Understanding the listening problems in noise experimented by children with Auditory Processing Disorders

Josée Lagacé[1*], Benoît Jutras[1], Jean-Pierre Gagné[1]

1 École d'orthophonie et d'audiologie, Faculté de Médecine, Université de Montréal, 2375, Côte Ste-Catherine, Montréal (Québec) H3T 1A8 Canada

* corresponding author: e-mail: josee.lagace@umontreal.ca

INTRODUCTION

Earlier studies have shown that children with normal hearing function perform more poorly than adults on different tasks that involve the perception of speech in noise (Fallon et al. 2000; Hall et al. 2002; Johnson 2000; Picard & Bradley 2001). Some authors have suggested that children's immature cognitive capacity and less developed coping strategies explain this difference between children and adults (Stansfeld & Matheson 2003). Others have proposed that children's poorer speech perception performances while they are in presence of background noise can be attributed to their immature central auditory processing system abilities (Blandy & Lutman 2005; Fallon et al. 2000). And, some have suggested that children's speech perception in noise difficulties can be accounted for by the fact that they have immature linguistic competencies (Elliott 1979). At the present time, there is no agreement about the causes that may explain why children perform more poorly on speech perception in noise tasks compared to adults. However, there is a consensus that, with children, the ability to perceive speech in noise improves as a function of age until they reach adolescence. As the hearing abilities and the brain are developing, it is conceivable that there is an increased specialization and fine tuning of the different perceptual and cognitive processes such as the ones involved for speech recognition in presence of background noise.

Children with auditory processing disorders (APD) have more difficulty perceiving speech in background noise compared to children presenting normal auditory functions. In general, APD are described as difficulties to interpret acoustic message without any peripheral evidence of hearing loss or lesions and this, particularly while in presence of background noise (Bellis 2003; Musiek & Geurkink 1980; Vanniasegaram et al. 2004). The American Speech-Language-Hearing Association (ASHA 2005) Working Group on Auditory Processing Disorders describes APD as a deficit in the neural processing of auditory stimuli that is not due to higher order language, cognitive, or related factors. Listeners with APD exhibit little or no difficulty understanding speech in ideal listening environments, but they do have difficulties in noisy backgrounds (Bellis 2003; Musiek & Geurkink 1980). However, some have proposed that these difficulties may be more related to attention problems (Cacace & MacFarland 2005; Keller & Tillery 2002) or to language comprehension problems (Rees 1981) than to central auditory dysfunction.

Children with APD are often referred for audiological evaluation because of academic problems (Smoski et al. 1992). But, the underlying cause of the problems to understand speech while in noisy conditions in the case of APD is still not clearly identified. Children with different types of learning difficulties have problems on some language measures and tests of central auditory functions (Sloan 1998). No one test is a perfect indicator of a specific disorder. Hence, we need different kinds of information in order to determine the nature of the difficulties, the possible methods for intervention, and the most effective coping strategies (Sloan 1998). Most of the time, the assessment team approach is favored, thus making it possible to proceed by elimination. Defining the problem can take months and in many cases, it is not possible. Intervention strategies could be more specific and effective if the audiologist could predict the underlying cause of the speech in noise difficulties. For instance, if the difficulties are language-based, the intervention should probably be more geared to the development of linguistic skills or strategies. On the other hand, if the difficulties have auditory causes, then the intervention should be more helpful if focused around the development of auditory skills or strategies.

The Speech In Noise (SPIN) test has been used in many studies to explore the underlying cause of the speech perception in noise problems, but never in cases of APD. The objective of the present article is to describe the various steps undertaken to develop of a French Canadian adaptation of the SPIN test as it seems to provide interesting information about the linguistic and auditory competencies of the listener.

The SPIN test was originally developed to assess how well individuals with acquired peripheral hearing loss utilize contextual information to facilitate speech-recognition (Kalikow et al. 1977; Elliott 1995). The Revised SPIN test material consists of eight tape-recorded lists of 50 sentences aligned with a multitalker speech babble (Bilger et al. 1984). Half of the sentences are *highly predictable* (HP) as they contain contextual information that facilitates the identification of the last word (ex.: *She made the bed with clean sheets*), while the other half of the list is composed of *low predictable* (LP) sentences (ex.: *I should have considered the map*). The listener has to report the sentence-final word after each sentence is presented.

This test was developed on the premise that essentially two processing operations are involved in speech perception 1) auditory processing of the signal and, 2) language-based processing of that information (Kalikow et al. 1977). Hence the recognition of the last word of HP sentences can be accomplished through one or both of these operations, while the recognition of the last word of the LP sentence depends essentially on the auditory processing of the signal (Kalikow et al. 1977). By comparing the performance that an individual obtained for the two types of sentences presented in background noise, the SPIN test sentences can be used to determine the extent to which listeners benefit from context (language-based function). The level of the speech babble can be varied while presenting the different lists of the SPIN sentences, which is relevant for determining the extent to which the listeners are affected by the signal-to-noise ratio (auditory function).

METHODS

The approach used is similar to the one reported by Kalikow et al. (1977) and includes: a) the development of a large set of sentences; b) the recording of the speech material; c) the determination of the key-word familiarity; d) the test of intelligibility in noise; e) the test of key-word predictability; and f) the establishment of equivalent test lists.

Participants

A total of 75 French Canadian participants took part at the various steps of the study but participated in only one individual step. Participants met the following inclusion criteria, they: 1) were native French-Canadian speakers who used primarily French for most of their daily activities; 2) were completing or had completed their education in French; 3) had hearing responses at 15 dBHL (20 dBHL for the children) from 0,25 to 4 kHz and 4) had a negative otological history.

Development of the speech material

As suggested by Kalikow et al. (1977), one of the first questions that must be addressed in formulating a sentence test concerns the type of response to be elicited from the participant. In order to simplify the task for the listener and to reduce the dependence on linguistic and memory skills, single-word responses are used in the SPIN test. The response word is the last word of the sentence, the key word. This allows a reasonable degree of flexibility in the design of the sentences. It is also convenient for the examiner as the task is simply to check for only one word response. In order to further control the types of sentences, an additional restriction is that the key word must be a monosyllabic word. By this limit, it is easy to formulate test sentences in which the key word receives main stress and in this way, a certain degree of acoustic control over the prosodic aspects of the sentences can be achieved (Kalikow et al. 1977). Another aspect of the original version of the SPIN test is the homogeneity of the sentence length. All sentences are constrained to contain five to eight words, and six to eight syllables. No equivalent French corpus was available. As a result, French sentences had to be developed, taking into account the previously discussed requirements as well as the familiarity of the key words. The word's familiarity influences their intelligibility when they are presented in noise (Kalikow et al. 1977). Hence, all the key words in the test materials were selected from the Manulex database (Lété et al. 2004). This database indicates the frequency at which each word is used in school manuals and books for children. Two hundred monosyllabic words with word frequency use within the range of 0,02 to 1106,32 per million words were taken as the initial pool of key words. It is assumed that words that are frequently used in children books are also the ones that are well known by children.

From this pool of frequently used monosyllabic words, and given the constraints previously noted with regard to sentence length, position of final stress, and familiarity, a set of 200 high-predictability (HP) sentences was developed. In addition, a set of 200 low-predictability (LP) sentences was produced by using the same key words with various combinations of constructions like '*Marie a un très gros ___', 'J'aime jouer avec mon* ___',. etc.

The corpus of 400 sentences resulting from this procedure underwent a paper-and-pencil test, to determine the predictability of the key words. Nine female participants, aged from 9 to 11 years old, took part to this test. The sentences were listed on answer sheets with the final word deleted. Participants were instructed to fill in the word that they thought would more likely occur at the end. No further instruction was given. HP sentences that obtained a score lower than 10 % were deleted from the corpus as well as LP sentences that obtained a score of more than 10 %. The remaining corpus consisted of 160 HP sentences and 160 sentences

Recording of the speech material

The remaining corpus was recorded using a female voice as this is known to be more recognizable by children than male voices (Fallon et al. 2000). A Quebec native French speaker who already participated in various recordings was chosen. The sentences were recorded by using the IMOVIE software (*.mov* file). The Cool Edit Pro software was used to modify the intensity of some sentences (59 sentences) that had a mean average intensity value of ± 2 dB compared to the total average of the corpus. This modification was to ensure that all the sentences of the corpus presented an average intensity value within the same range. The key words were then edited into individual files in order to obtain four lists of 40 key words.

Determination of key word familiarity

Forty (40) children from 5,42 and 7,33 years old (average = 6,5 years old) participated in that part of the study. Only the children who had signed the assent form, following the consent of their parents, were allowed to take part in this study.

Each child was seen individually in a quiet room of the school. First, a hearing screening at 20 dBHL was performed in both ears. The children were asked to put a little stone in a basket every time they heard a sound, no matter how loud it was. Screening audiometers (Beltone A2 and Maico MA41) were used, with TDH 39 headphones. If a child presented responses at higher level than 20 dBHL, he or she was given a letter that was addressed to the parents, suggesting that a complete audiological evaluation be performed. Ten participants could not participate for that reason, or because they refused to continue or, presented obvious language problems. When the hearing responses were obtained at 20 dBHL for all the frequencies tested bilaterally, the child was invited to take part to the experimentation. The four lists of 40 words were presented monaurally at 60 dBHL. The order of the lists was counterbalanced between the participants who were instructed to report each word that they heard, and to guess if necessary. After each list, the child was rewarded with a sticker. This was also the moment to take a short break. At the end of the testing session, a letter was given to the child to inform the parents about the hearing screening and to thank them also for their consent to let their child participate.

The majority (80 %) of the words were identified by 81 % or more of the participants. Results are presented on Figure 1. The key words that obtained a percentage of identification of 65 % or less were removed from the corpus, to ensure the familiarity of the key words. Hence, 20 keywords were removed from the corpus, which corresponds to 40 sentences as each key word appears in a HP and a LP sentence.

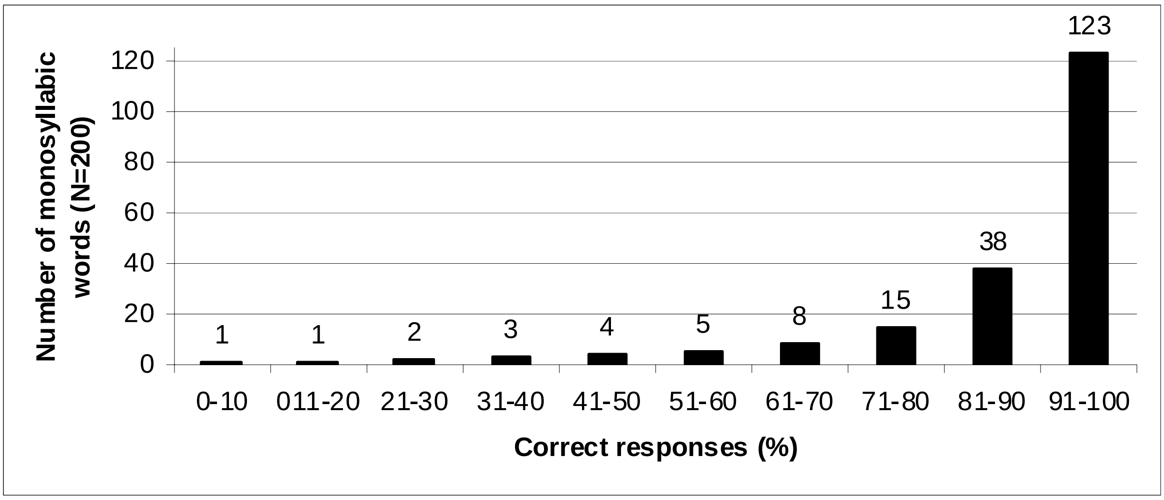

Figure 1: Distribution of the 200 monosyllabic words presented according to the percentage of times they were correctly identified by the 40 participants

Based on the results obtained from the key word familiarity testing, the remaining corpus of 280 sentences was divided into 7 lists of 40 sentences, ensuring that the familiarity value of the key words was evenly distributed across the lists. Each list contained 20 HP and 20 LP sentences. Each key word appeared only once in a given list.

Intelligibility in noise testing

Ten adults (4 female and 6 male participants) between 18 and 40 years of age (average= 22,70 years old) participated in the intelligibility in noise testing. Each participant was tested in the audiology laboratory at the University of Montreal during the summer of 2007. Once the consent form was signed, each participant had a general interview to rule out any conditions that would indicate any exclusion criteria (history of middle ear problems, language or academic problems, general development problems, etc.). If no exclusion criteria were identified, the participants were ask to undertake a bilateral 15 dBHL hearing screening at 500, 1000, 2000 and 4000 Hz.

The seven lists of 40 sentences were presented at 65 dBHL monaurally along with a speech babble at a signal to noise (S/N) of 0 dB, in ipsilateral condition. The sentences were presented with a compact disc player (Panasonic RXD 27) connected to the audiometer (Midimate 622). A French talkers speech babble (4 female and 4 male, by Perrin & Grimault (2005) was used as it is more representative of the noisy conditions of the target population (ie.: Canadian French children). The speech babble was on a separate CD and presented with a CD player (TASCAM) also connected to the audiometer. The order in which the lists were presented was counterbalanced across the participants, who were instructed to report the last word of each sentence they heard, and to guess if necessary.

The overall average percentage of correct answers was calculated for each list, as well as the average of the HP sentences and the LP sentences separately, as presented on Figure 2.

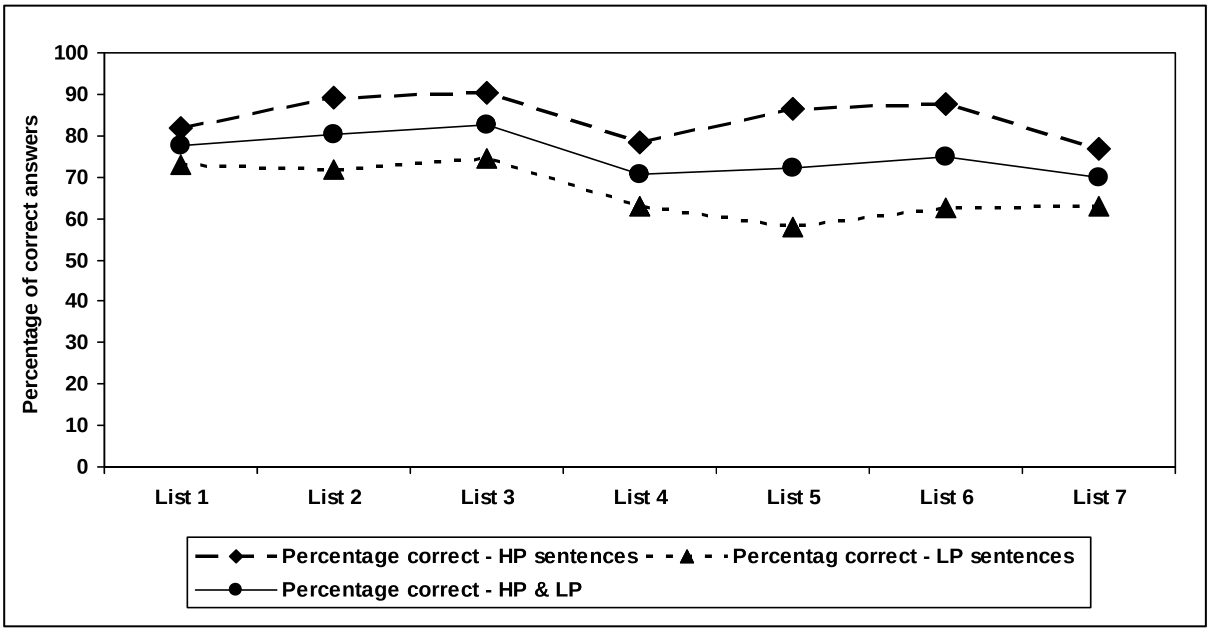

Figure 2: Percentage of correct answers obtained at the intelligibility in noise testing for each list

Based on the results obtained from the intelligibility in noise testing, the sentences were re-distributed in 7 lists of 40 sentences, ensuring an even distribution of the keywords across the lists according to their familiarity and intelligibility in noise value. The seven lists respected the previously discussed constraints, i.e.: 20 HP and 20 P sentences per list, each key word appearing only once in a given list, etc.).

Key word predictability testing

Although the corpus of sentences was developed by taking into account the results obtained at the paper-and-pencil testing to determine the predictability of the sentences, it was considered desirable to conduct further testing to ensure that the degree of predictability of the sentences was equivalent across the lists. This part of the study was carried out with 14 participants (11 female, 3 male) between 21 to 27 years age (average =23,43 years old). The participants were tested in the audiology laboratory of the University of Montreal during the fall of 2007. Prior to the testing, participants were also screened for normal hearing (responses at 15 dBHL, from 500 to 4000 Hz). The inclusion and exclusion criteria were the same as for the intelligibility in noise testing.

The seven lists of 40 sentences were presented at S/N ratio of -2 dB (sentences at 65 dBHL and speech babble at 67 dBHL) with monaural earphone presentation. The S/N ratio of -2 dB was selected following pilot data obtained with 3 participants that indicated that the maximum difference between HP and LP sentences was within that S/N ratio range. The equipment was the same as the one used for the intelligibility in noise testing.

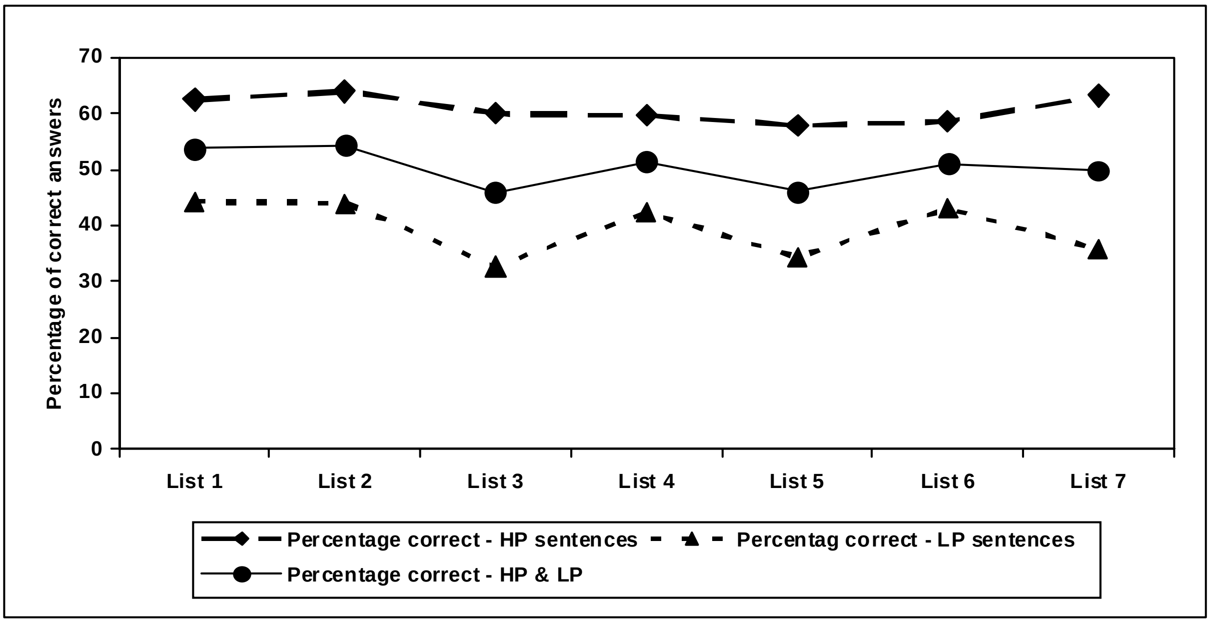

Figure 3: Percentage of correct answers obtained at the predictability testing for each list

The results obtained are illustrated on Figure 3 which shows the percentage of correct answers for the HP and LP sentences across the lists. The average percentage obtained for the LP sentences is 39,48 % (SD=5,3) and the average percentage obtained for the HP sentences is 59,67 % (SD=2,69). A difference of 20,25 % between HP and LP sentences is concordant with the literature about contextual benefit for speech recognition in noise.

The percentage of correct answers across the lists did not differ significantly, as confirmed by the results of the ANOVA for repeated measures ($F_{(1,6)}$= 0,508, p= 0,802). The percentage of correct answers obtained for the HP sentences was also analyzed separately from the one obtained for the LP sentences. The difference of the performance obtained for the HP sentences across the lists was not significantly different according to the results of the ANOVA ($F_{(1,4)}$= 0,689, p= 0,595), but was significant across the lists for the LP sentences ($F_{(1,4)}$= 3,62, p= 0,009)).

The difference of percentage obtained for each key word from the two types of sentences was also analyzed (difference of percentage between HP and FP). The key-words that obtained a higher percentage with the LP sentence compared to the percentage obtained with the corresponding HP sentence had to be removed from the corpus, as the contextual difference was the contrary to the one obtained from the pencil-and-paper predictability testing. From that analysis, 40 key words had to be removed the corpus (80 sentences).

Next steps

The remaining corpus consists of 100 HP sentences and 100 LP sentences, that was merged into five equivalent lists of 40 sentences, presenting the same previously mentioned constraints (i.e.: equal number of HP and LP sentences per list, a key word is appearing only once in each list, etc.).

The five lists are presently being tested at various signal to noise ratios, with three groups of participants presenting a normal hearing: 1) one group between 9 and 11 years of age, 2) one group between 11 and 13 years of age, and 3) one group of adults between 18 to 45 years of age), to investigate the effect of age on performance for normal hearing participants.

DISCUSSION

According to the results of earlier studies with different hearing impaired populations (Elliott 1979, 1995; Pichora-Fuller et al. 1995; Dubno et al. 2000), the SPIN test provides interesting information about the auditory and language-bases underlying competencies of the listener for speech perception in noise. As this test is not available in French, the adaptation of the SPIN test has been attempted and this article described the different issues that have to be taken into account when developing a speech perception in noise test for the children population.

This French Canadian adaptation of the SPIN test has not yet received adequate calibration and validation for its clinical use with the population of children diagnosed as having an auditory processing disorder. However, the performance of normally hearing children is currently being evaluated. Eventually, we expect to use the test with children who have APD diagnoses. It is believed that a better understanding of the cause of the hearing difficulties underlying speech perception in noise problems in the case of APD would lead to the development and use of more specific and effective intervention programs.

REFERENCES

ASHA, American Speech-Language-Hearing Association (2005). (Central) Auditory Processing Disorders. Available at http://www.asha.org/members/deskref-journals/deskref/default.

Bellis TJ (2003). Assessment and management of central auditory processing disorders in the educational setting: from science to practice. 2nd ed. Clifton Park: Thomson Delmar Publ.

Bilger RC, Nuetzel JM, Rabinowitz WM, Rzeczkowski C (1984). Standardization of a test of speech perception in noise. J Speech Hear Res 27: 32-48.

Blandy S, Lutman M (2005). Hearing threshold levels and speech recognition in noise in 7-year-olds. Int J Audiol 44: 435-443.

Cacace AT, McFarland DJ (2005). The importance of modality specificity in diagnosing central auditory processing disorders. Am J Audiol 14: 112-123.

Dubno JR, Ahlstrom JB, Horwitz AR (2000). Use of context by young and aged adults with normal hearing. J Acoust Soc Am 107: 538-546.

Elliott LL (1979). Performance of children aged 9 to 17 years on a test of speech intelligibility in noise using sentence material with controlled word predictability. J Acoust Soc Am 66: 651-653.

Elliott LL (1995). Verbal auditory closure and the speech perception in noise (SPIN) Test. J Speech Hear Res 38: 1363-1376.

Fallon M, Trehub SE, Schneider BA (2000). Children's perception of speech in multitalker babble. J Acoust Soc Am 10: 3023-3029.

Hall III JW, Grose JW, Bus E, Dev MB (2002). Spondee recognition in a two-talker masker and a speech-shaped noise masker in adults and children. Ear Hear 23: 159-165.

Johnson C (2000). Children's phoneme identification in reverberation and in noise. J Speech Lang Hear Res 43: 144-156.

Kalikow DN, Stevens KN, Elliott LL (1977). Development of a test of speech intelligibility in noise using materials with controlled word predictability. J Acoust Soc Am 61: 1337-1351.

Keller W, Tillery KL (2002). Reliable differential diagnosis and effective management for auditory processing and attention deficit hyperactivity disorders. Semin Hear 23: 337-347.

Lété B, Sprenger-Charolles L, Colé P (2004). MANULEX: a grade-level lexical database from French elementary-school readers. Behav Res Methods Instrum Comput 36: 156-166.

Musiek FE, Geurkink NA (1980). Auditory perceptual problems in children: considerations for the otolaryngologist and audiologist. Laryngoscope 90: 962-971.

Perrin F, Grimault N (2005). Fonds sonores. Laboratoire UMR CNRS 5020. Lyon, France.

Picard MS, Bradley JS (2001). Revisiting speech interference in classrooms. Audiology 40: 221-244.

Pichora-Fuller KM, Schneider B, Daneman M (1995). How young and old adults listen to and remember speech in noise. J Acoust Soc Am 97: 593-608.

Rees NS (1981). Saying more than we know: is auditory processing disorder a meaningful concept? In: Keith R (ed.): Central auditory and language disorders in children (pp 92-120). San-Diego: College-Hill Press.

Sloan C (1998). Management of auditory processing difficulties. Semin Hear 19: 367-378.

Smoski WJ, Brunt MA, Tannahill JC (1992). Listening characteristics of children with central auditory processing disorders. Lang Speech Hear Serv Schools 23: 145-152.

Sperry JL, Wiley TL, Chial MR (1997). Word recognition performance in various background competitors. J Am Acad Audiol 8: 71-80.

Stansfeld SS, Matheson MP (2003). Noise pollution: non-auditory effects on health. Brit Med Bull 88: 243-257.

Vanniasegaram I, Cohen M, Rosen S (2004). Evaluation of selected auditory tests in school-age children suspected of auditory processing disorders. Ear Hear 25: 567-597.