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Low-Level Speech Recognition of Children with Hearing Aids

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Abstract

Background For children with hearing loss, the primary goal of hearing aids is to provide improved access to the auditory environment within the limits of hearing aid technology and the child's auditory abilities. However, there are limited data examining aided speech recognition at very low (40 decibels A [dBA]) and low (50 dBA) presentation levels.

Purpose Due to the paucity of studies exploring aided speech recognition at low presentation levels for children with hearing loss, the present study aimed to (1) compare aided speech recognition at different presentation levels between groups of children with "normal" hearing and hearing loss, (2) explore the effects of aided pure tone average and aided Speech Intelligibility Index (SII) on aided speech recognition at low presentation levels for children with hearing loss ranging in degree from mild to severe, and (3) evaluate the effect of increasing low-level gain on aided speech recognition of children with hearing loss.

Research Design In phase 1 of this study, a two-group, repeated-measures design was used to evaluate differences in speech recognition. In phase 2 of this study, a single-group, repeated-measures design was used to evaluate the potential benefit of additional low-level hearing aid gain for low-level aided speech recognition of children with hearing loss.

Study Sample The first phase of the study included 27 school-age children with mild to severe sensorineural hearing loss and 12 school-age children with "normal" hearing. The second phase included eight children with mild to moderate sensorineural hearing loss.

Intervention Prior to the study, children with hearing loss were fitted binaurally with digital hearing aids. Children in the second phase were fitted binaurally with digital study hearing aids and completed a trial period with two different gain settings: (1) gain required to match hearing aid output to prescriptive targets (i.e., primary program), and (2) a 6-dB increase in overall gain for low-level inputs relative to the primary program. In both phases of this study, real-ear verification measures were completed to ensure the hearing aid output matched prescriptive targets.

Keywords
- hearing aids
- speech recognition
- aided thresholds

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Data Collection and Analysis Phase 1 included monosyllabic word recognition and syllable-final plural recognition at three presentation levels (40, 50, and 60 dBA). Phase 2 compared speech recognition performance for the same test measures and presentation levels with two differing gain prescriptions.

Conclusion In phase 1 of the study, aided speech recognition was significantly poorer in children with hearing loss at all presentation levels. Higher aided SII in the better ear (55 dB sound pressure level input) was associated with higher Consonant-Nucleus-Consonant word recognition at a 40 dBA presentation level. In phase 2, increasing the hearing aid gain for low-level inputs provided a significant improvement in syllable-final plural recognition at very low-level inputs and resulted in a nonsignificant trend toward better monosyllabic word recognition at very low presentation levels. Additional research is needed to document the speech recognition difficulties children with hearing aids may experience with low-level speech in the real world as well as the potential benefit or detriment of providing additional low-level hearing aid gain.

Children with hearing loss are at risk of delays in their spoken language development.[1,2] In particular, access to the speech of others, such as caregivers, has been shown to influence language outcomes in children with hearing loss.[3–10] For example, in children with moderate hearing loss, Dirks et al found the quantity and quality of spoken language input provided by the child's parents positively impacted expressive language ability.

A primary goal of fitting hearing technology on children with hearing loss is to improve audibility and provide access to the full range of auditory inputs.[11] Clinical practice guidelines recommend probe microphone measures to match the output of a child's hearing aids to independent, pediatric-focused, and pediatric-validated prescriptive targets at multiple input levels (e.g., 55, 65, 75 dB SPL [decibel sound pressure level]). In addition, probe microphone measures are needed to verify the maximum output of the hearing aid does not exceed prescriptive targets for maximum output levels.

Numerous studies have demonstrated the importance of hearing aid settings that optimize the audibility of speech.[2,12–17] For instance, Tomblin et al[2] reported children with the highest Speech Intelligibility Index (SII) values showed greater improvements in language scores over a 4-year period relative to children with lower SIIs.

Moreover, Tomblin et al[17] examined outcomes in school-age children with mild-to-severe hearing loss and found the degree to which hearing aids provide audible speech, as measured by the SII, positively impacted language and academic aptitude.

In addition, Marriage et al[12] examined speech-recognition differences in children with hearing aids programmed to desired sensation level (DSL) i/o, DSL 5.0, and National Acoustics Laboratory (NAL)-NL1 prescriptive targets.[18–20] The DSL 5.0 pediatric prescription provides greater gain for low-level inputs than NAL-NL1 targets. Word-recognition performance was similar for the three prescriptive methods at a 65 dBA (decibels A-weighted) presentation level, but performance was significantly better with the DSL prescriptions when evaluated at 50 dBA. Additionally, children were less likely to recognize manner cues (e.g., fricatives, affricates) when using NAL-NL1 compared with DSL, and aided thresholds were significantly poorer for the phoneme /s/ with use of NAl-NL1.

Scollie et al[14,15] compared real-world preferences and speech perception differences between hearing aids programmed with DSL i/o versus NAL-NL1 prescriptive formulas for school-age children with mild to moderately severe hearing loss. The DSL i/o prescriptive method provided more gain than NAL-NL1 for low-level inputs. Children preferred the DSL prescription when listening to soft speech, speech from behind, and when they wanted to hear speech at a higher loudness level. In contrast, children preferred NAL-NL1 to reduce background noise or when they wanted to reduce loudness in environments with high input levels.[14] No differences in speech recognition were reported for DSL i/o at 55, 70, and 80 dB SPL, but NAL-NL1 resulted in significantly poorer speech perception at 55 dB SPL compared with the higher presentation levels. The collective results of Marriage et al[12] and Scollie et al[14,15] indicate children prefer DSL for softer speech inputs, likely because this method prescribes more gain for low-level inputs than NAL-NL1.

Pediatric hearing aid prescriptive methods focus on target output prescriptions for speech presented at input levels from 50 to 80 dB SPL.[12,14,15] However, few research studies have explored children's aided speech-recognition performance for speech signals at very low presentation levels (i.e., less than 50 dB SPL) that may be important for spoken language development. Pearsons et al[21] reported that "casual" speech occurred at a level of 50 to 53 dBA one meter from the talker that will result in an even lower intensity at typical conversational distances (i.e., based on Pearsons' measurements, the level of the speech would likely be lower than 50 dBA if the listener is located more than one meter away from the talker). Cole and Flexer[22] suggest that ~90% of a child's spoken language development is facilitated by speech the child hears incidentally (i.e., speech that is not directed toward the child) that could include speech at low intensities. Incidental speech is likely to occur at input levels less than 50 dB SPL.[21]

Previous research indicates school-age children with "normal" hearing achieve ceiling-level performance for monosyllabic word recognition (i.e., PBK-50[23] and N.U. Auditory Test No. 6)[24] at very low presentation levels (e.g., below 50 dB SPL).[25] There are no studies that examine the aided speech-recognition of children with hearing loss at very low presentation levels (i.e., less than 50 dB SPL).

Study Objectives

Although it is well established school-age children with "normal" hearing achieve ceiling-level performance for monosyllabic word recognition at very low presentation levels (e.g., below 50 dB SPL),[25] there are no studies looking at these same effects in children with hearing loss. Given the limited research on speech recognition at very low input levels in children using hearing aids, the objectives of this study were to:

1. Evaluate and compare speech recognition at very low (40 dBA), low (50 dBA), and moderate (60 dBA) presentation levels for pediatric hearing aid users with a wide range of degrees of hearing loss from mild to severe to children with "normal" hearing.
2. Examine the effects of aided pure tone average (PTA) and aided SII on speech recognition for children with hearing loss ranging in degree from mild to severe.
3. For a smaller subset of children with hearing loss, evaluate the potential benefit of a modest increase in low-level hearing aid gain for speech recognition at very low, low, and moderate presentation levels.

Materials and Methods

Participants

Participants were required to meet the following inclusion criteria:

1. Ages 6 to 17 years to ensure the attention necessary to complete the testing across multiple conditions.
2. "Normal" hearing (determined by hearing screening with pass criteria of 15 dB HL (hearing level) at octave frequencies from 250 to 8000 Hz) or bilateral sensorineural hearing loss ranging from mild to severe defined as a four-frequency PTA (500, 1000, 2000, and 4000 Hz) no better than 30 dB HL and no poorer than 75 dB HL in the better ear. A wide range of degree of hearing loss was selected for this study to allow for an exploration of the effect of aided SII on speech recognition as a function of degree of hearing loss.
3. Children with hearing loss were to be experienced bilateral users of digital, behind-the-ear hearing aids. All children wore Phonak hearing aids.
4. Consonant-Nucleus-Consonant (CNC)[26] word-recognition score at 60 dBA of at least 50% correct in quiet in the best aided condition.
5. Spoken English as their primary mode of communication.

Demographic and hearing information for the 27 study participants with hearing loss are provided in ►**Table 1**. Twelve subjects with "normal" hearing, ages 6 years, 10 months to 14 years, 3 months (mean = 10.68, standard deviation [SD] = 2.94), participated in the study.

Phase 1 Methods

Phase 1 included 12 participants with "normal" hearing and 27 participants with hearing loss wearing their own personal hearing aids.

Equipment and Environment

Participants with hearing loss were evaluated using their personal hearing aids fitted using best practice real ear probe microphone verification measurements (see ►**Table 1**).[11] Specifically, real-ear-to-coupler difference (RECD) were measured for each child (AudioScan Verifit 2), and probe microphone measurements were conducted to match the children's hearing aid output to the DSL 5.0 pediatric targets (±5 dB) at 250, 500, 1000, 2000, 4000, and 6000 Hz for the Standard Speech signal presented at 55, 65, and 75 dB SPL. Maximum output was set to match (without exceeding) the DSL 5.0 real ear aided response targets for an 85 dB SPL swept pure tone signal. SII values were documented at a presentation level of 55 dB SPL on the Verifit. Phase 1 participants were evaluated while using their own personal hearing aids that were selected by their audiologist to provide appropriate gain and output of each child's degree of hearing loss. All children in the phase 1 were fitted with Phonak hearing aids, ensuring similar compression strategies.

Speech recognition for all participants was completed in the sound field in a double-walled audiometric test booth (7'6" by 7'0" by 6'5"). Test stimuli were generated from a Dell Optiplex (1 Dell Way Round Rock, Texas 78682) 9020 desktop computer and routed to an external sound card/audio interface (ROCCAT Juke Virtual 7.1 USB Stereo (Gasstraße 4 Hamburg, 22761 Germany)), which was coupled to the audiometer (Grason-Stadler 61) and loudspeaker (Grason-Stadler (10395 West 70th St. Eden Prairie, MN 55344)) at 0 degrees azimuth.

Test Materials and Procedures

Monosyllabic Word Recognition

Monosyllabic word recognition was evaluated with a full list of 50 CNC words presented at each of the three following presentation levels: 40, 50, and 60 dBA. Participant responses were scored based on the number of words repeated correctly at each presentation level. Presentation level and CNC word list order were randomized across participants to control for order effects.

Plural Recognition

The University of Western Ontario Plurals test[27] was used to evaluate plural recognition with words in the singular and plural form (i.e., fricatives /s/ or /z/ in in the word-final position). Full lists of 25 words were presented at 40, 50, and 60 dBA and were scored for percent correct. Presentation

Table 1 Demographic and hearing information for participants with hearing loss

Subject	Age	Personal Phonak hearing aid	Aided PTA	Right ear unaided PTA	Left ear unaided PTA	Right ear SII: 55 dB SPL	Left ear SII: 55 dB SPL
1[a]	6.3	Sky V50 P	32.5	55.0	53.8	61	60
2[a]	13.8	Sky M13 Q50 BTE	21.3	47.5	47.5	78	73
3	12.3	Sky V50 p	30.0	60.0	56.3	57	61
4	12.1	Naida V90 RIC	27.5	56.3	68.8	65	40
5	12.8	Sky Q90 SP	30.0	71.3	68.8	46	36
6[a]	9.4	Sky V50 RIC	27.5	46.3	47.5	76	78
7	12.8	Sky Q50 M13/ Sky Q50 SP	28.8	42.5	72.5	83	55
8	8.5	Bolero V90-P BTE	17.5	58.8	56.3	63	80
9	7.3	Audeo V90 13	32.5	65.0	62.5	51	54
10[a]	10.8	Sky V50 RIC	25.0	48.8	46.3	78	78
11[a]	14.4	Sky Q50-M13 BTE	21.3	42.5	43.8	71	71
12	16.3	Sky Q50-M13	30.0	61.3	66.3	53	46
13	11.5	Audeo V90 312	31.3	58.8	47.5	54	70
14	12.7	Audeo V90 13	27.5	52.5	52.5	61	66
15	10.0	Sky V90 SP	28.8	75.0	68.8	36	44
16	17.6	Naida SP Q50	22.5	51.3	53.8	63	68
17[a]	10.8	Sky V50 P	21.3	38.8	41.3	72	82
18	15.4	Sky v90 SP	33.8	80.0	72.5	40	48
18	8.2	Sky Q50 SP BTE	30.0	51.3	55.0	71	62
20	13.6	Bolero Q70-M13	23.8	63.8	58.8	55	51
21	7.7	Sky V90-SP BTE	35.0	71.3	71.3	47	47
22[a]	12.0	Audeo V90 13	33.8	53.8	55.0	54	67
23	8.0	Sky SP Q90	27.5	60.0	56.3	60	60
24	6.7	Sky V90 SP	35.0	78.8	72.5	38	35
25[a]	13.3	Sky Q50 M13	21.3	35.0	35.0	83	90
26	6.3	Sky Q50 SP	35.0	71.3	68.8	49	50
27	13.8	Audeo V50 RIC	32.5	63.8	60.0	43	50
Average (SD)	11.3 (2.9)		28.2 (4.9)	57.8 (11.8)	57.7 (10.4)	59.6 (13.4)	60.1 (14.5)

Abbreviations: dB, decibel; PTA, four-frequency pure tone average at 500, 1000, 2000, and 4000 Hz; SD, standard deviation; SII, Speech Intelligibility Index; SPL, sound pressure level.
Aided thresholds were conducted in the sound field and were conducted with the child's personal hearing aids; unaided thresholds were conducted with insert earphones.
[a]Participated in phase 2 of the study.

levels and word lists were counterbalanced across participants.

Phase 2 Methods

A subset of eight phase 1 participants (see ►**Table 1**) with mild to moderately severe hearing loss completed follow-up testing with a set of study hearing aids (Phonak Audeo B70 receiver-in-the-canal instruments with xP receivers).

Equipment and Environment

Hearing aid fitting procedures, including RECD and probe microphone measures, were identical to phase 1. The primary program was created with the hearing aid output matched to prescriptive targets as described in phase 1. A secondary program was created with a 6-dB increase in overall gain for 50 dB SPL inputs. The order in which the two programs were loaded into the hearing aid was counterbalanced (i.e., the order of the programs varied) across participants.

Test Materials and Procedures

Children used the study hearing aids for 2 to 4 weeks and were asked to switch between the two programs throughout this acclimatization period. After the trial, the same presentation levels and test materials described in phase 1 were used to assess speech recognition with the primary

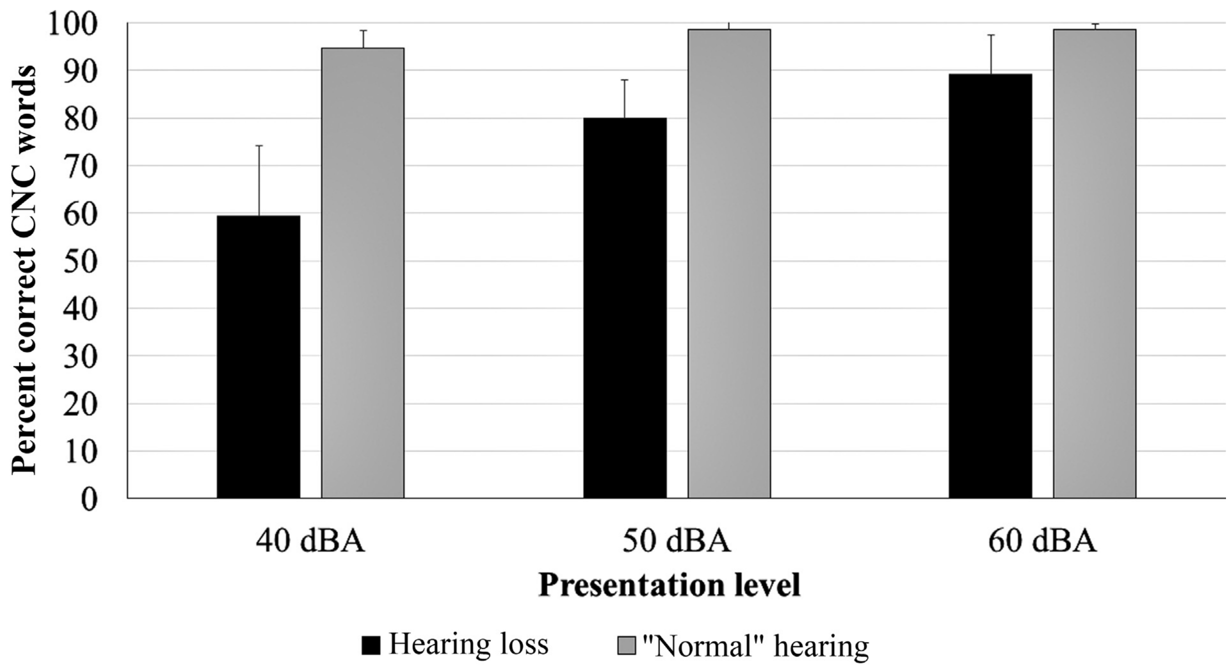

Fig. 1 Average CNC word-recognition scores at three presentation levels for children with hearing loss listening with hearing aids and children with "normal" hearing sensitivity listening unaided. Note. Bars indicate 1 standard deviation, and numbers above the bars provide significant

and secondary programs that were counterbalanced across participants.

Results

Phase 1

Prior to analysis, all data were arcsine transformed given that some participants had ceiling-level performance (i.e., 100%), and some of the data were not normally distributed according to a Shapiro–Wilk test.

Monosyllabic Word Recognition

Average word-recognition performance is shown in ►**Fig. 1**. A repeated-measures analysis of variance (RM ANOVA) was conducted to examine the independent variables of group and presentation level (40, 50, 60 dBA). This analysis showed a significant main effect of group [$F(1,37)= 156.2$, $p < 0.00001$], presentation level [$F(2,74)= 104.4$, $p < 0.00001$], and an interaction effect between group and presentation level[$F(2,74)= 6.6$, $p < 0.01$]. Post-hoc analyses with the Bonferroni Multiple Comparisons Test suggested significantly better performance for the group with "normal" hearing ($p < 0.05$) and significantly better performance at each increase in presentation level ($p < 0.05$). Regarding the interaction effect, for the group with "normal" hearing, the 40 dBA condition yielded significantly poorer performance than the 50 and 60 dBA conditions. However, for the group with hearing loss, all presentation levels resulted in significantly different performance ($p < 0.05$) and average scores that were significantly poorer than those in all three conditions for the "normal" hearing group ($p < 0.05$).

For the children with hearing loss, partial Spearman rank order correlations, controlling for age, between aided CNC scores at each presentation level, aided SII in the better ear, and aided four frequency PTA were evaluated. Aided SII in the better ear at a 55 dBA presentation level was significantly correlated with CNC scores at 40 dBA ($r = 0.50$, $p = 0.003$) (►**Fig. 2**), 50 dBA ($r = 0.51$, $p = 0.005$), and 60 dBA ($r = 0.44$, $p = 0.008$). When controlling for age, aided four frequency PTA was significantly correlated with CNC scores at 60 dBA ($r = -0.4$, $p = 0.03$) but not at 40 dBA or 50 dBA ($p > 0.05$).

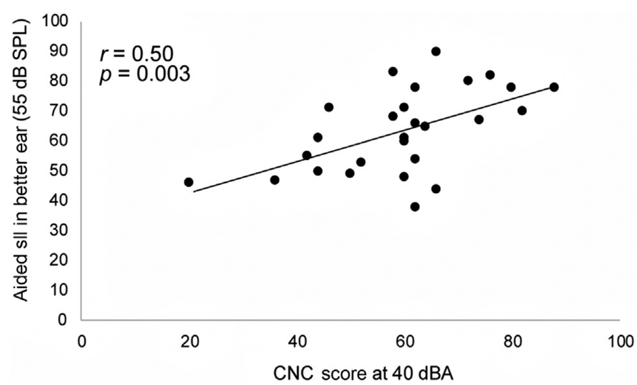

Fig. 2 Significant correlation between aided SII at 55 dB SPL and CNC scores at 40 dBA, controlling for age. The Spearman Rho correlation value and significance value are provided in the upper left corner. CNC, consonant-nucleus-consonant word recognition; dBA, decibel A-weighted; SII, Speech Intelligibility Index at 55 dB SPL.

Plural Recognition

Given that several "normal"-hearing listeners had ceiling-level plural recognition at 40 dBA, this group was only tested at the 40 dBA presentation level (►**Fig. 3**). A one-factor ANOVA was conducted to compare performance between groups at the 40 dBA presentation level, and this analysis

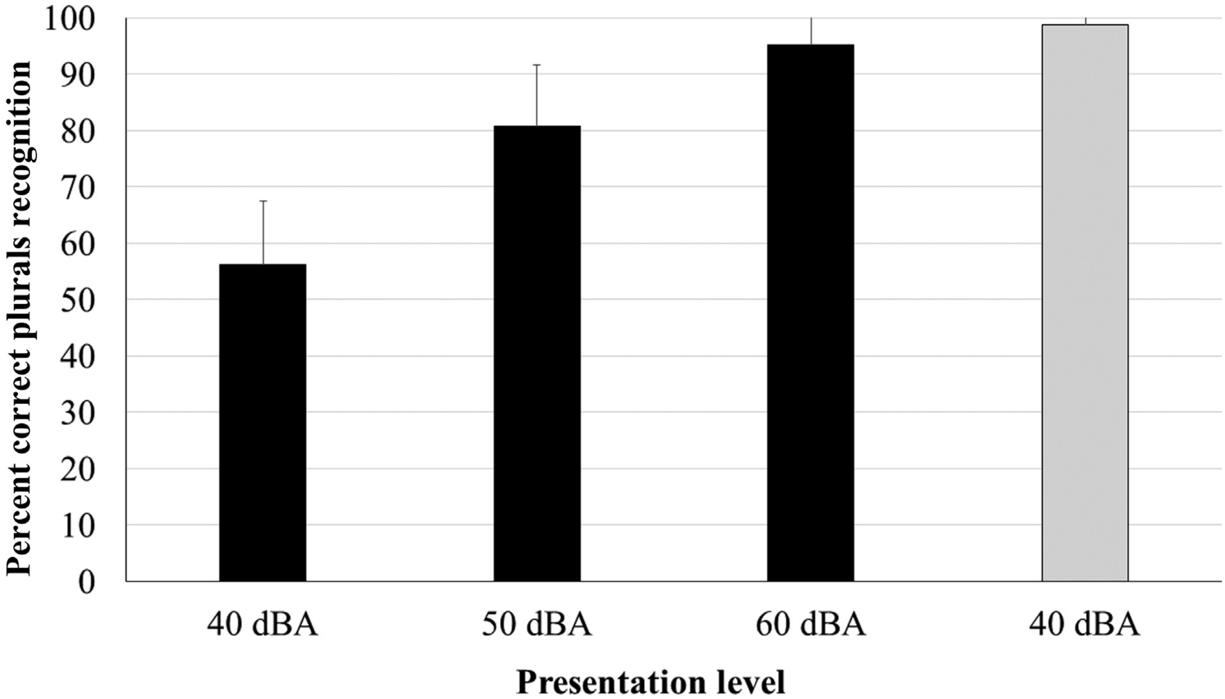

Fig. 3 Average Western University Plurals Test word-recognition scores at three presentation levels for children with hearing loss listening with hearing aids and children with "normal" hearing sensitivity listening unaided. Note. Bars indicate 1 standard deviation, and numbers above the bars provide significant results of the post-hoc analysis. dBA, decibel A-weighted.

suggested significantly poorer performance in the group with hearing loss [$F(1,37)= 327.6$, $p < 0.00001$].

In the listeners with hearing loss, a one-factor RM ANOVA with the independent variable of presentation level revealed a significant main effect of condition [$F(2,52) = 187.6$, $p < 0.00001$]. Post-hoc analyses suggested significant differences ($p < 0.05$) between all three condition comparisons with the 40 and 60 dBA conditions yielding the worst and best performance, respectively.

Partial Spearman rank correlations, controlling for age, between aided plural scores at each presentation level, aided SII in the better ear, and aided four frequency PTA were computed. There were no significant relationships between aided SII and plural recognition or aided PTA and plural recognition at any presentation level ($p > 0.05$).

Phase 2

Monosyllabic Word Recognition

Average word-recognition performance for the two programs is shown in ►**Fig. 4**. A RM ANOVA was performed to examine the independent variables of presentation level (40, 50, 60 dBA) and hearing aid prescription (DSL 5.0; custom gain prescription for soft sounds). The results showed a significant main effect of presentation level [$F(2,14)= 41.2$, $p < 0.00001$]; however, the main effect of hearing aid prescription and the interaction between presentation level and hearing aid prescription were not significant ($p > 0.05$). Post-hoc analyses with the Bonferroni Multiple Comparisons Test revealed word-recognition performance significantly differed across all presentation levels, with performance at 40 dBA being the poorest and 60 dBA the best ($p < 0.05$).

Plural Recognition

To evaluate plural recognition, a separate RM ANOVA was performed with the independent variables of presentation level (40, 50, 60 dBA) and hearing aid prescription (DSL 5.0; custom gain prescription for soft sounds) (►**Fig. 5**). Results indicated significant main effects of presentation level [$F(2,14)= 25.2$, $p < 0.00001$] and hearing aid prescription [$F(1,7)= 41.4$, $p < 0.00001$], and a significant interaction between presentation level and hearing aid prescription [$F(2,14)= 14.8$, $p < 0.01$]. Post-hoc testing showed performance with the custom gain prescription for soft sounds was significantly better at the 40 dBA presentation level ($p < .05$), but not at the 50 dBA or 60 dBA presentation levels ($p > .05$).

Discussion

Comparison of Speech Recognition between Groups

In the first phase of this study, speech perception was examined at very soft (40 dBA), soft (50 dBA), and moderate (60 dBA) presentation levels in children with "normal" hearing and with hearing aids set to evidence-based prescriptive targets. Compared with the children with "normal" hearing, the children with mild to severe hearing loss had significantly poorer monosyllabic word recognition at all presentation levels as well as significantly poorer plural recognition at 40 dBA.

In the present study, the excellent speech-recognition performance of children with "normal" hearing at low presentation levels was similar to the ceiling-level performance reported in previous research.[25] To the best of our knowledge, the current study is the first to examine aided speech

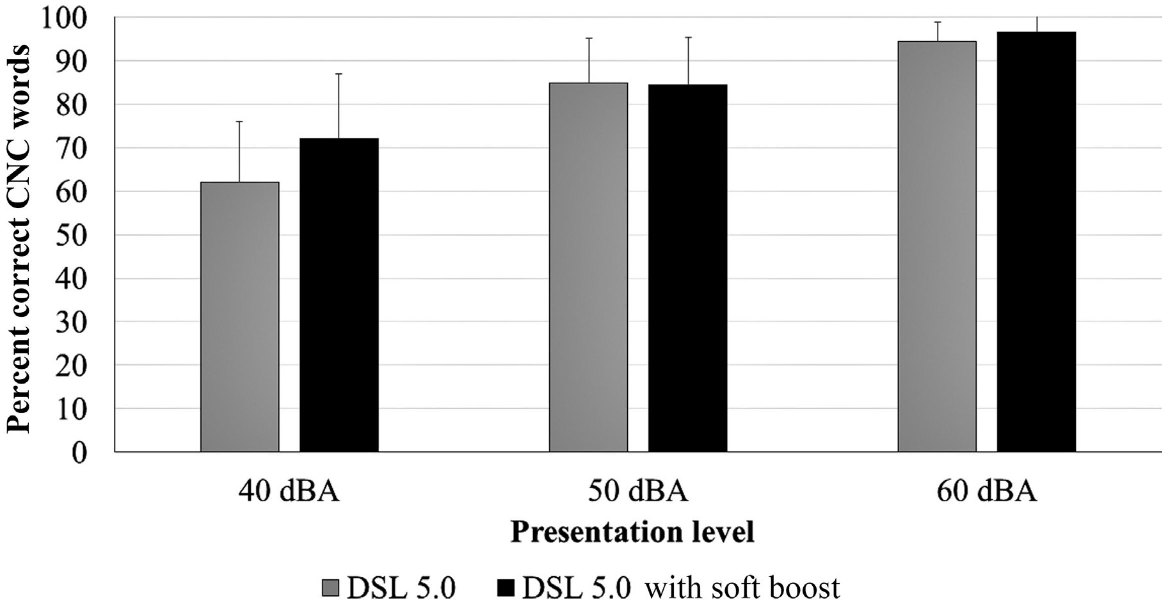

Fig. 4 Average CNC word-recognition scores at three presentation levels for children with hearing aids in Program A (programmed to DSL 5.0 prescriptive targets) and Program B (programmed to DSL 5.0 prescriptive targets with a 6 dB increase in overall gain for 50 dB inputs). Note. Bars indicate 1 standard deviation and numbers above the bars provide significant results of the post-hoc analysis. CNC, consonant-nucleus-consonant word recognition; dBA, decibel A-weighted; DSL, desired sensation level.

recognition for school-aged children with hearing loss at very low presentation levels. Although children were using digital hearing aids with wide dynamic range compression and outputs matched to prescriptive targets, participants struggled to recognize low-level and very low-level speech relative to their peers with "normal" hearing. As a result, additional research is necessary to explore optimal hearing aid settings, technologies, and signal processing strategies to improve access to very low-level inputs.

The Relationship between Aided SII and Speech Recognition

Previous research suggests children with hearing loss prefer prescriptive formulas that provide higher levels of gain and

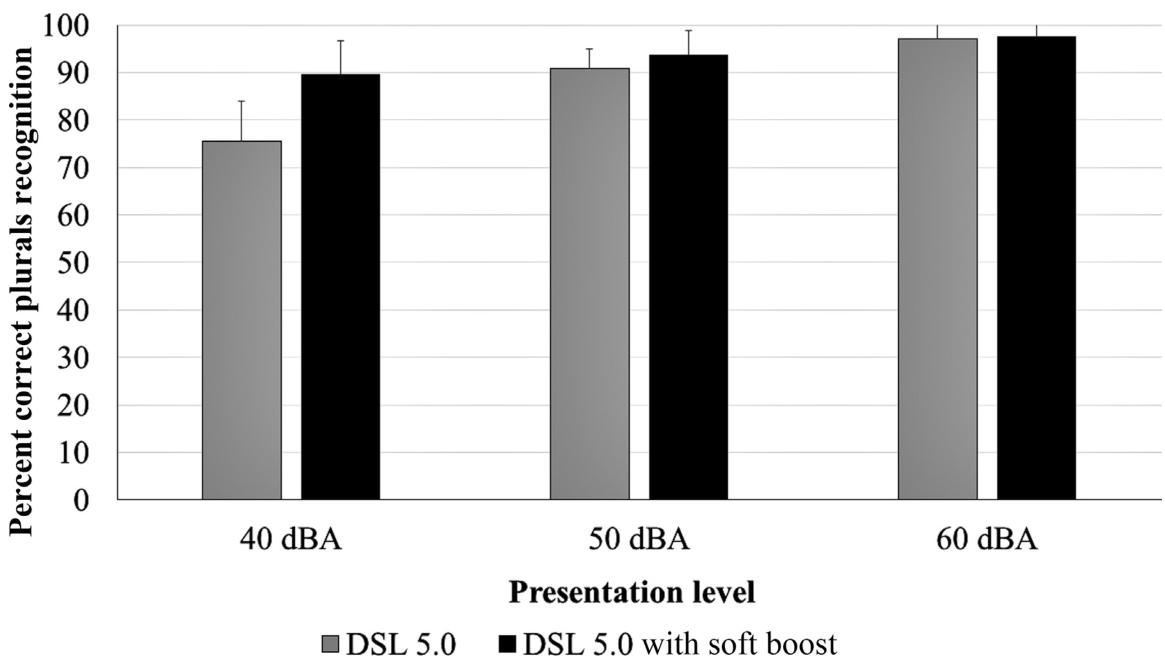

Fig. 5 Average Western University Plurals Test word-recognition scores at three presentation levels for children with hearing aids in Program A (programmed to Desired Sensation Level [DSL] 5.0 prescriptive targets) and Program B (programmed to DSL 5.0 prescriptive targets with a 6 dB increase in overall gain for 50 dB inputs). Note. Bars indicate 1 standard deviation and numbers above the bars provide significant results of the post-hoc analysis. dBA, decibel A-weighted.

also perform better on word-recognition tests at low input levels in quiet (e.g., 50–65 dBA) when provided with greater gain.[12,14,15] Because many prescriptive fitting methods were developed prior to modern digital hearing aids and signal processing algorithms, these existing strategies may not address optimal gain for very low-level inputs. However, in this study, with appropriately fit and verified hearing aids, children's aided word-recognition performance at a presentation level consistent with soft speech (50 dBA) was 80% correct (SD = 8.0), on average. This finding suggests that DSL 5.0 provided appropriate audibility of low-level speech for most of the children in this study. However, scores did vary in the 40 dBA condition (range: 20–88%) and mean monosyllabic word recognition dropped to 60% correct (SD = 14.6). Children with higher SII scores did have better speech-recognition performance at very low presentation levels (►**Fig. 2**). These findings do suggest children with hearing loss may experience difficulty understanding very low-level speech and additional audibility for very low-level speech may improve their speech recognition. Additional research is needed to better understand the ideal hearing aid settings that will optimize audibility for soft and very soft sounds of interest while maintaining acceptable sound quality and listening comfort and avoiding potential masking of low-level noise.

For the children with hearing loss, the aided SII score at 55 dB SPL was correlated with CNC scores at all presentation levels, whereas the four frequency PTA was correlated only with CNC scores at 60 dBA, controlling for age. As a result, aided SII appears to be a better predictor of word recognition across low and moderate presentation levels. These findings are consistent with Stiles et al[28] who reported the SII was a better predictor of receptive vocabulary and speech recognition at a conversational level (70 dBA) than the four frequency PTA in children with hearing loss. In the present study, anecdotal reports from children with hearing loss suggested much greater difficulty at the lowest presentation levels compared with the children with "normal" hearing who found the open-set word-recognition tasks at all input levels very easy, which suggests the provision of additional audibility for very low-level speech may be helpful for pediatric hearing aid users.

Despite the significant association between aided SII and speech recognition at very low presentation levels, the aided SII was not a perfect predictor of word recognition at very low presentation levels. For instance, for children with aided SII scores (55 dB SPL input) of ~50, CNC word-recognition scores at a 40 dB A presentation level ranged from ~20% to 50% correct. It is probable that word recognition at low and very low presentation levels is influenced by multiple factors such as aided SII, combined with age, vocabulary, language aptitude, and cognitive ability. For instance, Davidson et al[29] and Eisenberg et al[30] both reported that speech recognition improved with improvements in language aptitude. Furthermore, McCreery et al[31–33] have shown that cognitive and linguistic abilities affect speech perception of children with hearing loss. Children who have better cognitive and language abilities may be able to use higher-order processes (i.e., top-down processing) to achieve relatively better speech recognition at low presentation levels. Further research is needed to distill the influences of aided audibility as well as other factors on aided speech recognition at low and very low presentation levels.

Additionally, age-related adjustment factors to the SII may be needed[34] because the original SII measure was developed for adults, and children with hearing loss require increased audibility to achieve comparable performance to adults.[34,35] Overall, however, SII is likely a better predictor of speech recognition over aided thresholds because the SII represents the full frequency range of the speech signal at different presentation levels, and it can also be measured with children who cannot complete reliable behavioral testing.[36]

The present study found no relationship between plural recognition level and either the aided four frequency PTA or the aided SII at 55 dB SPL across input levels. Plural recognition requires access to fricative speech sounds with spectral energy peaks as high as 4 to 6 kHz. In contrast, the aided SII value takes frequency importance bands across the speech bandwidth into account and reflects the proportion of the speech signal audible to a listener for a given stimulus. The aided SII provided by the Verifit reflects the audibility of running speech; thus, it does not reflect the specific audibility of the high frequency region needed for fricative/plural recognition. Previous work has shown the SII does not capture the importance bandwidth plays in speech recognition for children with "normal" hearing.[37] Moreover, maximizing the speech bandwidth with hearing aids has been shown to be vitally important for speech and fricative recognition in children with hearing loss.[38,39]

Effect of Increased Low-Level Hearing Aid Gain on Low-Level Speech Perception

In an attempt to better understand the potential benefits and limitations of the provision of additional low-level gain for children whose hearing aids are fitted to evidence-based prescriptive targets, eight children were fitted with hearing aids with two programs: a standard program and a program providing an additional 6 dB of overall gain for 50 dB inputs. The program with additional low-level gain did not improve speech recognition for words presented at 40, 50, or 60 dBA compared with the standard program. However, it just failed to reach significance at 40 dBA ($p = 0.055$). It is possible that a larger sample size or that a different type of measure (e.g., working memory, listening effort) could yield significant differences between the programs. Use of the program with additional gain did improve performance on the Plurals test at a 40 dBA presentation level, a finding that suggests additional low-level gain may improve a child's ability to hear low-level fricative sounds.

Limitations of the Current Study and Need for Additional Research

Primary study limitations relate to sample size and methodology. First, because phase 2 only included eight children, the small sample size may have impacted the ability to examine potential benefits and limitations that may exist in speech recognition at very low presentation levels with the use of increased hearing aid gain for low-level inputs. Also, the current study did not evaluate the potential benefits and limitations of the use of hearing aids with additional gain for low-level inputs in real-world settings. Future work will need to examine the relationship between perception for very soft speech and real-world hearing performance as well as the potential benefits and detriments/side effects of increased audibility for very low-level sounds in everyday environments (e.g., will children find the additional low-level gain to be beneficial, or will they report that low-level environmental noises are too loud or annoying). Future research should also further explore modified verification measures that are necessary to ensure optimal audibility at very low presentation levels. Furthermore, McCreery et al[31–33] have shown that cognitive and linguistic abilities affect speech perception in noise. Additional research is needed to better understand the cognitive and linguistic contributions to the perception of soft and very soft speech in the laboratory and real-world settings for children with hearing aids relative to children with "normal" hearing. Finally, the improvement seen with increased low-level gain here might not generalize to older products given that contemporary technologies may allow for additional gain before feedback, contain a wider bandwidth, and have more sophisticated noise cleaning processing. For example, greater amplification of low-level noise may be annoying or mask low-level, high-frequency speech sounds. It is possible gain increases for low-level inputs will require signal processing that can distinguish speech from broadband noise and provide gain increases accordingly.

Summary and Clinical Implications

Children with mild to severe hearing loss have poorer aided speech perception at moderate, soft, and very soft presentation levels when compared with their peers with "normal" hearing. Clinicians may consider using aided SII over aided thresholds to document optimal hearing aid fittings as well as predict speech recognition at low-input levels. Additional low-level hearing aid gain may improve speech recognition at very soft levels, especially for low-level fricatives such as /s/. Further research is required to better understand the difficulties children with hearing aids may experience with low-level speech perception in real-world environments as well as the potential benefit and detriment of providing additional low-level hearing aid gain for children with mild to severe hearing loss.

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Conflict of Interest
None declared.

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