Early hearing detection and communication development (EHDCD) programs enable us to identify hearing loss in early infancy, making intervention by 6 months of age a reasonable goal. For infants and children fitted with hearing instruments, it is critical that the devices be adjusted appropriately so that the pre-lingual listener has full and consistent access to sound, without discomfort for loud sounds.

Several published pediatric amplification guidelines are available to assist clinicians with the hearing aid fitting process for infants and children.1-5 While the guidelines were developed in different jurisdictions, similar recommendations are made for all stages of the hearing instrument fitting process. For example, the use of a systematic, evidence-based approach to hearing aid fitting that accounts for an infant’s external ear acoustics at the assessment, selection, and verification stages and that includes the measurement of hearing aid output limiting is a requirement of every current pediatric amplification protocol.

While it is encouraging to see consensus in pediatric hearing aid fitting guidelines, there continue to be substantial differences among clinical practice behaviors. Surveys have indicated that the majority of pediatric audiologists use sound field-aided threshold measures to verify the electroacoustic performance of hearing instruments for young infants.6 Probe-microphone measures were used by roughly 20% of the audiologists fitting hearing aids to infants.6 It has been well-documented that behavioral measures (i.e., aided threshold measures) do not provide accurate estimates of the aided audibility of soft, average, and loud speech or the real-ear saturation response of the hearing aid and that infants 6 months of age and younger are not developmentally capable of performing this task.7,8 Failure to appropriately verify the electroacoustic performance of the hearing aid in terms of predicted speech audibility and maximum hearing instrument output can result in obstructing the language benefits an infant would have otherwise received from being identified at an early age and optimally fitted.

It is also important to consider the prescriptive targets used to determine the recommended levels for amplified speech and target limits for hearing instrument output as a function of frequency. Prescriptive algorithms provide the foundation on which the hearing instrument performance characteristics are selected for the infant or child to be fitted. Recent survey data indicate that most audiologists fitting hearing aids to infants and young children use a published hearing aid prescriptive procedure.6,9 At present, prescriptive procedures can be divided into two classifications: (1) evidence-based generic prescriptive algorithms and (2) manufacturer-specific proprietary algorithms.

Evidence-based generic prescriptive algorithms for children include the DSL m[i/o]10 and the NAL-NL1,11 both of which are intended for use with any hearing aid. Proprietary prescriptive methods incorporate prescriptive algorithms developed by manufacturers for use with their specific hearing instruments. The lack of published information regarding the development of pediatric manufacturer-specific proprietary algorithms makes it difficult for the audiologist to make an informed choice about which procedure will be best for their young patient.12 Some manufacturers have decided to forego the development of a proprietary pediatric algorithm and use either the NAL or DSL prescriptive algorithms for fitting children and have implemented these formulas in their fitting software. These generic prescriptive algorithms may have been adapted by the manufacturer to account for the unique characteristics (e.g., compression kneepoint) of their hearing aids.

Several investigators have compared proprietary prescriptive algorithms for use with adults. Keidser and colleagues found a 10-dB variation in the amount of gain prescribed by NAL-NL1, DSL[i/o], and four proprietary algorithms for the same audiogram.12 A study by Hawkins and Cook compared simulated 2-cc versus actual 2-cc gain as well as simulated insertion versus actual insertion gain measures from the fitting software for 28 hearing aids of various styles from four major manufacturers.13 Results indicated a clear trend for the simulated values to overestimate what was actually provided by the hearing aids for both the 2-cc coupler and insertion gain comparisons.13 Differences of as much as 10 to 20 dB were noted for the various hearing aids and prescriptive algorithms in the study.
A more recent study examined behind-the-ear (BTE) hearing aids from six major manufacturers programmed using their “default” fitting procedure.14 For some this was a generic fitting formula and others applied their own proprietary prescriptive method. The OSPL90 was measured at the default program settings with all special features deactivated. Results indicated maximum output values ranging from 90 to 109 dB SPL (re: 2-cc coupler) at 2000 Hz across the six hearing aids for a flat 50-dB-HL hearing loss.14

RATIONAL
Despite the unexpected degree of variation among prescriptive methods, for everyday listening the average adult listener may be able to adjust the volume control of the hearing instruments to compensate for the 10- or 20-dB variation provided from one algorithm to the next. However, in the case of a 6-month-old infant who can neither manipulate the gain of the hearing aid nor verbalize concerns, these recent findings would seem to be clinically important. Infants and young children must live and learn with the hearing instrument characteristics provided (or not provided) to them. They cannot accommodate a 10-dB variation in prescribed overall gain by adjusting a volume control wheel as an adult would. They also cannot “fill in the blanks” when words or speech sounds are inaudible the way adults do because they have not yet developed sufficient knowledge of spoken language.

The results reported above make it apparent that for the same audiometric hearing loss there may be differences in the prescribed gain from various prescriptive procedures. In addition, it may be that there is some variation in the gain prescribed from manufacturer-specific implementations of the same generic prescriptive procedure. As a result, an infant can end up with substantially different electroacoustic characteristics in hearing aid performance depending on which prescriptive algorithm is chosen by the audiologist within the hearing aid fitting software. It is important to systematically quantify the differences that may exist among manufacturer-specific implementations of prescriptive algorithms that potentially affect audibility and comfort of amplified speech.

RESEARCH QUESTIONS
This study was designed to address three questions:

1. Will the prescribed output-limiting levels differ for the same 6-month-old infant depending on the manufacturer-specific prescriptive algorithm chosen?
2. Will the prescribed gain by frequency characteristics differ for the same 6-month-old infant, as a function of input level, depending on the manufacturer-specific algorithm chosen?
3. Will predicted speech audibility differ across manufacturer-specific prescriptive algorithms evaluated?

METHOD
BTE instruments recommended for use with the pediatric population were chosen from five manufacturers. The hearing aids were programmed using the most current version of each of the manufacturer’s proprietary fitting software, installed as modules in the NOAH® client module software system. Where proprietary prescriptive algorithms for pediatric fittings were not available, three of the BTE instruments were programmed using the manufacturer’s default prescriptive method. In two cases this was the manufacturer’s implementation of the NAL-NL1 procedure and in another case this was the manufacturer’s implementation of the DSL method. Advanced features (i.e., noise reduction, directional microphone) were deactivated in all devices. Average real-ear-to-coupler difference (RECD) values for a 6-month-old infant were applied to 2-cc coupler measures to predict the hearing aids’ responses in the ear canal.15

Nine audiograms, ranging from mild to profound, were used to program each hearing aid (see Table 1). Simulated real-ear measurements (S-REM) were performed for soft (55 dB SPL), average (65 dB SPL), and loud (75 dB SPL) speech and maximum power output (MPO), using the Audioscan® VeriFit VF-1 real-ear measurement system (Software Version 2.0.18). Each BTE instrument was coupled to the standard HA-2 coupler available on the VF-1 and placed inside the test chamber. The test chamber was closed prior to making all electroacoustic measurements. The equipment (i.e., cables, programming boots) supplied by the manufacturers specific to each BTE instrument was connected to a HI-PRO box for programming each hearing instrument.

For each BTE instrument programming, the 1/3-octave band measurements obtained from the VF-1 were collapsed into a single Speech Intelligibility Index (SII) value, based on the 1/3-octave band SII calculation procedure.16 The SII value ranges from 0 to 1, and was converted to a value between 0% and 100% for the purposes of this study. A Microsoft Excel spreadsheet was used for all SII calculations.17 Separate SII values were calculated for each BTE instrument across the nine audiograms and for each of the three input levels. The nine audiograms were converted to equivalent adult hearing levels18 before SII calculations were performed. It has been documented that young children are not able to use

Table 1. Nine audiograms (A-I) in dB HL, used in this study.

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<th>Audiogram</th>
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contextual information in the same way as adults. Thus, an equal band importance function was used in calculating the SII values.

RESULTS AND DISCUSSION

Output limiting

Simulated real-ear saturation response (S-RESR) measurements differed significantly across the five manufacturer-specific prescriptive algorithms (F[4,32] = 47.66, p < .001). Post hoc analyses indicated that this effect was present per frequency (Tukey’s HSD, p < 0.05). The results of the S-RESR measurements for the five manufacturer-specific algorithms at 3000 Hz for the nine audiograms are presented in Figure 1.

Substantial variation is evident in the simulated RESR measurements across manufacturers for the nine audiograms used in this study. A review of the data presented by individual audiograms further revealed the significant variation in the output being produced by some of the manufacturer-specific prescriptive algorithms. For example, for audiogram A, values range from 100 dB SPL (Manufacturer 4) to 130 dB SPL (Manufacturer 1) in the higher frequencies. In the lower frequencies, values range from 90 dB SPL (Manufacturer 3) to 105 dB SPL (Manufacturer 4) (see Figure 2). Moreover, the shapes of the output limiting responses are different for each manufacturer. Some responses are relatively flat across frequencies (Manufacturer 4), while others are not (Manufacturer 1) (see Figure 2).

Determining the basis for manufacturer-specific prescriptive algorithm output limiting targets is difficult, as the derivation of these algorithms is often neither clearly described nor accessible. However, from the present study, it can be seen that there is a large range of variation among the S-RESR for the manufacturer-specific prescriptive algorithms evaluated in this study. Clearly the output limits of some manufacturer-specific prescriptive algorithms may be inappropriate for pediatric hearing aid fittings.

Prescribed gain by frequency for different input levels

Simulated real-ear aided response (S-REAR) measurements for soft, average, and loud speech inputs differed significantly across manufacturers: soft inputs (F[4,32] = 18.11, p < 0.001); average inputs (F[4,32] = 24.67, p < 0.001); loud inputs (F[4,32] = 31.89, p < 0.001). Post hoc analyses indicated that these differences were significant at most test frequencies (Tukey’s HSD, p < 0.05). An example is shown for Audiogram E (Figure 3, A-C). It can be seen that, in this example, S-REAR values differ by as much as 20 dB at some frequencies for soft, average, and loud inputs.

Predicted speech audibility

Substantial differences among SII values were noted from the various manufacturer-specific prescriptive algorithms’ responses for soft speech input levels. Relatively less difference in these values was noted for average level inputs and even smaller differences for loud input levels (Figure 4 A-C).

It is evident that the observed differences in frequency response characteristics of the manufacturer-specific algorithms resulted in differences in SII values. Currently, there is no way to predict real-life outcome differences from SII value differences for a 6-month-old infant. However, from a habilitative audibility perspective, increased audibility should result in more language-learning opportunities. Research has shown that children require and prefer audibility of the entire speech range and at higher sensation levels than adults in order to understand speech. Therefore it is prudent to consider that more
audibility is desirable for the pediatric population.

Clinical implications

Despite the published recommendations for pediatric amplification, real-ear or simulated real-ear verification of hearing instrument performance is not routine clinical practice for many pediatric audiologists.6,9 With the recent proliferation in EHDCD programs, more infants are being fitted with hearing aids by 6 months of age.

The current study has demonstrated the substantial variation that is generated among manufacturer-specific prescriptive algorithms for the same 6-month-old infant. Some manufacturer-specific algorithms resulted in unexpectedly high output limiting values, generating concern about the potential for discomfort in a 6-month-old fitted with these algorithms. Many of the manufacturer-specific prescriptive algorithm output-limiting values were substantially higher than output-limiting values recommended by published evidence-based generic procedures for output limiting in pediatric hearing aid fittings.10,11 Additionally, the variation in manufacturer-specific prescriptive algorithm hearing aid response characteristics to speech inputs resulted in substantial differences in predicted audibility as measured by the SII.

It is important in any pediatric hearing aid fitting to ensure that speech inputs are audible in order to facilitate speech and language learning. The results of this study suggest that the manufacturer-specific prescriptive algorithms examined provide very different simulated real-ear responses even for the same infant. This research highlights the importance of verifying and comparing the output limiting and responses to speech inputs provided by various manufacturer-specific implementations of prescriptive algorithms.

Regardless of the approach taken for electroacoustic prescription, the responsible clinician should want to know the levels of amplified sound that hearing aids deliver to the child’s ear. Therefore, pediatric audiologists must apply comprehensive and evidence-based electroacoustic verification strategies that are compatible with the population they are working with.

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