initial regression, 11% of this population was born to teenage mothers. The mother's educational level and ethnicity showed that Hispanic populations had poorer rescreen rates than non-Hispanic populations for both levels of education. Mother's age and level of education continue to be predictive factors in the Cunningham et al. (2017) article for LTF.

**Figure 2.** Percentage of infants not rescreened by ethnicity (Hispanic, non-Hispanic), mother's level of education (> 12, < 12), and hospital rescreen rates (> 90%, 89%–90%, < 79%).




### *Audiology Involvement*

The audiology involvement variable had an impact on whether the individual variables significantly impacted failure to receive a rescreen. These variables were hospital birth rates, level of NICU, technology used for the screen, refer rates, scheduling of the outpatient rescreen, and location of the outpatient rescreen. These variables lost significance in the final model when an audiologist was involved.

Audiology involvement reduces the impact of hospital rescreen rates. Infants born in hospitals with the best rescreen rates (90% or greater) were least likely to be lost to follow-up/lost to documentation than hospitals with rescreen rates from 80% to 90% and those with 79% or less. The poorest hospital rescreen rates were those less than 79%, and the most effective way to improve the rescreen rates of the hospitals with poorest rates was to have an audiologist involved. Analysis of the procedures within each hospital system that might contribute to higher rates of failure to follow-up should be the first step in improvement of systems. Hospitals with rescreen rates less than 79% should be targeted because infants born in these hospitals are seven times less likely to receive a rescreen. An effective way to improve overall state rescreen rates is to improve individual hospital rescreen rates. Finitzo et al. (1998) found that audiology involvement reduced hospital refer rates.

Infants who failed the initial screen and were born in hospitals without an audiologist accounted for 40% ($n$ = 334) of the infants who did not receive the follow-up screen for this cohort. For the cohort of infants who failed the initial screen and were born in hospitals with an audiologist involved, 28% ($n$ = 619) were born in hospitals with rescreen rates of less than 79%.

**Table 5.** Explanation of the odds ratio for variables before accounting for audiology involvement in the regression model.

| Variable | Explanation |
|---|---|
| Nursery level | Infants born in hospitals with a Level 3 neonatal intensive care unit are 27% less likely to receive the outpatient follow-up screen at $p < .06$ as compared with those born in hospitals with only a well-baby nursery. |
| Audiologist | Infants born in hospitals that do not have an audiologist involved with the screening program are 63% less likely to receive the outpatient follow-up screen at $p < .001$. |
| Technology | Infants born in hospitals that use both OAEs and AABR are 67% more likely to receive the outpatient follow-up screen at $p < .0003$. |
| Refer rates | Infants born in hospitals with refer rates greater than 10% are 60% more likely to receive the outpatient follow-up screen at $p < .0001$. |
| Screening personnel | Infants born in hospitals who are screened by technicians (vs. nurses) are 59% more likely to receive the outpatient follow-up screen at $p < .0002$.<br>Infants born in hospitals who are screened by contract staff are 70% more likely to receive the outpatient follow-up screen at $p < .06$. |
| Follow-up appt. scheduling | Infants born in hospitals that schedule the follow-up outpatient rescreen after discharge are 96% less likely to miss the outpatient screen at $p < .0001$ as compared with hospitals that schedule the appointment before hospital discharge.<br>Infants who are born in hospitals that rely on parents to schedule follow-up appointments are 95% less likely to receive the follow-up outpatient screen at $p < .0001$. |
| Outpatient screen | Infants born in hospitals that refer outside their hospital system are almost three times less likely to receive the outpatient follow-up rescreen at $p < .0004$ as compared with hospitals that bring infants back to the hospital nursery. |
| Hospital rescreen rates | Infants born in hospitals that have rescreen rates between 80% and 89% are 2.5 times less likely to miss the outpatient rescreen at $p < .0001$ as compared with hospitals that have rescreen rates of $\geq 90\%$.<br>Infants born in hospitals that have rescreen rates less than 79% are 6.3 times less likely to miss the outpatient rescreen at $p < .0001$ than those born in hospitals with rescreen rates of 90% or greater. |

*Note.* OAEs = otoacoustic emissions; AABR = automated auditory brainstem response; appt. = appointment.

Audiology involvement decreases the impact of hospital birth rate. Hospitals with birth rates between 2,000 and 3,000 had the highest likelihood of failure to follow-up. They were 38% less likely to receive a rescreen, accounting for 20.4% of the 558 babies who did not get rescreened. These hospitals had a higher percentage of volunteer screening and a higher percentage of parents responsible for scheduling the outpatient rescreen. Infants born in hospitals with less than 1,000 births were 44% less likely to receive the outpatient screen compared with hospitals with > 3,000 births. These hospitals had refer rates of greater than 10% and follow-up rates of less than 79%.

Audiology involvement decreases the impact of type of nursery. Infants born in Level III NICU were 38% more likely than infants born in hospitals with only a well-baby nursery to have a follow-up screen before audiology involvement was added to the regression model. However, with audiology involvement, type of nursery lost significance. In an earlier study, Christensen et al. (2008) had found that infants who had high risk factors of low birth weight (< 2500 g) and Apgar scores of less than 7 at 5 min were less likely to obtain a hearing screen. This previous Colorado study also indicated that infants with low Apgar scores were 45% less likely to obtain a rescreen. Because these results were found, presentations have been given to the Colorado Perinatal Care Counsel and all hospitals with an NICU, which improved the return rate to 95%. This effective remediation may be applicable to other states. Follow-up in the NICU nurseries is extremely important because of the higher probability of hearing loss for these infants.

Audiology involvement decreases the impact of the type of screening technology used. Before adding audiology involvement into the regression, infants born in hospitals that used both otoacoustic emissions (OAEs) and automated auditory brainstem response (AABR) were 67% more likely to receive the outpatient follow-up screen at $p < .0003$. The technology variable lost significance (AABR vs. OAEs vs. AABR + OAE) if an audiologist was involved with the hospital system's UNHS program. When an audiologist was involved, technology choices had similar follow-up rates.

Colorado's newborn hearing legislation or state guidelines do not mandate the type of screening technology that hospitals should use in their programs. When Colorado started the newborn screening project in 1992, most hospitals were encouraged to use AABR because of the lower refer rate, and at that time, OAE screening technology was not automated. In 2005, 60% of Colorado birthing hospitals used AABR only. Hospitals began to replace old technology with new technology that contained both AABR and OAE. This newer technology has the advantages of decreasing the cost of disposables associated with the AABR and using OAE in the well-baby nursery.

Using both technologies also provides the hospitals with a mechanism to meet the recommendation set forth by the Colorado Infant Hearing Advisory Committee and Joint Committee on Infant Hearing for AABR screening in the NICU. There is a higher incidence of auditory neuropathy in the NICU that can only be detected by AABR. The rescreen rates were poorer when an audiologist was

not involved with the programs that used both OAE and AABR. The new technologies were initially wrought with problems. Manufacturers had problems with OAE probes and AABR algorithms, and the technical support was not present as had been available. Audiologists who are involved in screening programs have the expertise to work directly with the manufacturers to solve issues and provide technical assistance to the screening staff. Technology choices will continue to change. The obvious solution to this problem was to increase the audiology support to every hospital for technical assistance and training on screening equipment.

Audiology involvement decreases the impact of hospital refer rates at discharge. Before adding audiology involvement into the regression analysis, infants born in hospitals with refer rates of 5.1%–10% at discharge were 32% more likely to receive the outpatient rescreen as compared with hospitals that had refer rates of less than 5%. This result seemed counterintuitive. Further investigation found that this outcome was directly correlated to the audiology variable. Hospitals that had an audiologist involved in the program had higher percentages of infants who obtained the rescreen than hospitals that did not.

The national debate over the importance of refer rates has been ongoing since the inception of newborn hearing screening. Colorado reported that refer rates in this article are based on hospital discharge rather than refer rates based on the outpatient rescreen. In 2005, the average statewide refer rate at hospital discharge was 4.7%. If we calculated those infants who failed the outpatient rescreen and needed to be referred to an audiologist for a diagnostic evaluation, the refer rate would be only 0.2% (143 infants who failed the outpatient rescreen divided by the entire screened cohort of 67,261). In Colorado, there are currently no state funds to support the newborn hearing program. Many states have increased the newborn screening fee to provide funding to the newborn hearing programs. Additional funding would provide audiology support for hospitals and improve the data management system to track infants more quickly through refer, rescreen, and diagnostic processes. If state or national legislatures perceive that follow-up is not an issue, then they will not be interested in funding programs for improvement through grants or state general monies.

Audiology involvement decreases the impact of type of screening personnel. In this study, the type of screening personnel only made a difference when an audiologist was not involved with the screening program. The screening personnel variable was also directly correlated with whether or not an audiologist was involved in the program. Because hospitals are not funded to provide the newborn hearing screen, it is at the hospitals' discretion to choose screening personnel. Of the infants who did not receive the follow-up rescreen, 33% ($n$ = 185) were screened by nurses; 28% ($n$ = 158), by technicians; and 39% ($n$ = 215), by volunteers.

The initial regression analysis on the follow-up result showed that infants born in hospitals that used technicians were 52% ($OR$ = 0.66) more likely than hospitals using nurses to receive the rescreen. This would make sense if hearing screening was the primary technician's main job responsibility, much like a laboratory technician's job responsibility is to draw the blood for the newborn metabolic screen. Volunteers were often recommended as the choice of screener in the beginning stages of newborn hearing screening in Colorado to defray costs. The advent of automated technology did not require an audiologist to perform the screen. There are several hospitals that have been successful with using volunteers if they have an audiologist on site who provides direct supervision and training. Nurses are the primary screeners in hospitals with lower birth rates, and technicians and volunteers are used in the higher rate birthing hospitals. Again, increasing the support with local audiologists for the smaller or more rural hospitals was implemented to improve the follow-up outpatient rescreen.

Audiology involvement decreases the role of who schedules the outpatient rescreen. There was an interaction between who scheduled the outpatient screen, the hospital, or the parents, but it was related to whether or not an audiologist was involved. Forty-seven percent ($n$ = 262) of the infants who did not receive a rescreen were born in hospitals that scheduled the appointment before or after discharge. The remaining 53% ($n$ = 296) were born in hospitals that asked the parents to call for an outpatient rescreen appointment. The initial regression analysis showed that infants born in hospitals that asked parents to take responsibility for scheduling the outpatient rescreen were 60% less likely to receive the rescreen than if the hospitals took responsibility. This variable was directly related to the audiologist variable. When infants were born in hospitals without an audiologist involved, they were 62% less likely to receive the outpatient screen.

This finding indicated that it was an area for potential dramatic improvement. Screening programs need to make the recommendation for the follow-up appointment in a manner that helps families understand the importance of the outpatient rescreens. The Colorado Infant Hearing Program worked with Hands & Voices to develop materials that could be given to families at discharge, explaining the importance of follow-up from the parents' perspective. Utilizing the audiology regional coordinators to work with hospital staff on protocols and materials for the outpatient screen was also implemented.

Audiology involvement significantly decreases the impact of the location of the outpatient rescreen. The programs with the highest rate of rescreen or the best follow-up were those with an audiology department. The next most effective characteristic was to refer the infant back to the nursery for rescreen. The highest failure to follow-up rate occurred when the families were referred to a local audiologist. Of the 558 infants who did not receive the outpatient rescreen, 52% ($n$ = 291) should have returned to the nursery; 44% ($n$ = 244), to the audiology department; and 4% ($n$ = 23), to local audiologists. This variable was the crux of the hypothesis. Hospitals that brought families back to the nursery

or to the audiology department were far more likely to have higher rescreen rates, and this was further strengthened when an audiologist was involved in the program. When hospitals had an audiology department, infants were 27% more likely to receive the outpatient rescreen than to return to the nursery. In these situations, the audiologist was on staff and also supervised and coordinated the screening program. When hospitals referred families outside the hospital system for the follow-up rescreen, there was a 40% chance that the family would not return.

The outpatient rescreens need to be accessible to families without barriers such as language, transportation, or ability to pay. The variable for whether a charge is incurred was not significant, but the Colorado Infant Hearing Program does receive phone calls from parents requesting alternatives to the outpatient rescreen when the ability to pay is an issue. Fortunately, all of the Colorado educational audiologists have OAE equipment and are willing to see these families. Without this option, many families would not have been able to receive a rescreen for their infant.

When the data were initially analyzed, about half of the hospitals were utilizing their regional audiology coordinator. On the basis of the significant findings, the EHDI program infused more funding in the regional audiology coordinator program, the roles of the audiology coordinators were clearly defined, and all screening hospitals were contacted by their regional audiology coordinator. The Colorado audiology regional coordinators all have other full-time jobs and typically get paid between 8 and 20 hr per year depending on the area they are covering.

Eight years after reinforcing the role of the audiology coordinators, almost no hospitals indicated that they did not have this coordinator. Cunningham et al. (2017) found that the audiology involvement variable was no longer significant and all of the variables identified in this study as having impact on the follow-up statistics did not reappear as significant predictors of follow-up to outpatient screen. This systems intervention is similar to an intervention study, in which an intervention is established and then the impact of this intervention is assessed. Therefore, because of this systems intervention, the audiology involvement variable is a causal factor in reducing the significance of the variables noted in this article.

Involving the primary care physicians is a top priority for the EHDI program. As with the newborn metabolic screen, the primary care physicians should be notified when their patient fails the screen or misses the screen. Engaging the primary care physicians to take responsibility for follow-up could significantly improve the rescreen outcomes.

The EHDI program must identify resources to ensure that all families have access to the services they need and that they understand the follow-up recommendations and the importance of follow-up. Cunningham et al. (2017) found similar findings with the exception of the Hispanic population noted above. Infants born to mothers with lower education were at risk for not obtaining a rescreen. However, the audiology involvement variable was no longer significant, nor were the variables that had significant interactions with audiology involvement, indicating that the work that the state EHDI program did connecting individual hospitals with regional audiology coordinators and increasing the regional audiology coordinators' time did work. The cost of audiology involvement in the Colorado EHDI system is critical but minimal. Audiologists are contracted by the hour, and total costs to the systems are about $10,000–12,000 per year. Cunningham et al. also came to similar conclusions that quality improvement at the hospital level, such as appropriate counseling to the parents and the results relayed directly to the primary care physician, would increase follow-up. Culturally appropriate education, access to services, and a focus on teen parents, racial minorities, and families with low incomes are critical because these groups are at risk for LTF.

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