Critical Review: Are amplification features such as digital noise reduction, directional microphone technology, or additional programs beneficial in noisy situations for school-aged children with mild to severe hearing loss?

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The goal of this critical review was to examine the literature investigating the effectiveness of digital noise reduction (DNR), directional microphone technology, or additional programs using a specific prescriptive algorithm in order to improve speech intelligibility or comfort in noisy situations for school-aged children. All studies included are categorized as within groups (repeated measures) experimental designs. Current research suggested that DNR and additional programs may improve comfort in noise but not intelligibility, and directional microphone technology may improve signal-to-noise ratio (SNR) but only in certain situations. While this research was suggestive, the clinical implications are that these strategies should be implemented with caution and concern for each individual patient.

Introduction

For those who are hearing impaired, hearing in noise is a difficult problem with few solutions. Since hearing in noise is even more difficult for children than adults (Neuman, Wroblewski, Hajicek, & Rubinstein, 2010; Blandy & Lutman, 2005; Fallon, Trehub, & Schneider, 2000), children who are hearing impaired, may experience considerable difficulty communicating in noisy situations.

The best solution for increasing SNR in noisy situations for both adults and children, is the use of frequency modulated (FM) systems (Lewis, 1991). While FM systems are always recommended for school-aged children with hearing loss, they may be rejected by some children due to issues with multiple talkers, lack of convenience outside the formal learning environment, limitations on learning through overhearing, self-image, or financial restrictions (Lewis, 1991).

Digital noise reduction (DNR), directional microphone technology, and additional programs are examples of features that may be additional strategies or in some scenarios, alternatives to FM use. However, due to lack of research of the use these technologies in pediatrics and school-aged children, using these technologies with children must be carefully considered based on the individualized needs of the child (Bagatto & Scollie*,* 2010).

Recently, numerous researchers have investigated the use of DNR and directional microphones in children (Auriemmo, et al., 2009: Ricketts, Galster, & Tharpe, 2007; Stelmachowicz, et al., 2010). Furthermore, some studies compared different prescriptive algorithms, and while the goal of these studies was not to develop a strategy for hearing in noise, the results indicated that perhaps a second hearing instrument program could be implemented as a fixed noise program. (Scollie, et al., 2010a&b).

Objectives

The review of these studies was aimed to determine if DNR, directional microphones, or additional programs could provide additional or alternative benefit for hearing impaired school-aged children in noisy situations.

Methods

Search Strategy

The computerized database PubMed was searched using the following search strategy: [(digital noise reduction) OR (directional microphones) AND (children)].

The search was limited to articles written in English. No other limits were used. Suggested articles from advisors were also considered. Citation searching was also utilized.

Selection Criteria

The studies selected for inclusion in this critical review were studies that addressed potential strategies for hearing in noise with school-aged populations, where the strategies were physically investigated through the use of amplification (there are numerous studies that investigated head turning in response to sound that generalized their results towards the use of directional microphones in children, but did not specifically test directional benefit). Three of the studies included investigated DNR and directional microphone technology as tools used for hearing noise. While the Scollie et al. (2010a&b) studies did not directly investigate prescriptive algorithms for the purpose of hearing in noise, the results of those studies were included in this review because they potentially suggested the strategy of using an additional fixed noise program. Furthermore, the five articles that were selected also equally represent research conducted on each strategy.

Data Collection

Five studies were selected for critical review and all studies used a within groups (repeated measures) research design, which provides a level 2b of evidence. Each study provides suggestive results (Dollaghan, 2007).

Results

Auriemmo et al. (2009) investigated the affects of adaptive directional microphones and DNR on the speech production of school-aged children. In this mixed groups, non-randomized, double-blind experimental study, 19 children, ages 6 to 12 years from two separate educational sites, with mild to moderately severe sensorineural hearing loss were evaluated after a trial of 6 weeks in each of the following conditions: 1) adaptive directional mode, 2) omni-directional mode, and 3) omni-directional mode with DNR. Lastly, the hearing instruments were programmed so that adaptive directionality and DNR were "on" and performance was evaluated after one year.

Speech recognition was tested using the CID W-22 in quiet, +5dBSNR, 0dBSNR, and -10dBSNR, with loudspeakers oriented at 0° (signal) and 180° (ANSI speech-shaped noise generated from the audiometer) for all subjects. Speech recognition scores were analysed using a factorial repeated measures General Linear Model (GLM) examining within-subject factors of "hearing aid setting" and "noise condition" and between-subjects factor "site". Post hoc testing was completed using a paired-sample t-test with Bonferroni adjustment for multiple comparisons. Results indicated that the adaptive directional mode produced a 7.6 dB increase in SNR, whereas the DNR mode produced no significant improvement in SNR. Fifteen subjects completed follow-up studies at six months and one year. Results indicated that there was significant improvement over time, but no significant difference between results at six months and one year. Subjective assessment was completed using the parent version of APHAP for 13 of the test subjects after the initial three trials. The results were analyzed using a repeated measures GLM analysis to study the main within-subjects effect of hearing instrument setting and listening categories. No significant affect was observed. Furthermore, subjective assessment was also conducted by surveying subjects using directional subscales developed by Ricketts, Henry, and Gnewikow (2003), with minor changes in wording so that it could be administered to children. No significant differences were observed for the three trials when the sound source was located in the front, sides or back. After one year, 15 subjects completed Oral and Written Language Scales or the Comprehensive Assessment of Spoken Language tests to determine any affect on language progress. Furthermore, receptive and expressive vocabulary measures were also assessed in 18 subjects using the Peabody Picture Vocabulary Test-Third Edition and the Expressive Vocabulary Test Second Edition or Expressive One Word Picture Vocabulary Test. All subjects performed the same or better on these standard tests after using adaptive directional microphones and DNR for one year.

The authors concluded that adaptive directional microphones create an increase in SNR when the sound source is located in front and no decrement in performance is noted when the sound source is located to the sides or the back. DNR does not create an increase in SNR but does not create a decrement in performance either. Language progress was stable after one year with adaptive directional microphone and DNR programming.

One of the challenges with using an adaptive directional and DNR system is determining when the hearing instruments are actually in directional and DNR mode. This design flaw may have affected the results, specifically in subjective situations where the speaker source was located at the back or sides. Since the researchers indicated no decrease in performance in these situations, the hearing instruments may have switched to omni-directional mode inadvertently. Also, the laboratory results may have overestimated the amount of directional benefit because the authors were limited to a single correlated noise source. Ricketts (2001) indicated that a multiple speaker array and an uncorrelated noise source will generate more realistic results when measuring directivity. Furthermore, the results pertaining to DNR cannot be generalized to other manufacturer's hearing instruments, as DNR algorithms differ from manufacturer to manufacturer. Despite these limitations, these data suggest that adaptive directional microphones and DNR may be beneficial for school-aged children in certain situations.

Ricketts et al. (2007) investigated the difference between omni-directional and directional microphones in various simulated classroom environments. In this study 26 children from 10 to 17 years of age with mild to severe hearing losses participated in 3 experiments. In the first experiment, participants were fitted with Oticon Gaia and Phonak Supero hearing instruments for 1-month cross-over trials with omni-directional and fixed directional microphone modes. At the end of each month participants completed the HINT-C in five different listening situations. All testing was completed in a simulated classroom. The first listening situation simulated the teacher speaking at the front. The second situation simulated the teacher talking at the back. For the third situation, the participants were given a math question and told to focus on their work while listening to speech from the front. The fourth situation simulated a roundtable discussion, and the participant was instructed to look at the speaker. In this situation, three speakers were set up and speech was played as equally as possible from each speaker in a non-overlapping fashion. Lastly, the fifth situation simulated bench seating or listening to two people talking to the sides. Also, two subjective questionnaires were administered after each month: the CHILD and a questionnaire specifically developed for this study.

The second experiment further examined the differences between directional and omni-directional microphones in the speaker front and back situations and whether the negative effects of listening to a speaker from the back could be limited by directional processing that focuses on the lower frequencies. Test stimuli consisted of items selected from the CUNY recorded in directional, omni-directional, and low-pass directional with speaker front and back for each microphone mode.

The last experiment investigated the differences between directional and omni-directional microphones when there were multiple talkers, some in front and some behind. Only 12 participants from the first two experiments participated. NU-6 items were delivered through 3 speakers at 63 dB SPL in competition with 4 bipolar speakers delivering four uncorrelated samples of cafeteria noise that was spectrally matched to the NU-6 competing noise at 57 dB SPL, producing a 6 dB SNR.

All three experiments used a two-factor ANOVA and post hoc testing was done using the Tukey honestly significant difference test. Briefly, performance was significantly better in directional mode for teacher front, desk work and discussion but significantly worse for the teacher back situation. While there were missing items in the subjective questionnaires, after accounting for the missing data, no significant differences between directional and omni-directional microphones were observed. The second experiment revealed that when the speaker was in the front, performance was significantly better in directional mode. The third experiment revealed that there was no significant difference between microphone modes except when the speaker was behind, performance was significantly better in omni-directional mode. The researchers concluded that although benefit in some situations was demonstrated, omni-directional mode would be more beneficial for school-aged children, especially in noisy environments with multiple talkers.

The limitation of this study was that two different hearing instruments were used. While the similarities in directivity index, which is a ratio comparing a single speaker located at the front and a diffuse noise source of equivalent acoustical power thereby effectively estimating SNR (Ricketts, 2001), was discussed, no statistical analyses were completed comparing results from the separate hearing instrument groups. Despite this limitation, these data are suggestive, indicating that while omni-directional mode may be better overall, in certain situations directional microphones may provide an advantage.

Stelmachowicz et al. (2010) investigated the degradation of speech caused by a spectral subtraction noise reduction scheme in school-aged children. Sixteen children from 5 to 10 years of age with mild to moderately severe hearing loss were amplified binaurally and tested using 15 vowel-consonant-vowel (VCV) nonsense syllables, 90 monosyllabic words from the Phonetically Balanced Kindergarten List (PBK), and 90 meaningful sentences from the Bamford-Kowal-Bench (BKB) all mixed with speech-shaped noise at 0, +5, and +10 dB SNR to determine the differences between conditions where noise reduction is on and off. The participants were fit with Starkey Destiny 1200 hearing instruments where DNR is triggered by a voice-activity detector and is carried out in the frequency domain using a modified spectral subtraction algorithm that compares ongoing input spectrum levels with an estimated noise level. Noise levels were attenuated by a maximum of 6 dB.

The affects of DNR on speech recognition were determined using a factorial analysis of variance for all stimuli (VCV nonsense syllables, PBK words and BKB sentences), SNR (0, +5, +10 since DNR is not designed to work in – SNR situations), and DNR (on and off) as within-subjects factors, and age group (5 to 7 years of age and 8 to 10 years of age) as a between subject factor. Post hoc comparisons of stimulus type using

Bonferroni-adjusted alpha levels of 0.017 (0.05/3) were conducted.

Performance improved as SNR improved, with less affect as SNR changed from +5 to +10 for the older group. The younger group had lower scores overall, suggesting that older children perform better in noisy conditions. DNR did not have a significant effect on performance. Furthermore, the two-way interaction between DNR and age group did not reveal any significant differences. Despite the group effects, individuals experienced both improvement and a decline in performance, indicating that there is individual variability, especially in the 5 to 7 years age group. The authors concluded that while DNR does not have a negative effect on speech perception, it may not always result in an improvement. It is important to consider each child individually.

This study has numerous limitations: 1) multiple talkers or multiple repetitions of the nonsense syllables were not presented due to the attention span of the youngest children in the group, 2) the results cannot be generalized to other DNR algorithms because other algorithms may include a greater degree of attenuation, and 3) the results also cannot be generalized to children with extremely reduced dynamic ranges, since any attenuation may greatly affect audibility. Also, wide dynamic range compression may reduce the effectiveness of DNR by increasing gain for low-level noise and reducing the modulation depth of the signal (Chung, 2004). It would have been prudent to analyze the results of participants with mild hearing losses compared to those with more severe hearing losses to evaluate if differing compression ratios affected performance with DNR. Furthermore, this study did not investigate the affects of DNR on comfort in noise and resulting listening effort or attentiveness. Despite these limitations, these data are suggestive, indicating that performance with DNR is variable and some individuals may benefit from its implementation.

Scollie et al. (2010b) reported real world preferences of children comparing two different prescriptive algorithms. The findings discussed in this report were collected from a larger study where 48 children (24 from University of Western Ontario and 24 from the National Acoustics Laboratory) from 6 to 19 years of age with mild to severe hearing loss participated in a double blind cross-over trial. All children participated in 4 trials: during the first trial, half of the participants were assigned DSL[i/o] v4.1 and the other half NAL-NL1 for eight weeks each, a period of time that allowed for acclimatization. When comparing DSL v4.1 and NAL-NL1, NAL-NL1 reduces low frequencies and high frequencies relative to DSL v4.1. In comparison, many DNR algorithms will also attenuate low and high frequencies. While NAL-NL1is not a DNR program, it will act similarly to a separate DNR program when directly compared with DSL v4.1, which is why this study has been included in this review. After the initial trial, the prescriptive algorithms were switched for another 8 weeks. During the third trial, which lasted 4 weeks, DSL v4.1 and NAL-NL-1 were counterbalanced in either program one or program two. For the last trial, the program allocations were reversed for another 4 weeks. After each trial numerous outcome measures were administered. The measures described in this report were administered at the end of the third and fourth trials and consisted of both a diary recording the participant's impressions and experiences of the two separate programs as they switched between them in their daily lives as well as a rating scale for numerous situations. The preference ratings were collected because qualitative data is subject to statistical analysis and the comments were collected to provide a greater understanding of the experiences of the participants. The qualitative data was analyzed using an inductive procedure called immersion and crystallization. This process analyzes the responses of the participants for emerging themes. Unblinded preference ratings were analyzed with the intra-class correlation coefficient for consistency and for absolute agreement, using a mixed two-way model. Preference ratings with poor response rates were appropriately excluded from the study. Averaged preferences were entered into an analysis of variance with item as a repeated measure and site as a between-participants variable. Post hoc analyses for significant preference per situation and site were completed using the t-statistic.

Results from both quantitative and qualitative analyses indicated that many participants prefer DSL v. 4.1 in quiet situations where they prefer to hear loudly and NAL-NL1 in noisy situations where they prefer to reduce the background noise and listen in comfort. No differences were found in preferences between the two sites. The clinical implications of this study are that 1) children in this study made effective use of multiple programs and 2) participants benefitted from two different levels of audibility, indicating that various amplification characteristics are needed for various listening environments.

Scollie et al. (2010a) investigated loudness ratings and speech perception differences between two different prescriptive algorithms. The results reported in this paper were collected from the larger study discussed above. Consonant recognition in quiet using nonsense syllables at 55, 70, and 80 dB SPL in soundfield, sentence recognition in noise (HINT-C at the Canadian site and BKB-A at the Australian site), and loudness ratings using digitized recordings of the Rainbow passage in both Australian and Canadian accents were all measured prior to and after the 8 week trials with each prescription. Consonant recognition in quiet results were analyzed using the General Linear Model (GLM) repeated measures analysis of variance with time, level, and prescription as repeated measures variables and site as a between groups variable. Bonferroni post hoc testing was also performed. Sentence recognition results were analyzed using a repeated measures analysis of variance, with time and prescription as within-participants variables and test site as a grouping variable. Loudness ratings results were subjected to analysis of variance using time, prescription, and level as repeated measures factors and site as a grouping variable. Post-hoc analysis was completed using the false discovery rate (FDR). Results indicated that there was no significant difference in speech perception between the prescriptions in any of the conditions. While this seems to contradict the results obtained in the earlier study, this may indicate that while participants preferred less gain in noisy situations, this does not necessarily lead to better understanding of speech in noise. There was a significant difference between site and time in all conditions. The test stimuli were different across sites and this may account for some of the between-site differences in scores. Results for the loudness ratings indicated there is a high degree of acclimatization for loudness. However, 80 dB SPL was rated as "much too loud" for both prescriptions, suggesting that while participants acclimatized to louder prescriptions, a method of reducing loudness discomfort is warranted.

This study was very well designed and has few limitations. One potential limitation is that in the investigation of speech perception (Scollie et al., 2010a), different test stimuli may have led to the differences observed between site. Despite this minor limitation, these data suggest that different levels of audibility are preferred for different situations, even though speech perception is unaffected. Furthermore, these data also suggest that many school-aged children are very capable of making purposeful program changes to their hearing instruments.

Discussion

All five studies are of sound design with good reliability and validity. While the five studies are assessing three different strategies for hearing in noise, they all use comparable measures for testing speech recognition. While more research on each individual strategy would be preferable, the initial results of these studies are suggestive that these strategies may be helpful for school-aged children in noisy situations if applied in an appropriate manner considering the individual child. Auriemmo et al. (2009) and Ricketts et al. (2007) found that directional microphones provided an increase in SNR if the participant was facing the speaker. While Auriemmo et al. (2009) found no decrement in performance on speech recognition tasks from the sides or the back, these data may have been compromised by the adaptive nature of the directionality and Ricketts et al. (2007) found a significant decrease in SNR when the speaker was located on the sides or the back. As a result, evidence from these two studies is suggestive that omni-directional microphone mode is more beneficial overall, but if the child can reliably face the speaker, directional microphones may be favourable in certain situations.

Both Auriemmo et al. (2009) and Stelmachowicz et al. (2010) found that while DNR did not reveal an increase in performance on speech recognition tasks, DNR did not cause a decrease in performance either. Unfortunately, Stelmachowicz et al. (2010) did not include any subjective measures in their test battery as to determine whether the participants were more comfortable during the testing with DNR on, and while Auriemmo et al. (2009) used the PAPHAP, this survey does not address comfort in noise. More research is needed to determine the benefits of greater comfort in noise for school-aged children. Studies that have investigated the affects of DNR in adult populations have demonstrated that while there is no increase in speech perception abilities, greater comfort in noise is observed (Bentler & Chiou, 2006), which may lead to increased attention and less listener fatigue. Therefore, it is possible that while DNR does not increase SNR or speech perception ability, it may have other advantages for school-aged children. It is also important to consider that the results from the Stemachowicz et al. (2010) study showed great variability in the individual results, where several participants showed improvement in speech recognition tasks. This indicates again that it is important to consider the individual.

Scollie et al. (2010a & b) demonstrated two things that are important to consider for this review: 1) children prefer NAL-NL1 in noisy and loud situations although there was no significant difference in speech perception scores, and 2) school-aged children are capable of making use of multiple programs. As a result, these data indicate that since school-aged children are capable of making use of multiple programs in an effective and rational way, a second program that is designed to provide comfort in noise may be beneficial.

In conclusion, with the exception of directional microphones used when facing the speaker, these strategies do not lead to an increase in SNR. Therefore, FM system use is still very important for children with hearing loss to improve SNR in noisy situations. However, it is also important to consider preference and comfort in noisy situations. Since school-aged children have been shown to be able to make use of multiple programs, depending on the individual, it may be beneficial to design a noise program that makes use of one or more of these strategies. It is important to consider the individual carefully, provide adequate counselling on these features, how they work and how they may be beneficial, and continued monitoring of benefit and use through both objective and subjective tests.

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