Purpose: To determine whether Desired Sensation Level (DSL) v5 Noise is a viable hearing instrument prescriptive algorithm for children, in comparison with DSL v5 Quiet. In particular, the authors compared children’s performance on measures of consonant recognition in quiet, sentence recognition in noise, and loudness perception when fitted with DSL v5 Quiet and Noise.

Method: Eleven children (ages 8 to 17 years) with stable, congenital sensorineural hearing losses participated in the study. Participants were fitted bilaterally to DSL v5 prescriptions with behind-the-ear hearing instruments. The order of prescription was counterbalanced across participants. Repeated measures analysis of variance was used to compare performance between prescriptions.

Results: Use of the Noise prescription resulted in a significant decrease in consonant perception in Quiet with low-level input, but no difference with average-level input. There was no significant difference in sentence-in-noise recognition between the two prescriptions. Loudness ratings for input levels above 72 dB SPL were significantly lower with the noise prescription.

Conclusions: Average-level consonant recognition in quiet was preserved and aversive loudness was alleviated by the Noise prescription relative to the Quiet prescription, which suggests that the DSL v5 Noise prescription may be an effective approach to managing the nonquiet listening needs of children with hearing loss.

Key Words: children, speech recognition, amplification or hearing aids

The Desired Sensation Level (DSL) method has had a specific focus on pediatric hearing instrument use since its inception. Since the development of DSL v3, the algorithm has sought to maximize audibility across frequencies while remaining within the auditory range (above threshold and below level of discomfort) across the amplified frequency range (Dillon, 2001; Gagné, Seewald, Zelisko, & Hudson, 1991a; Gagné, Seewald, Zelisko, & Hudson, 1991b; Seewald, Ross, & Spiro, 1985). The advent of nonlinear amplification in hearing instruments led to expanded goals for prescriptive formulae. Algorithms intended for use with nonlinear hearing instruments aimed to provide frequency-gain responses for speech at levels both above and below the average level of conversational speech (e.g., prescriptive targets for speech at a low level such as 50 dB SPL, and a high level of 75 dB SPL) (Byrne, Dillon, Ching, Katsch, & Keidser, 2001; Cornelisse, Seewald, & Jamieson, 1995). DSL v4.1 was developed to incorporate the application of nonlinear circuitry, which allowed for normalization of loudness across a broad range of input levels (Jenstad, Pumford, Seewald, & Cornelisse, 2000; Jenstad, Seewald, Cornelisse, & Shantz, 1999; Scollie et al., 2005). Maximizing the audibility of speech sounds across input levels is especially important in the prescription of hearing instruments for children (American Academy of Audiology, 2003; College of Audiologists and Speech-Language Pathologists of Ontario, 2002; The Pediatric Working Group, 1996); research has shown that children with hearing loss require more audibility and a larger bandwidth in order to perceive and thus develop speech (Pittman & Stelmachowicz, 2000; Stelmachowicz, Hoover, Lewis, Kortekaas, & Pittman, 2000; Stelmachowicz, Lewis, Choi, & Hoover, 2007; Stelmachowicz, Pittman, Hoover, & Lewis, 2001; Stelmachowicz, Pittman, Hoover, Lewis, & Moeller, 2004). The literature regarding the speech recognition abilities of children with moderate to severe hearing losses who wear hearing instruments fitted with a DSL prescription shows that these children generally achieve, on average, consonant recognition scores in the 80% to 95% correct range (Jenstad et al., 1999; Scollie, 2008; Scollie, Ching, Seewald, Dillon, Britton, Steinberg, & King, 2010; Sininger, Grimes, & Christensen, 2010). Also, lower gain prescriptions can lead...
to decrements in speech recognition performance at lower input levels for some but not all children (Marriage, Vickers, Baer, & Moore, 2010; Scollie, Ching, Seewald, Dillon, Britton, Steinberg, & King, 2010).

Limitations of Current Hearing Instrument Prescriptions

Although the DSL prescriptive method has evolved in a way that allows for somewhat different listening situations (e.g., a single speech-source at varied levels), the scope of hearing instrument prescription may still be considered narrow when compared with the number of listening environments and situations experienced by listeners on a day-to-day basis, many of which include multiple talkers. Multi-talker environments often include background noise, competing speech, and reverberation (Brungart & Simpson, 2007; Cherry, 1953; Scollie, Ching, Seewald, Dillon, Britton, Steinberg, & Corcoran, 2010), and may be broadly characterized as “noisy” listening situations. Difficulty understanding speech-in-noise is a leading cause of listeners’ dissatisfaction with hearing instruments (Kochkin, 2007). Real-world, nonquiet listening environments can be divided into two general categories: (a) speech amid moderate background noise, a situation in which speech clarity is a primary goal, and (b) in a loud environment, a situation in which comfort is a primary goal.

Research has indicated that children experience background noise levels ranging from approximately 40 to 80 dBA across the variety of environments they typically encounter on a daily basis (Crandell & Smaldino, 2000; Olsen, 1998; Pearsons, Bennett, & Fidell, 1977). Crukley, Scollie, and Parsa (2011) reported that the children experienced noise levels ranging from 40 to greater than 90 dBA over the course of a school day. These reported broad ranges of noise levels result in an equally broad range of signal-to-noise ratios (SNR) across the environments that children experience in a given day. Listening across these environments ranges from very difficult to relatively easy when SNR is low or high, respectively. Children with hearing loss experience greater listening difficulty when background noise is present and require higher SNRs than do children with normal hearing in order to understand speech (Elliott, 1979; Fallon, Trehub, & Schneider, 2002; Kortekaas & Stelmachowicz, 2000; Pittman & Stelmachowicz, 2000; Scollie, 2008; Stelmachowicz et al., 2000, 2001; Stelmachowicz, Pittman, Hoover, & Lewis, 2004). Although the challenges presented by the range of noise levels and SNRs in a child’s daily life exist for all children, the needs of children with hearing loss who use hearing instruments are unique.

A series of recent studies that compared NAL-NL1 and DSL v.4.1 nonlinear prescriptive algorithms in children identified unique listening needs and preferences of the children with hearing loss (Ching, Scollie, Dillon, & Seewald, 2010; Ching, Scollie, Dillon, Seewald, Britton, & Steinberg, 2010; Ching, Scollie, Dillon, Seewald, Britton, Steinberg, & Corcoran, 2010; Ching, Scollie, Dillon, Seewald, Britton, Steinberg, & King, 2010). The data indicated two distinct listening categories of children’s prescription preference: (a) loud, noisy, and reverberant situations and (b) quiet or low-level listening situations (Scollie, Ching, Seewald, Dillon, Britton, Steinberg, & Corcoran, 2010). Children demonstrated a preference for the DSL fitting when listening to lower level sounds or when they desired louder and clearer output. Children also demonstrated a preference for the NAL fitting when listening to louder signals or when listening in the presence of background noise. Ching, Scollie, Dillon, Seewald, Britton, and Steinberg (2010) described the electroacoustic differences between DSL v4.1 and NAL-NL1 fittings for the children in the comparison studies. In general, the DSL fittings provided more gain across frequencies than did the NAL fittings and the NAL fittings had steeper response slopes than did the DSL fittings. DSL v4.1 prescribed approximately 10 dB more low-frequency gain and 5 to 10 dB more high-frequency gain than did NAL-NL1.

Frequency-gain shaping is the adjustment of the amount of amplification provided across the frequency range. Use of alternate hearing instrument frequency-gain response shapes to facilitate speech understanding in the presence of noise has been the subject of research for several decades. Some studies have demonstrated improved speech recognition with increased frequency response bandwidth using simulated hearing instruments (Skinner, Karstaedt, & Miller, 1982; Skinner & Miller, 1983). However, use of alternate frequency responses in hearing instruments has generally shown no difference in speech recognition in noise performance (Dirks, 1982; Kamm, Dirks, & Carterette, 1982; Scollie, Ching, Seewald, Dillon, Britton, Steinberg, & King, 2010; van Buuren, Festen, & Plomp, 1995).

Despite the lack of performance differences, children have indicated a preference for having access to both DSL v4.1 and NAL-NL1 prescriptions as separate programs to be selected depending on a given listening situation (Scollie, Ching, Seewald, Dillon, Britton, Steinberg, & Corcoran, 2010). It has been suggested that level, location, and SNR of target sounds are important factors that contribute to children’s listening preferences (Scollie, Ching, Seewald, Dillon, Britton, Steinberg, & Corcoran, 2010). Research has shown that children prefer different amplification characteristics for the varied listening environments they encounter during daily living (Scollie, Ching, Seewald, Dillon, Britton, Steinberg, & Corcoran, 2010). Fitting children with a separate hearing instrument memory that can be manually selected as needed has been suggested as a clinically feasible approach to managing children’s nonquiet listening needs (Scollie, Ching, Seewald, Dillon, Britton, Steinberg, & Corcoran, 2010; Scollie et al., 2005).

Marriage et al. (2010) assessed the effectiveness of DSL v4.1, DSL v5, and NAL-NL1 in restoring the audibility of soft speech sounds for children with moderate to severe hearing loss. Open- and closed-set speech detection and discrimination tests were used to evaluate children’s performance when fitted with the three fitting rationales. Results indicated that consonant discrimination was significantly better with either of the DSL prescriptions than with the NAL-NL1 prescription; phoneme identification was highest with DSL v4.1 and lowest with NAL-NL1; word recognition at 50 dBA was highest for DSL v4.1 and lowest
for NAL-NL1; and the NAL-NL1 prescription required the highest presentation level for the phrase recognition test. There were no significant differences between the three rationales on measures of vowel discrimination, word recognition at 65 dBA, or recognition of words in noise. The results of this study serve to highlight the implications regarding the use of different fitting rationales for children with hearing loss. Improved detection and discrimination of soft speech sounds are important clinical considerations for young children who are developing speech and language.

**Children’s Aided Nonquiet Listening Needs**

Studies of speech-in-noise recognition with children who wear hearing instruments have shown a range of SNR required for 50% correct performance of approximately ±5 dB (Ng, Meston, Scollie, & Seewald, 2011). Although audibility is a likely factor in performance, previous research has indicated no difference in speech-in-noise recognition between hearing instrument prescriptions, specifically when used to compare the DSL v4.1 and NAL-NL1 frequency responses in combination with nonlinear amplification (Scollie, Ching, Seewald, Dillon, Britton, Steinberg, & King, 2010).

Studies of aided loudness perception have shown differences in loudness ratings between hearing instruments fitted with linear and wide dynamic range compression (WDRC), with WDRC instruments resulting in lower reported loudness for loud sounds than linear instruments (Jenstad et al., 2000; Jenstad et al., 1999). Loudness differences have also been reported between hearing instruments fitted with prescriptions with different levels of prescribed gain, with lower gain prescriptions resulting in lower reported loudness ratings (Scollie, Ching, Seewald, Dillon, Britton, Steinberg, & King, 2010).

**Hearing Instrument Prescription for Nonquiet Listening**

The DSL v5 Noise prescription is a generic approach that can be applied to any hearing instrument fitting. Although digital noise reduction (DNR) algorithms are available in most high-end hearing instruments available on the market today, DNR implementations differ across manufacturers and devices. The function of most DNR algorithms is to reduce the aided level of noisy speech or nonspeech sounds in the output of a hearing instrument. While most manufacturers offer DNR in their products, these noise reduction systems vary significantly in the philosophy and processing strategy involved in the implementations. Some implementations may impose gain reduction strategies similar to what is prescribed by DSL v5 Noise (using Speech Intelligibility Index [SII] weighting), while others may impose gain reduction for all or most frequencies (Bentler & Chiou, 2006). For these reasons, DNR implementations have to be considered individually and on a product-by-product basis.

In addition, in order for DNR processing to provide benefit, it must be activated. That is, the algorithm must correctly classify the listening environment or situation occupied by the hearing instrument wearer. In general, DNR algorithms are most effective for stationary noise sources that have small degrees of modulation (Bentler & Chiou, 2006). However, in real-world environments, competing noise sources generally contain more modulation than do typical stationary noise sources (Fikret-Pasa, 1993). For this reason, the signal classification systems that modern hearing instrument DNR algorithms rely upon can incorrectly classify listening situations and fail to engage DNR when it may be beneficial. The dynamic and nonquiet nature of the listening environments experienced by children have been shown to lead to large errors in signal classification, whereby situations that involve speech signals amid dynamic competing noise sources are classified as speech alone across a variety of products and thus would not lead to the activation of DNR processing (Crukley & Scollie, 2010). For these reasons, the authors explored the efficacy of a prescriptive approach to manage listening in noisy situations. A prescribed frequency-gain response for listening in noise is not dependent upon signal classification or activation; its benefits would be seen for competing signals of any type, either stationary or dynamic.

The most recent version of DSL (version 5) introduced separate sets of prescriptive targets for individuals with congenital and acquired hearing loss as well as separate prescriptions for use in quiet and noisy situations (Scollie et al., 2005). The noise program prescription within the DSL v5 fitting method is designed for use as an additional hearing instrument memory with an alternate frequency response and reduced gain (Scollie et al., 2005). The prescribed frequency response is designed to maintain audibility of the frequency regions of speech believed to contain acoustic cues that are most important for speech intelligibility based on the Speech Intelligibility Index (SII; ANSI S3.5, 1997). In addition, the prescribed compression threshold is elevated by 10 dB in order to reduce the gain applied to lower level background noise. Relative to the prescription for quiet environments, the noise program prescription places speech at a lower sensation level at low and high frequencies and provides less gain for low-level sounds. This prescription is designed to manage comfort in noisy environments without degrading speech recognition in the presence of background noise (Scollie et al., 2005). This prescription may differ from the NAL-NL1 approach used in the NAL-DSL comparison studies cited above in several ways. First, the prescription uses a higher compression threshold to specifically reduce noise levels during pauses between speech, whereas the NAL-NL1 fittings described by Ching, Scollie, Dillon, Seewald, Britton, and Steinberg (2010) used a low compression threshold. Second, although both the DSL v5 Noise and NAL-NL1 prescriptions use SII-based weighting strategies, the NAL-NL1 prescription combines this with corrections for effective audibility (Byrne et al., 2001; Ching, Dillon, Katsch, & Byrne, 2001), whereas the DSL prescription does not. Taken together, these two factors would predict that the DSL v5 Noise prescription may provide less low-level gain but greater prescribed bandwidth for mid- to high-level speech when compared with NAL-NL1. However, experimental evaluation of this lower gain prescription has
not been completed to date. Such an evaluation would require consideration of listening in noisy environments.

Rationale for Current Study

Although there is no consensus for noise management in pediatric hearing instrument fittings (American Academy of Audiology, 2003; College of Audiologists and Speech-Language Pathologists of Ontario [CASLPO], 2002; Foley, Cameron, & Hostler, 2009), children have demonstrated a desire for nonquiet amplification options (Scollie, Ching, Seewald, Dillon, Britton, Steinberg, & Corcoran, 2010). The DSL v5 Noise prescription takes a generic prescriptive approach to adjusting the frequency-gain response of a hearing instrument in order to accommodate listening in noisy situations (Scollie et al., 2005). This noise prescription uses a lower gain setting and a higher compression threshold, which may have either positive or negative effects on speech recognition across input levels, when compared with the corresponding DSL v5 Quiet prescription. Therefore, the present study includes outcomes associated with speech in quiet, speech in noise, and loudness perception for both DSL v5 prescriptions: Quiet and Noise.

Research Questions

The current study addressed three research questions regarding the DSL v5 Quiet and Noise prescriptions. First, does use of the two prescriptions result in differences in consonant recognition? Second, does use of the two prescriptions result in a difference in sentence recognition in noise performance? Third, does use of the two prescriptions result in different loudness ratings?

Differences in speech recognition in quiet scores were expected between the two prescriptions with the DSL v5 Noise prescription, resulting in lower scores due to lower prescribed gain and thus potentially reduced audibility relative to the DSL v5 Quiet prescription. The two prescriptions were expected to result in equivalent speech-in-noise recognition scores because noise floor is the primary limitation to audibility in most noisy environments. The DSL v5 Noise prescription was expected to result in lower loudness ratings than was the DSL v5 Quiet prescription because of the lower gain prescribed by the Noise prescription.

Method

Participants

Eleven children were recruited to participate in the study. Participants included two cohorts of students with hearing loss from local schools; five children from an elementary school self-contained class for the deaf and hard of hearing and six children from a high school hearing resource class. The average age of the elementary school children was 8.85 years (range: 8.0 to 9.75 years); the average age of the high school children was 15.18 years (range: 13.83 to 17.58 years). Both schools were located in London, Ontario, Canada, and are a part of the local school board’s deaf and hard of hearing program. All participants were full-time hearing instrument users with stable, congenital sensorineural hearing loss.

Hearing Threshold Levels

Hearing threshold levels were measured by the participants’ clinical audiologists within 6 months prior to study enrollment. Hearing losses ranged from moderate to profound (see Figure 1). Most of the participants (8 out of 11) had symmetrical hearing loss, with symmetrical hearing loss defined as less than a 15 dB-difference in four-frequency pure-tone average between ears.

Hearing Instrument Fitting Procedure

Hearing instruments were fitted following recommended procedures (Bagatto et al., 2005). Individual Real-Ear-to-Coupler Difference (RECD) was measured for each participant with the Audioscan RM500SL Hearing Instrument Fitting System. All participants were fitted with behind-the-ear hearing instruments with instrument performance verified using the simulated real-ear measurement (S-REM) feature of the Audioscan RM500SL to measure hearing instrument output relative to prescriptive targets. The S-REM strategy was used to promote fitting accuracy across participants and prescriptions as well as fitting environment consistency across participants and prescriptions.

Target Derivation

DSL v5 Quiet prescription targets were generated by the RM500SL and custom software was used to generate targets for the DSL v5 Noise prescriptions using the participants’ audiometric thresholds and RECDs. DSL v5 prescriptive targets for both Quiet and Noise were calculated for input levels of 55, 65, and 70 dB SPL.

Hearing Instrument Adjustment and Verification

All participants were fitted with Phonak Versata SP behind-the-ear hearing instruments. Hearing instruments were adjusted in an HA2-2cc coupler to match the real-ear aided response (REAR) targets for both prescriptions using the speech signal generated by the Audioscan RM500SL across input levels. The hearing instruments were manually adjusted to match targets from 250 to 6000 Hz. For nine of the 11 participants, targets could be met to 6000 Hz using the multichannel amplitude compression processing. Two remaining participants had steeply sloping hearing losses and could not be provided with an audible band of speech to 6000 Hz. For these two participants, Phonak SoundRecover was enabled in their fittings with cut-off frequencies of approximately 2000 Hz. SoundRecover is a proprietary form of nonlinear frequency compression, which compresses the high-frequency output of the hearing instrument into a lower frequency range in which the listener has better hearing sensitivity (Simpson, Hersbach, & McDermott, 2005). The specific settings were verified and fine-tuned following previously suggested procedures (Bagatto, Scollie, Glista, Parsa, & Seewald, 2008; Glista & Scollie, 2009; Glista et al., 2009).
Hearing instruments were fitted to match targets within 0.97 dB on average (SD = 1.12) for the DSL v5 Quiet prescription and within 1.54 dB on average (SD = 1.37) for the Noise prescription, averaged across ears, frequencies, and input levels. This target-matching evaluation excluded frequencies above 2000 Hz for the two subjects with Sound Recover enabled. The fittings to the DSL v5 Quiet and Noise prescriptions were stored to hearing instrument fitting software for later use as experimental listening conditions.

The difference between fittings using the DSL v5 Noise prescription relative to the Quiet prescription is shown in Figure 2, which illustrates the difference between Quiet and Noise targets for the better hearing ear of each participant. The figure demonstrates the lower gain and speech-importance weighting of DSL v5 Noise relative to Quiet targets. On average, DSL v5 Noise targets are approximately 10 dB lower for low frequencies and approximately 5 dB lower for high frequencies when compared with DSL v5 Quiet targets. The SII values associated with each fitting were automatically calculated by the Audioscan Verifit. SII values ranged from 0.24 to 0.92. However, these values do not account for frequency lowering effects present in two of the fittings. Excluding these fittings, the SII values for the DSL v5 Noise fittings were lower than those for the Quiet fittings by approximately 10% at 55 dB SPL and 5% at 65 dB SPL. At test levels of 70 to 75 dB SPL, the differences were within 3 dB, and were 1.3% on average.

Participants wore the hearing instruments for a period of 2 weeks prior to data collection in order to adjust to their new devices. During the adjustment period, children wore the study hearing instruments, which were fitted according to pediatric preferred practice guidelines (CASLPO, 2002). Specifically, the aids were programmed for FM plus environmental microphone input, fitted to the DSL v5 Quiet prescription, without an active volume control or manually selectable programs. Children did not have access to the DSL v5 Noise prescription during the adjustment period in order to allow a period of use with the Quiet fitting, which is commonly used in clinical practice (Jones & Launer, 2010). In the second week of adjustment, each participant had two practice sessions to become familiarized with the tasks in the study. Middle ear status was monitored by immittance testing with a Maico MI26 portable tympanometer at the beginning of each data collection session. If the tympanometry results differed from previous measurements, testing was delayed until tympanometry results agreed with previous results. A tympanometry discrepancy occurred once with one participant, which resulted in a two-week delay in testing.

**Equipment and Setup**

A test system consisting of a laptop running custom software and a custom-built external hardware interface was used to control the presentation of test stimuli and record subject responses for the outcome measures. Target stimuli were presented from 0° azimuth through a tripod-mounted, Simeon 500WU-powered speaker at a height of 1.4 m to the center of the speaker. Competing stimuli were presented from 180° through a Simeon 900AU Omnipanel speaker system at a height of 1.5 m to the center of the speaker. The Simeon Omnipanel speaker was chosen because it is a distributed mode loudspeaker (DML), which uses multiple piezoelectric elements in place of conventional electromagnetic coils. DMLs disperse sound in a spherical pattern, which is essentially random and therefore less directional than conventional cone-based loudspeakers (Bai & Huang, 2001). The DML was chosen to create a more diffuse noise

![Figure 1. Audiometric thresholds for all subjects. Panel a shows left ear thresholds, panel b shows right ear thresholds; bold lines are average audiograms.](image-url)
source behind the listener, rather than a discrete point source. The speakers were positioned approximately 6 m apart with the participant seated between them (approximately 3 m from each speaker).

The test system was set up within a classroom at both the elementary school and high school. The room at the elementary school measured 9.5 m long by 7.0 m wide by 2.4 m high; the room at the high school measured 10.4 m long by 5.1 m wide by 7.7 m high. Prior to data collection, the reverberation time and noise floor of the two rooms were estimated using a computerized system equipped with SpectraPlus software (Pioneer Hill Software, 2008). The \( \text{RT}_{60} \) estimates were 200 ms and 550 ms, respectively, for the elementary and high school rooms; noise floor estimates were 21.7 dBA and 31.0 dBA, respectively, for the elementary and high school rooms.

Outcome Measures

The first goal of a pediatric hearing instrument prescription is to provide audibility of speech sounds (Scollie et al., 2005; Seewald et al., 1985). Thus, we decided to measure consonant recognition in quiet. As discussed in the introduction, listening in noise is a significant challenge for hearing instrument wearers. Thus, we also measured sentence recognition in noise to determine if DSL v5 Noise affords any improvement in this regard. The linguistic context of consonants versus sentences is notably discrepant; this difference in context level is appropriate to the purpose of each outcome measure. In the first case—consonant recognition—audibility is of interest. In the second case—sentence recognition in noise—a realistic representation of a common challenge for hearing instrument wearers was sought.

Consonant Recognition in Quiet

The consonant recognition in quiet task was a modified version of the University of Western Ontario Distinctive Features Differences test (UWO-DFD; Cheesman & Jamieson, 1996). The computer-controlled system was used to present the test stimuli, which consisted of 21 consonants (\( C = b, \text{ch}, d, f, g, h, j, k, l, m, n, p, r, s, \text{sh}, t, \text{th}, v, w, y, \) and \( z \)) presented in a nonsense disyllable format (\( /\text{CIL}/ \)) and in random order. The test was originally developed with two male and two female talkers. For this study, one male and one female talker were used, with each talker presenting the 21 disyllables twice each for a total of 84 nonsense disyllable presentations at both presentation levels. This modification was made to facilitate assessment of test-retest reliability: The task was divided into two blocks of 42 presentations by the same two talkers, and the difference between these block scores was used as a measure of test-retest difference. A visual list of the 21 consonant sounds was displayed on a computer monitor and participants were asked to select the
sound they heard by clicking the respective sound on the screen with a computer mouse. The test stimuli were presented from the front speaker at 50 and 70 dB SPL in the test position, which was calibrated at the start of each day. The order of prescription condition was counterbalanced across subjects.

**Sentence Recognition in Noise**

The Bamford–Kowal–Bench Speech-in-Noise test (BKB-SIN; Niquette et al., 2003) was administered through the computer-controlled system according to the test manual’s instructions (Etymotic Research, 2005). The test system was calibrated daily using the speech-shaped noise provided on the test CD. The target level from both the target signal speaker and competing noise speaker was 70 dB SPL at the test position, and tolerance for daily checks was ±0.5 dB. The split tracks from the CD at fixed SNR values were used to present target sentences from the front speaker and competing four-talker babble from the rear speaker. Three list pairs were administered in each prescription condition. A difference of more than 2 dB between conditions is considered significant, given the administration of three list pairs with the age range of this study’s participants (Etymotic Research, 2005). The order of prescription was counterbalanced across subjects.

**Loudness Perception**

The Contour Test of Loudness Perception (Cox, Alexander, Taylor, & Gray, 1997; Cox & Gray, 2001) was administered in the sound field according to the methods of Cox and Gray (2001) with the following modifications: Groups of four BKB sentences were presented first in ascending 4 dB steps from 52 to 80 dB SPL and then in descending 4 dB steps, and then back down to 52 dB SPL from the speaker in front of the subjects. Loudness perception categories spanned 8 levels (0 = did not hear, 1 = very soft, 2 = soft, 3 = comfortable but slightly soft, 4 = comfortable, 5 = comfortable but slightly loud, 6 = loud but okay, 7 = uncomfortably loud). The task would automatically reverse direction after the presentation level reached 80 dB SPL or as soon as uncomfortably loud was selected, whichever happened first.

The categorical ratings were shown as text on a computer monitor in front of the participant, and each participant was asked to click his or her elected rating with a computer mouse after presentation of each group of four sentences at each level. To assist the younger participants with the task, the categories were combined with pictures on a sheet of paper; participants would point to their elected rating on the paper (see Figure 3) and the researcher would select the corresponding category on the computer monitor. The order of prescription and loudness perception conditions were counterbalanced across participants.

Loudness ratings from the ascending and descending runs were averaged together to create a single loudness rating for each input level for analysis. This scoring method has been previously validated and provides results that are equivalent to a random presentation of levels (Jenstad, Cornelisse, & Seewald, 1997). In instances when the participant selected uncomfortably loud before presentation at 80 dB SPL, thus reversing the direction of the task, missing data were replaced with uncomfortably loud ratings. For example, if a participant rated 72 dB SPL as uncomfortably loud, uncomfortably loud was then also inserted as the rating for 76 and 80 dB SPL.

**Test Administration Details**

Children were blinded to conditions. The researcher was not blind to conditions; however, for the computer-administered tasks (consonant recognition in quiet and loudness perception), the researcher was not involved in the scoring of the data and thus the effect of blinding was achieved. For the BKB-SIN, the researcher scored the task and thus blinding was not achieved. This was not expected to affect the results, as the experimenter’s task was merely to score key words correct, and counterbalanced test orders prevented the experimenter from having prior knowledge of a child’s score in an alternative test condition. Test order was kept constant, with prescription order effects addressed by counterbalancing the sequence of hearing instrument conditions across participants. Multiple short test sessions and rewards for task completion (sticker charts) were used to prevent fatigue and maintain participant motivation across test sessions.

**Results**

Following the recommendation of Max and Onghena (1999), we used the Greenhouse-Geisser correction to
adjust degrees of freedom universally in all repeated measures analyses of variance reported below in order to control for any potential violations of the sphericity assumption. Eta squared ($\eta^2$) is reported as a measure of effect size for the statistical analyses presented below.

**Consonant Recognition in Quiet**

Raw scores for the consonant recognition in quiet task ranged from 45% to 98% correct across participants, levels, and prescriptions. The test-retest difference between blocks of 42 presentations averaged 3.5% (range = 0% to 16.7%) across participants, levels, and prescriptions. Raw percent correct scores for all participants across levels are shown in Figure 4 by prescription, along with the 95% confidence interval for significant difference between scores for the task. Scores within the displayed confidence interval do not differ significantly, indicating that neither prescription provided either superior or inferior consonant recognition performance. Only one score was significantly higher with DSL v5 Quiet than with DSL v5 Noise.

Raw scores were converted to rationalized arcsine units (RAU; Studebaker, 1985) for analysis. RAU scores were analyzed using the General Linear Model repeated measures analysis of variance (SPSS v16.0) with level (two levels) and prescription (two levels) as repeated measures within-subjects factors. Results indicated that there was a significant main effect of level, $F(1, 10) = 7.86, p = .02, \eta^2 = .44$. The main effect of prescription was not significant, $F(1, 10) = 4.85, p = .052, \eta^2 = .33$. There was a significant interaction between prescription and level, $F(1, 10) = 5.270, p = .04, \eta^2 = .34$. Post hoc testing of performance across level indicated that performance varied with level for the DSL v5 Noise prescription, $t(10) = 4.03, p = .002, d = 8.59$, but not for the DSL v5 Quiet prescription, $t(10) = 0.47, p = .65, d = 0.83$. These results demonstrated a decrease in consonant recognition scores for low-level speech for the DSL v5 Noise prescription; in other words, the audibility differences between prescriptions affected performance with a 50 dB SPL input level. This change was 4.2% on average, and individual changes ranged from −2.4% (higher performance with DSL v5 Noise) to 10.7% (higher performance with DSL v5 Quiet). Mean percent correct scores are listed in Table 1 for both test levels and prescriptions.

**Sentence Recognition in Noise**

SNR-50 scores were averaged across three list pairs in each prescription. Average scores across participants ranged from −0.8 to 16.0 dB SNR. Individual SNR-50 scores are shown in Figure 5 for both prescriptions, along with the 95% confidence interval for significant change in individual scores for the youngest participants. Scores within the displayed confidence interval do not differ significantly, indicating that neither prescription provided either superior or inferior sentence recognition in noise. Three participants

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Figure 4. Individual scores on the consonant recognition in quiet task (in percent correct) across level and prescriptions. Filled symbols represent scores at an input level of 50 dB SPL and open symbols represent scores at an input level of 70 dB SPL. Diamond symbols represent scores for subjects with Sound Recover enabled. Dashed lines indicate the 95% confidence interval for significant change in individual score.
showed better performance (lower SNR-50 score) with DSL v5 Quiet, three showed better performance with DSL v5 Noise, and five showed no significant performance difference between prescriptions.

Mean performance (SNR-50) was 5.40 dB (SD = 5.57) with the DSL v5 Quiet prescription and 5.39 dB (SD = 5.60) with the DSL v5 Noise prescription. The SNR-50 scores were analyzed by a repeated measures analysis of variance (ANOVA) with prescription as the within-subjects factor. Results indicated that the main effect of prescription was not significant ($p > .05$).

### Loudness Perception

Mean loudness ratings for the loudness perception task for each level and prescription are shown in Figure 6.

Mean loudness ratings were subjected to a repeated measures analysis with level (eight levels) and prescription (two levels) as repeated measures factors. The main effect of level was significant, $F(2.02, 20.25) = 251.43$, $p < .001$, $\eta^2 = .94$, indicating higher ratings with increasing input levels. The main effect of prescription was significant, $F(1, 10) = 4.14$, $p = .04$, $\eta^2 = .36$. The interaction effect of level by prescription was not significant, $F(2.32, 23.18) = 1.70$, $p = .20$, $\eta^2 = .14$.

The data plotted in Figure 6 show a distinct pattern in loudness ratings between the two prescriptions. Visually, the plotted loudness contours for each prescription diverge at the 72 dB SPL presentation level. Previous research has shown that loud speech occurs at approximately 73 dB SPL on average (Pearsons et al., 1977). For these reasons, further analysis of the loudness perception data was conducted by analyzing loudness ratings at presentation levels from 52 to 68 dB SPL and from 72 to 80 dB SPL, separately. The results of this subsequent analysis indicated no significant difference in loudness ratings between the two prescriptions for presentation levels of 52 to 68 dB SPL, $F(1, 10) = 0.99$, $p = .34$, $\eta^2 = .09$. However, analysis of the loudness ratings for presentation levels of 72 to 80 dB SPL indicated significantly lower loudness ratings with the DSL v5 Noise prescription, $F(1, 10) = 16.46$, $p = .002$, $\eta^2 = .62$.

### Discussion

The presented study provided a preliminary behavioral evaluation of the DSL v5 Noise prescription, which has not

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**Table 1. Mean ± SD UWO-DFD scores for DSL Quiet and DSL Noise prescriptions.**

<table>
<thead>
<tr>
<th>Prescription</th>
<th>50 dB SPL</th>
<th>70 dB SPL</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$M$</td>
<td>SD</td>
</tr>
<tr>
<td>DSL Quiet</td>
<td>77.11</td>
<td>15.46</td>
</tr>
<tr>
<td>DSL Noise</td>
<td>73.21</td>
<td>15.33</td>
</tr>
</tbody>
</table>

$^a$Scores presented in percent correct.

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Figure 5. Individual scores on the speech-in-noise task (in SNR-50) across prescriptions. Diamond symbols represent data for subjects with Sound Recover enabled. Dashed lines indicate the 95% confidence interval for significant change in individual scores.
been formally evaluated to date. The outcome measurement data presented may help in the continued refinement of a prescribed frequency-gain response for use in nonquiet listening situations. Overall, when compared with DSL v5 Quiet, the DSL v5 Noise prescription preserves consonant recognition in quiet at average levels and affords improved comfort for loud inputs.

Consonant Recognition in Quiet

The authors assessed children’s consonant recognition in quiet with hearing instruments fitted to DSL v5 targets for use in Quiet and Noise. Results indicated that the lower gain Noise prescription resulted in a small (4%) but significant decrease in consonant recognition in quiet for soft speech but equivalent results for average-level speech. These results are not surprising, given that Scollie, Ching, Seewald, Dillon, Britton, Steinberg, and Corcoran (2010) showed a similar trend with NAL-NL1 relative to DSL v4.1 (recall that DSL v5 Noise is similar to NAL-NL1 and DSL v5 Quiet to DSL v4.1). In general, children in the present study performed well with both the Quiet and Noise prescriptions, with an average performance of 79% correct across prescriptions and levels. These scores agree with data published on the UWO-DFD test with children in this age range (Jenstad et al., 1999; Scollie, 2008; Scollie, Ching, Seewald, Dillon, Britton, Steinberg, & King, 2010).

One might think that given the small decrement in consonant recognition in quiet with DSL v5 Noise, it may be advisable to use the Noise prescription as an alternative to the Quiet prescription. However, studies using similar speech perception tasks have demonstrated better detection and discrimination of low-level speech sounds with the higher gain prescribed by DSL v5 relative to lower-gain prescriptions (Marriage et al., 2010). Thus, we suggest being cautious and are more comfortable considering DSL v5 Noise as an additional program for nonquiet listening, and not as a replacement.

The DSL v5 Noise prescription may not be appropriate for a single-memory hearing instrument fitting in clinical practice, if audibility of low-level speech is a primary goal. However, it may be appropriate for use with higher level speech inputs as a supplementary listening program. These applications were not directly evaluated in the present study, and further research would be needed to further explore this possibility. For example, it is not yet known whether a multi-memory application would be best accessed by either the child or the caregiver, or via hearing instrument classification algorithms. Also, the present data set does not address whether a child’s hearing instrument would be best configured with a single-memory strategy that uses a low compression threshold and moderate gain (e.g., NAL-NL1, NAL-NL2) or with a two-memory strategy that uses audibility-driven gain and a low compression threshold (DSL v5 Quiet) paired with a lower-gain, higher-compression-threshold program (DSL v5 Noise). Finally, the relative advantages or disadvantages of using any of these prescriptive approaches versus the use of signal processing strategies for noise management is not addressed by the current data set.
Sentence Recognition in Noise

Children’s sentence recognition in noise with hearing instruments fitted to DSL v5 Quiet and Noise targets was assessed in this study. Results indicated no significant difference in sentence recognition in noise between the two prescriptions when averaged across participants. These results are similar to those reported in previous research that have indicated no difference in sentence recognition in noise performance between frequency response shapes (Dirks, 1982; Kamm et al., 1982; Scollie, Ching, Seewald, Dillon, Britton, Steinberg, & King, 2010; van Buuren et al., 1995). This pattern in results may reflect the similarity between DSL v5 Noise and NAL-NL1 prescriptive targets, as described above. Additionally, the DSL v5 Noise prescription was not expected to improve speech recognition scores because it was designed to provide comfort in noisy situations, and was not intended as a strategy for improving speech recognition in noise (Scollie et al., 2005).

Loudness Perception

Lastly, children’s loudness perception with hearing instruments fitted to DSL v5 Quiet and Noise targets was assessed. As shown in Figure 6, loudness ratings were significantly lower with the DSL v5 Noise prescription than with the DSL v5 Quiet prescription. In general, the loudness data appear similar to those reported in Scollie, Ching, Seewald, Dillon, Britton, Steinberg, and King (2010), although the loudness growth functions cannot be directly compared because of the use of different ratings scales and input levels between studies. However, both data sets demonstrate two important results related to dynamic range. First, the data in the current study and those of Scollie, Ching, Seewald, Dillon, Britton, Steinberg, and King (2010) indicate audibility of the lowest input levels across all prescriptions tested. This is important, given the necessity of audibility in order for children to perceive and develop language (Pittman & Stelmachowicz, 2000; Stelmachowicz et al., 2000; Stelmachowicz et al., 2007; Stelmachowicz et al., 2001; Stelmachowicz, Pittman, Hoover, Lewis, & Moeller, 2004). Second, the data of Scollie, Ching, Seewald, Dillon, Britton, Steinberg, and King (2010) demonstrated ratings of much too loud for an 80 dB SPL input level with both DSL v5 and NAL-NL1 almost equally with both prescriptions. The current data demonstrate reduced loudness ratings for an 80 dB SPL input level with the DSL v5 Noise prescription (see Figure 6). However, the data of Scollie, Ching, Seewald, Dillon, Britton, Steinberg, and Corcoran (2010) also showed that children’s loudness ratings when fitted with the NAL-NL1 prescription increased after a period of acclimatization, so acclimatization is likely an important factor to consider when comparing results with the current study. Nonetheless, children experience noise levels exceeding 80 dB SPL on a daily basis (Crukley et al., 2011), so a prescription that can help in alleviating aversive loudness may warrant clinical consideration.

Conclusions and Future Directions

The current study addressed three research questions regarding use of the DSL v5 Quiet and Noise hearing instrument prescriptions with a group of school-age children. First, did use of the two prescriptions result in differences in consonant recognition? Although there was a difference between prescriptions for consonant recognition in quiet at low levels, recognition was good across levels, prescriptions, and participants. Second, did use of the two prescriptions result in a difference in sentence recognition in noise? There was no difference in sentence recognition in noise between the two prescriptions. Third, did use of the two prescriptions result in differences comfort ratings for loud sounds? The perceived loudness of loud sounds was rated lower with the DSL v5 Noise prescription than with the DSL v5 Quiet prescription.

Speech perception was preserved and aversive loudness was alleviated by the Noise prescription relative to the Quiet prescription, which suggests the DSL v5 Noise prescription may be an effective approach to managing the nonquiet listening needs of children who wear hearing instruments. Although the DSL v5 Noise prescription afforded reduced loudness perception ratings and did not impede speech perception at average levels, it is not advisable to use the Noise prescription full time in the interest of children’s speech and language development. The increased low- and high-frequency output prescribed by the DSL v5 Quiet prescription has been shown to improve detection and discrimination of low-level speech in the current study and in other studies examining speech perception across prescriptions and children’s preferences in real-world use of hearing instruments (Marriage et al., 2010; Scollie, Ching, Seewald, Dillon, Britton, Steinberg, & Corcoran, 2010).

Overall, loudness was reduced with the DSL v5 Noise prescription, but this came at the cost of poorer consonant recognition in quiet for soft speech. Examination of individual data indicated that the results from one child were responsible for this overall reduction of soft speech consonant recognition. Some children in the present study had steeply sloping and profound hearing losses. Previous research has suggested that a child with a greater degree or steeper slope of hearing loss is likely to have poorer speech recognition scores than a child with a lower degree or a shallower slope of hearing loss (Scollie, 2008). It is possible that these larger degrees and steeper slopes of hearing loss contributed to lower average scores relative to the average scores of greater than 85% published by Scollie, Ching, Seewald, Dillon, Britton, Steinberg, and King (2010). This warrants future investigation.

More generally, it appears that a lower-gain prescription can be used to alleviate excessive loudness for children, but that assessing the impact of lessened gain on an individual child’s aided speech sound recognition may be warranted. Given the small sample and varied nature of hearing losses used in this study, further investigation may help to determine whether the findings presented here generalize to others. Also, further investigation could determine whether the use of lower-gain noise programs result in improved outcomes in real-world nonquiet environments, whether the use of digital noise management strategies could be combined with prescriptive strategies to improve outcomes, and how best to apply alternative prescriptions in multi-memory hearing instruments for children of various ages.
We set out to determine whether Desired Sensation Level (DSL) v5 Noise could be a viable hearing instrument prescriptive algorithm for children, with reference to DSL v5 Quiet. In particular, we compared children’s performance on measures of consonant recognition in quiet, sentence recognition in noise, and loudness perception when fitted with DSL v5 Quiet and DSL v5 Noise. We concluded that DSL v5 Noise may be useful to children as an approach to ameliorate the effects of loudness and noise. However, further research is needed to ascertain the risks of lower gain for children, the potential benefits of combining DSL v5 Noise with other noise management strategies perhaps as a second program option, and the differences in outcomes between DSL v5 Noise and other generic prescriptive algorithms. Overall, this study is an encouraging early step in developing a generic prescriptive approach that attends to the problems of loudness and noise. It also introduces two potentially useful research design options: the use of a real classroom environment as test suite and the use of a distributed mode loudspeaker for the presentation of competing signals, both of which are relevant to real-world circumstances.

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References


